The Effectiveness of Truck Rollover Warning Systems

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ABSTRACT

This paper investigates different types of intelligent rollover systems that are being deployed by road agencies across North America. In particular, this study focuses on the importance of weight for maximum effectiveness of rollover warning messages for commercial vehicles in a potential rollover situation on sharp curves or exit ramps. The type of information that may be used to activate a rollover is discussed to analyze the number of correctly warned vehicles as compared to the number of false warnings generated by the rollover warning system. A case study is presented regarding the effectiveness of an intelligent rollover system.

Based on the case study considered in this analysis, is was found that speed based rollover warning systems generate anywhere from 44 to 49 percent more false rollover warnings for commercial vehicles compared to rollover warning systems that employ weight information in the rollover decision criteria.

1 INTRODUCTION

Truck rollover accidents are a serious and too frequent occurrence at many locations on the North American highway system. Trucks traveling at high speeds are often caught off guard at exit ramps and tight curves that require a greatly reduced speed from the normal traveling speed on the freeway. As a result, commercial vehicle rollover accidents commonly occur resulting in injury, loss of life, traffic delays, environmental damage, and property damage.

According to the Fatality Analysis Reporting System (FARS) (1), operated by the National Highway Traffic Safety Administration, 207 trucks where involved in fatal rollover accidents in the U.S. in 1998. In addition, the General Estimates System (GES) (1), a probability-based nationally representative sample of all police-reported fatal, injury, and property-damage-only accidents, stated that approximately 10,582 commercial vehicles were involved in non-fatal rollover accidents. According to the FARS and GES, rollover accidents are the fourth highest accident type involving commercial vehicles, accounting for roughly 4 percent of all truck accidents.

Currently, the goal of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce the number of large trucks fatalities recorded in 1998 by at least 50 percent by the end of 2009 (2). As a result, public road agencies are investigating the potential for intelligent safety systems to reduce the number of rollover accidents, thus improving the commercial vehicle and bus safety on the US national highway system. Using various Intelligent Transportation System (ITS) solutions as a risk-mitigation tool could help road agencies improve highway safety and meet the FMCSA goal.

1.1 Background

One of the primary functions of the road transport infrastructure is to safely and efficiently transport goods and people. When commercial vehicle accidents occur, the mobility of the road user is impeded and significant user delay costs may be incurred. With proven ITS safety systems, public road agencies will have more tools to assist them with improving the safety and efficiency of our road system.

One such safety system being investigated by public road authorities is a heavy vehicle rollover warning system.

Whether it is in the rural or urban area, road agencies must consider numerous issues when deciding if a rollover system is needed in their jurisdiction:

a) Property damage
b) Human life
c) User costs - delays
d) Environmental liability
e) Loss of traffic mobility/efficiency
f) Capital infrastructure costs

It is the road agencies responsibility to determine the cost/benefit tradeoffs, while keeping in mind the interests of public safety. According to Winkler et al (3) commercial vehicle rollover accidents are strongly associated with severe injury and fatalities. Therefore, it is intuitive that the prevention of one commercial vehicle accident outweighs the cost of the rollover safety system.

2 ROLLOVER WARNING SYSTEM SOLUTIONS

To help mitigate the occurrence of rollover accidents at problem locations, several solutions have been developed. At a minimum, problem locations may have speed reduction signs, rollover warning signs, and chevrons to pre-warn all drivers of the potentially dangerous curve ahead. Although signing is present at most problem locations, many drivers become desensitized to a specific warning amongst the multitude of other roadside signs.

Intelligent rollover safety systems are designed to calculate the rollover potential for the specific vehicle and direct a warning if required. The directed message is achieved by activating a sign or flashing lights only when a potential rollover vehicle is detected. In this way, active warning signs alert the drivers with a high probability of entering into a rollover situation.

Modern intelligent rollover systems can incorporate several vehicle parameters such as speed, weight, live load, non-live load, vehicle height, and vehicle configuration into the rollover threshold equation. By incorporating more vehicle information into the rollover decision threshold the accuracy and effectiveness of the rollover warning system can be significantly increased.

2.1 Case Study

The case study presented here considers rollover warnings generated by three rollover system types: static signing, speed based rollover systems and speed / weight based rollover systems. Each system is evaluated based on a theoretical rollover threshold with the objective to evaluate the effectiveness of each system with regards to mitigating the potential risks that are assumed when selecting a rollover warning system.

To provide data for the case study, a typical vehicle stream was obtained from an automatic truck rollover system installed on I-495W/Route 123N in McLean, Virginia (4). In the past, this site had a history of commercial vehicle rollovers and an intelligent rollover warning system was installed to help alleviate the problem in 1993. Figure 1 illustrates the layout of the Virginia rollover safety system, which has two weigh in motion systems upstream of the curve to calculate the weight, speed, height, vehicle configuration and deceleration in order to determine if the warning sign needs to be activated. Data was collected between May 15, 2000 and May 21, 2000. Although all types of vehicle configurations were obtained, only FHWA Class 9 vehicles (5-axle single trailer) were used for the evaluation.

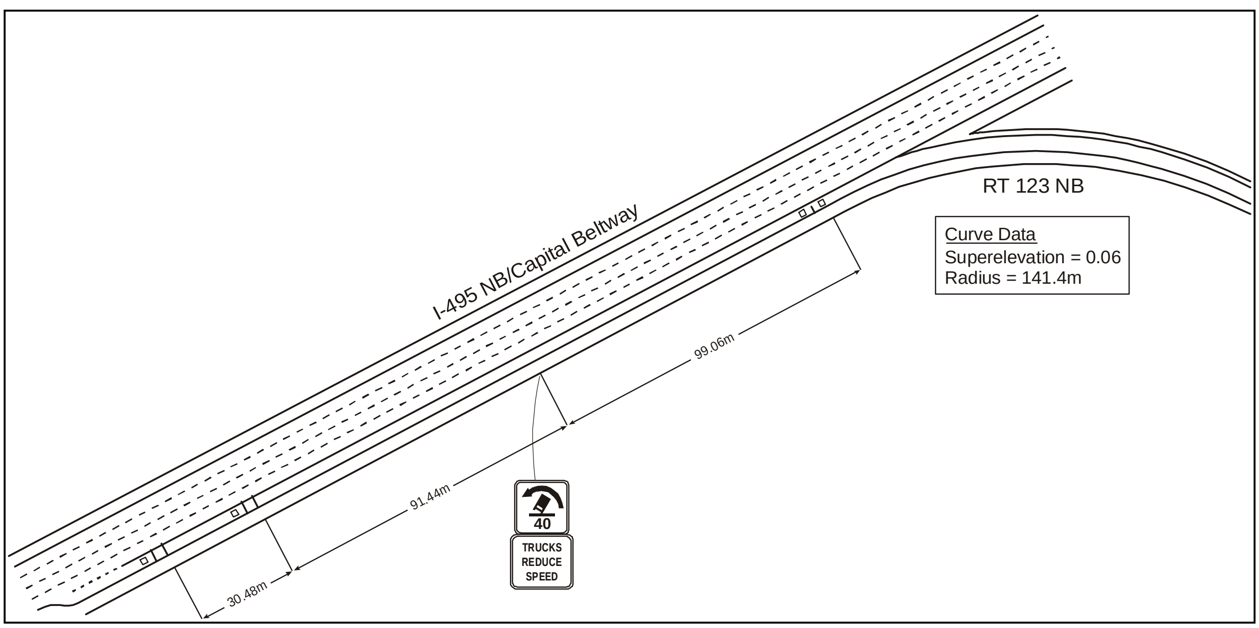

FIGURE 1 Truck Warning System Layout in McLean, Virginia.

Vehicle weight data was retrieved from Class 1 piezoelectric weigh-in-motion sensors, which is an ASTM type III weigh in motion sensor (5) and speeds are projected to the point of curvature based on the deceleration calculated between the two WIM locations upstream of the curve. For the purpose of this evaluation, projected speeds were used instead of actual speeds on the curve, since rollover systems use the projected speeds to determine if the system should be activated. Using this sample data, an understanding can be gained of how using the different decision criteria will influence the precision with which a targeted message can be applied. Figure 2 illustrates the projected speed at the point of curvature base and the gross vehicle weight for the Class 9 trucks detected at this location.

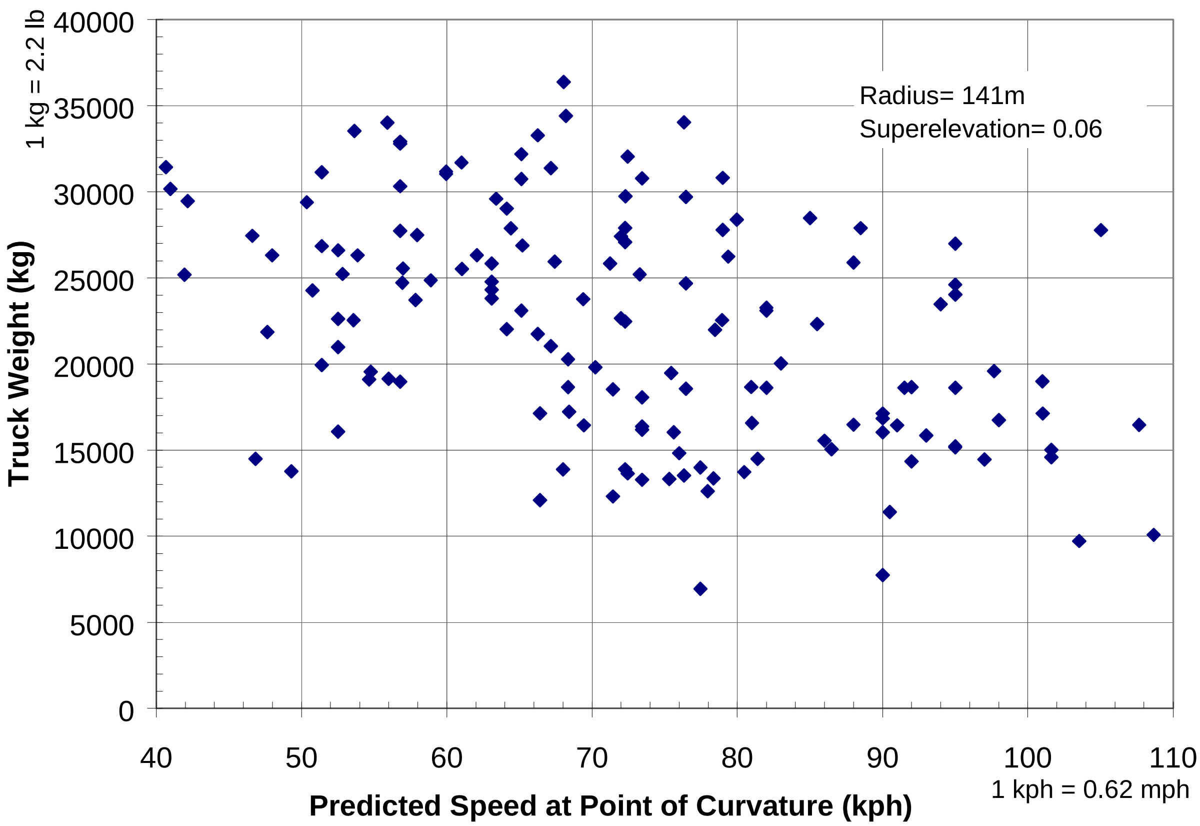

FIGURE 2 Typical Class 9 Vehicle Speed Distribution at I-495W/Route 123N in McLean, VA.

2.2 Static Signing

The conventional method for warning drivers of rollover locations is through static signing. In particular, warning signs are used to inform motorists of upcoming conditions, in hopes to minimize the number and severity of accidents.

The benefit of using static signing is all trained drivers understand conventional signing and there is minimal need for the driver to interpret the meaning of the sign. However, due to the large quantity of roadside signs throughout the highway network, many drivers become desensitized to the warning application.

For static signing, 100 percent of the motorists receives a warning, whether they need it or not. Therefore, each driver will perceive and react to the curve based on his or her previous experience. Although human factors of static signing are not studied in this paper, they were mentioned to illustrate the point that each member of the public may perceive the general warning of static signing differently. Static signing serves its purpose as a cost-effective warning device for many dangerous curves throughout North America, however, more effective systems that target individual drivers exist that can drastically improve the safety of the curve.

2.3 Speed Detection Warning System

In an attempt to increase the effectiveness of a rollover warning system, vehicle parameters that affect a vehicle in a rollover situation, such as speed, can be incorporated into an ITS rollover system. Usually, some type of sensor is used that has the capability to detect the presence and speed of a vehicle, and the speed is used to determine a warning decision. Several states such as California, Washington, Colorado and Texas have installed rollover systems that incorporate speed into an intelligent rollover system. CalTrans successfully deployed the Sacramento Canyon Advanced Curve Warning System in a rural environment and for their efforts received an award from ITS America for developing a safety system shown to save lives.

In Figure 3, the warning speed of 65 kph (40 mph) was used as the activation speed for the speed-based rollover system. As a result, 62 percent of the Class 9 trucks in the vehicle stream would receive a warning, which includes all the trucks in a real danger of a rollover. Now that speed has been integrated into the rollover system, some of the vehicles that do not need a warning are eliminated from the standard warning of static signing, therefore targeting vehicles that may be driving too fast for the curve.

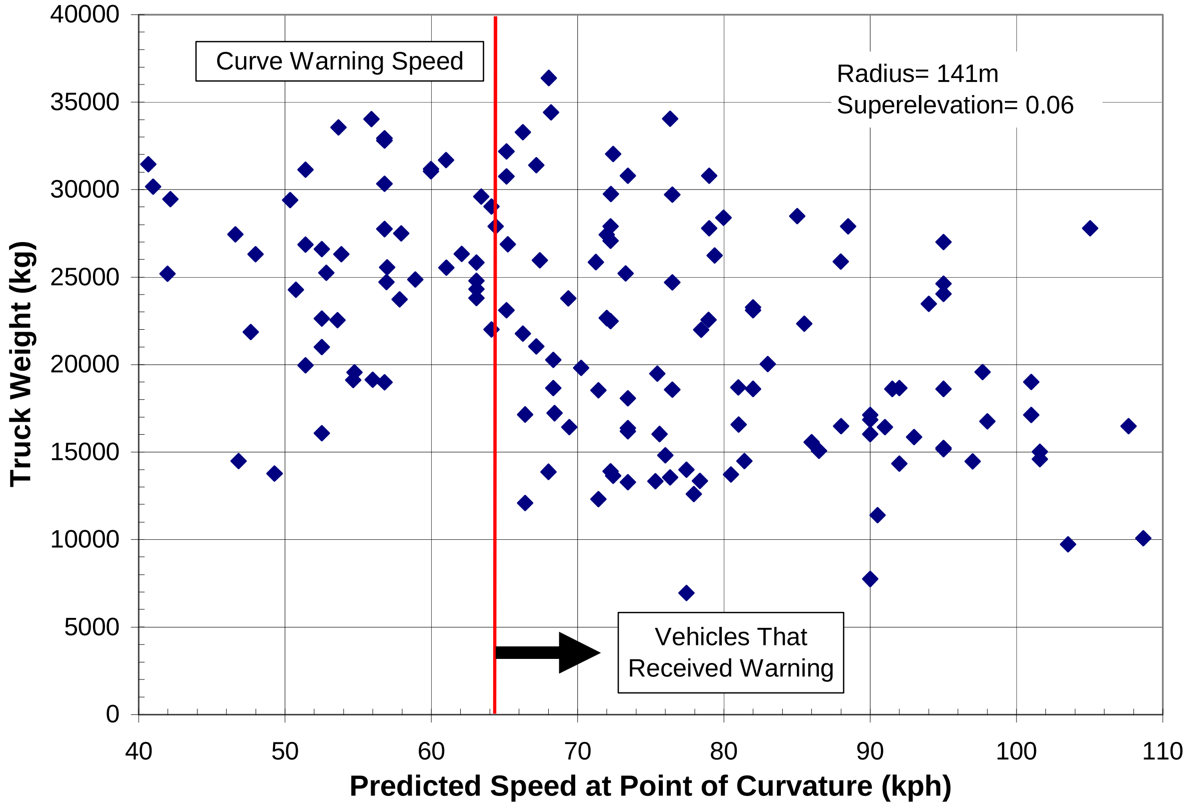

FIGURE 3 Speed Based System Activation.

However, if speed were the only criteria used in making the decision, the normal traffic population would also be eligible for receiving a warning. In general it can be expected that normal traffic will be traveling at a higher speed than commercial vehicles. Therefore, if the speed threshold is set at lower speeds in order to warn the commercial vehicle traffic much of the general traffic population will also receive a warning message. At this location the intention of the rollover system is to target heavy vehicles that have a real danger of a rollover situation.

In addition, a system based on speed only will treat loaded and unloaded trucks as equal. A driver with an empty truck traveling past this location may receive the warning many times without any relevance or consequence if the message is disregarded. At the same time, a truck with a high rollover potential may receive no message because of his reduced speed. Adjusting the activation speed can be used to try to maximize the effectiveness of a speed-based system, although it may be difficult without incorporating another vehicle parameter.

For example, if the warning is activated at lower speeds, the system will not miss any activations for vehicles with a high rollover potential. However, the rollover warning system will provide a higher number of false alarms for cars and light trucks that pass the site. The original intent of these systems was to make them relevant to the driver but at this speed setting the system may become irrelevant over time because of constant activation. Without knowing another rollover vehicle parameter, such as weight or vehicle configuration, it is difficult to have a system that effectively warns vehicles in danger and has a low number of false alarms.

2.4 Speed, Vehicle Configuration and Weight Detection Warning System

Systems that include vehicle configuration and/or weight provide a more detailed analysis of the vehicle than a strictly speed based system to determine whether a warning condition applies. The design of this type of system recognizes the fact that in some circumstances, cars and commercial vehicles will behave very differently. By incorporating a larger number of vehicle parameters that are directly related to the rollover of the individual vehicle, the rollover warning system will become more effective and reliable in the long run.

The weight / speed based system in Virginia includes factors such as weight, vehicle classification, vehicle speed and deceleration for determining the system activation (4). From the sensors located upstream of the curve, the trucks deceleration (d) is determined from the following equation:

$$d = \frac{V_1^2 - V_2^2}{2L_1} \quad (1)$$

where V_1 and V_2 are speeds at the each upstream sensor location and L_1 is the distance between them.

Based on the deceleration rate (d), the speed of the truck at the point of curvature is calculated as follows:

$$V_{PC} = \sqrt{V_2^2 - 2d(L_2 + L_3)} \quad (2)$$

where ($L_2 + L_3$) is the distance from the second station to the point of curvature.

The maximum values of lateral acceleration a_{max} beyond which the truck will roll over is calculated as follows:

$$a_{max} = \frac{(RT - SM)g}{1.15} \qquad (3)$$

based on the weight of the vehicle, the rollover threshold (RT) is taken from Table 1 and the safety margin (SM) is normally 0.1.

TABLE 1 Rollover Threshold for Various Weight Ranges

Non-Tanker	
Weight Range (kg)	**Rollover Threshold**
0 – 15,875	0.73g
>15,876 – 22,680	0.60g
>22,681 – 29,484	0.50g
>29,485 – 36,287	0.38g
>36,288 – 45,359	0.36g

1 kg = 2.2 lb

The maximum rollover threshold speed (V_{max}) is determined from the following equation:

$$V_{max} = \sqrt{(a_{max} + ge)R} \qquad (4)$$

where e is the superelevation of the curve and R is the radius of the curve.

Virginia, Maryland and Pennsylvania have all installed systems that use parameters such as speed, deceleration, and weight and also taking into account site characteristics such as superelevation and radius of curvature. Three rollover-warning sites installed in Virginia and Maryland have had no rollover accidents since the systems were installed in 1994 and the newer site in Pennsylvania has had similar short-term results.

These types of systems are designed to address a specific problem related to commercial vehicles, such as freeway exit ramps. The performance and handling characteristics of a commercial vehicle can vary greatly with differences in the amount and type of loading and site characteristics. These systems account for as many of the vehicle and site parameters as possible in determining the warning condition.

Figure 4 illustrates the benefits of integrating weight into the algorithm for a truck rollover warning system. The algorithm used was based on research from the University of Michigan

Transportation Research Institute (4,6). Incorporating weight into the rollover equation results in 10 percent of the class 9 trucks that receive a warning. This is a dramatic decrease from 62 percent of the class 9 vehicle rollover warnings that were activated by the speed-based system. The addition of weight into the rollover algorithm can decrease the number of activations, therefore increasing the long-term effectiveness of the system by only activating the rollover system for vehicles with high rollover potential.

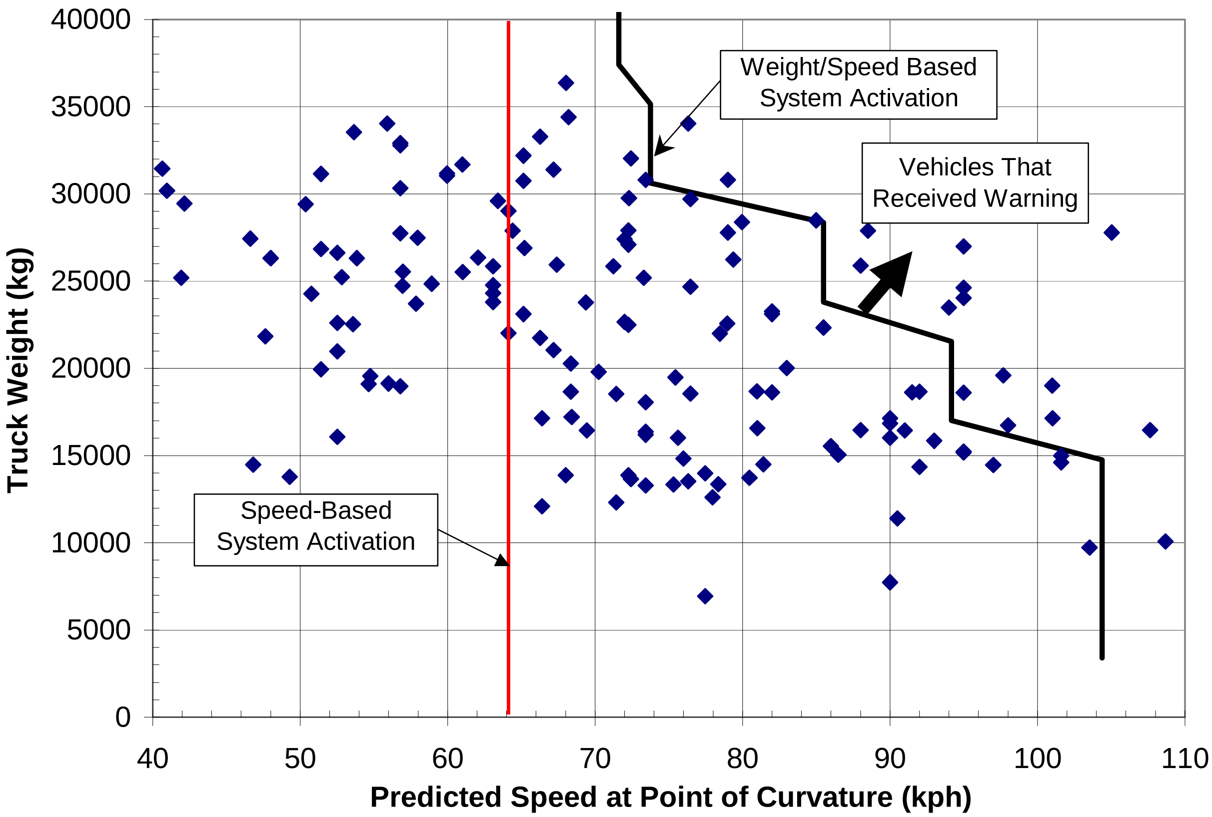

FIGURE 4 Speed and Weight based System Activation

The weight of a vehicle can be determined from a number of weigh-in-motion systems. ASTM Designation: E 1318-94, Standard Specifications for Highway Weigh-in-Motion (WIM) Systems, states that there are three types of WIM systems based on accuracy levels (7). For a 95 percent probability of conformity, Type III has a +/- 6 percent error, Type I has a +/- 10 percent error and Type II has a +/- 15 percent error. Consequently, the weight / speed based systems accuracy must also take into account the type of weigh-in-motion (WIM) technology used. In order to compare the performance of each system, the error for each WIM system was incorporated into the algorithm and is illustrated in Figure 5. As seen in Figure 5, Type III, I and II WIM systems 4.8 percent, 7.2 percent and 12.7 percent of the class 9 vehicle stream are enclosed in the error envelope respectively. Therefore, when selecting a WIM system for an intelligent rollover warning system, road agencies must consider the level of risk they are willing to assume. In the long run, higher WIM accuracy of the intelligent rollover warning system will significantly decrease the probability of false rollover warning messages .

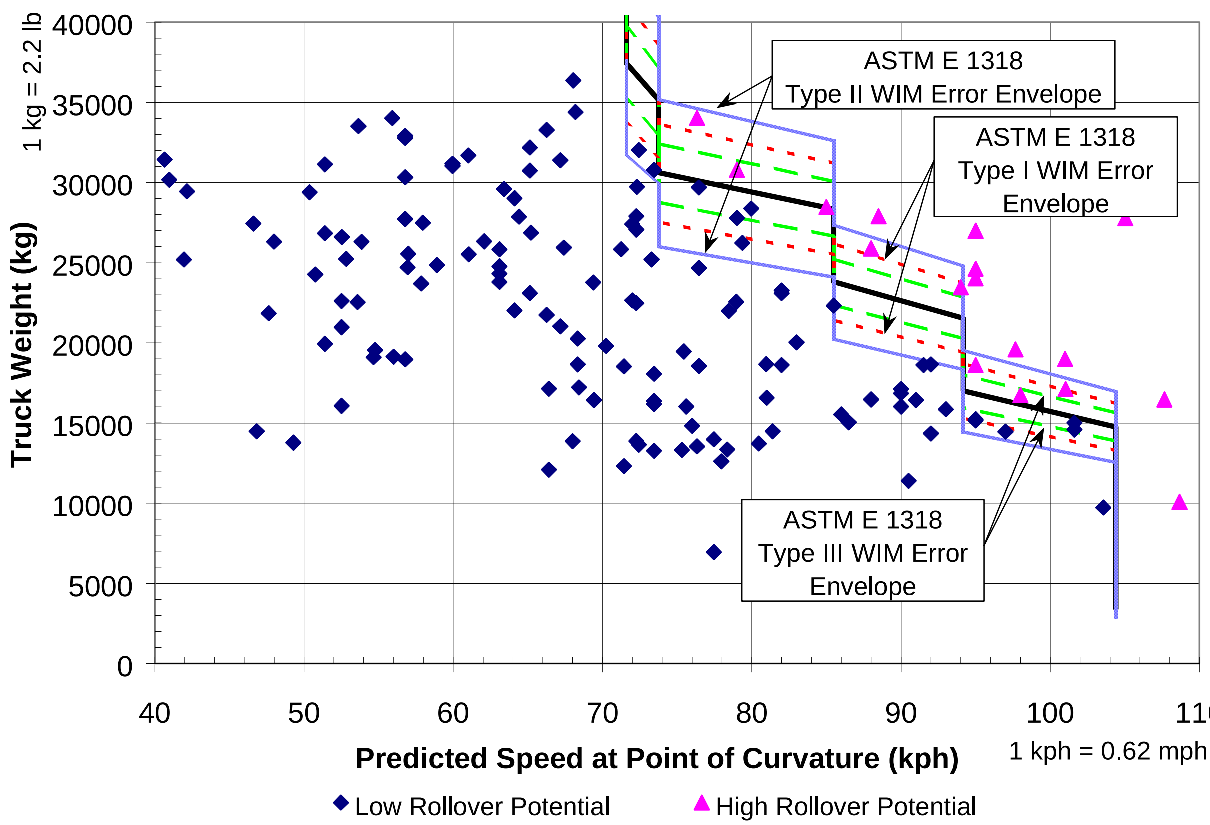

FIGURE 5 Effect of Weigh-In-Motion Error on Rollover Warning Distribution.

3 SYSTEM COMPARISON

In order to maximize the effectiveness of a traffic warning system, the warning must be well targeted to specific drivers. If the sign is activated repeatedly when there is no actual danger, this type of signing poses the threat of being ignored over the long-term by most drivers. This scenario is potentially dangerous for vehicles that are in real danger and need to be warned of that danger.

Figure 6 conceptually compares the rollover warning thresholds obtained from a speed-based and weight-based rollover warning systems. As seen in Figure 6, there are four possible message outcomes when evaluating rollover thresholds between each system. A vehicle may be classified as either having or not having rollover danger and they may receive a warning or not receive a warning.

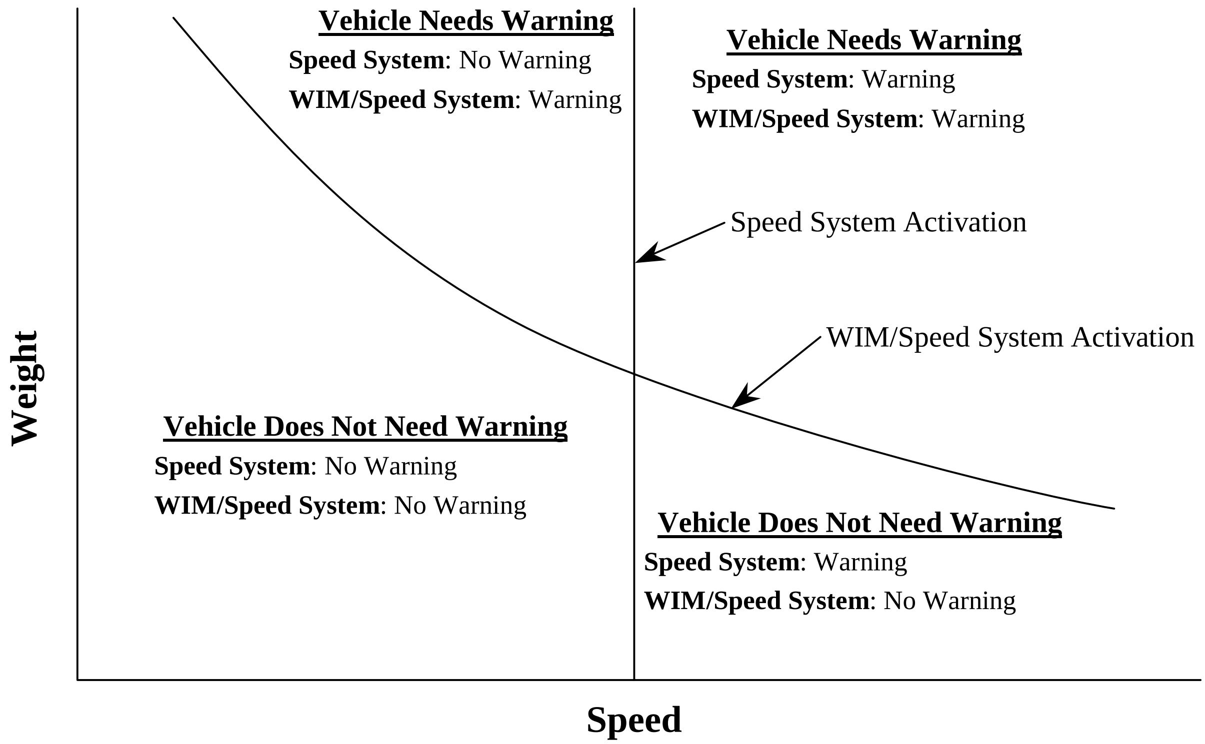

FIGURE 6 Comparison between a Speed-Based and Weight-Based Rollover System.

Therefore, there are two possible outcomes for each type of vehicle and each type of system, a warning that is correct, and a warning that is in error. Based on the case study, and as seen in Figure 4, Table 2 summarizes the number of false rollover warnings and missed rollover warnings across the two rollover warning systems. The analysis assumes that the UMTRI algorithm for commercial vehicles is correct and all vehicles greater than the calculated rollover potential are considered to have high rollover potential. The summary data is based on projected speeds instead of actual speeds on the curve, since rollover systems use the projected speeds to determine if the system should be activated. To this date, there have been no rollover accidents at the curve in McLean, Virginia.

TABLE 2 Case Study - Rollover Warning System Summary

	False Warnings[a]	**Missed Warnings[a]**
Static Signing	149	0
Speed Based System	86	0
Weigh/Speed Based System with Type II WIM[b]	13	8
Weigh/Speed Based System with Type I WIM[b]	7	5
Weigh/Speed Based System with Type III WIM[b]	5	3

[a] Assume UMTRI rollover threshold is exactly correct
[b] 95 percent confidence level

As revealed in the case study, the implementation of static signing on the freeway exit ramp would result in 149 (90 percent) false alarms and 0 (0 percent) missed vehicles for class 9 vehicles. Furthermore, lighter vehicles that are not necessarily in any danger are also warned. An additional factor that influences the overall effectiveness of the warning system is the human factor of signing. Due to the large number of signs adjacent to the roadway, each driver will perceive and react to the curve based on his or her previous experience. As a result, common signing may not be an effective warning system on dangerous curves. It should be noted that, the data in Table 2 was obtained for a period of one week and therefore, the number of false warnings would be exceptionally high for an entire year.

To increase efficiency, a speed-based intelligent rollover warning system was analyzed in the case study. It revealed that 86 (52 percent) false alarms and 0 (0 percent) missed would incur for the class 9 vehicles. However, general traffic such as cars and light trucks, which have the capability to negotiate the curve at higher speeds, are not included. Therefore, it can be expected that there would be a larger number of false alarms from smaller vehicles that approach the curve at higher speeds. As a result, the effectiveness of the system is compromised if the system activates when a vehicle is in no apparent danger. In addition, depending on where the speed activation threshold is placed, the system may also miss vehicles that are in real danger of rolling over.

The final system analyzed was a speed / weight based rollover warning system. Speed / weight based systems must take into account the type of weigh-in-motion (WIM) technology used. The three types of WIM systems specified in ASTM E 1318 and their corresponding errors, at a 95 percent confidence level, were incorporated into the algorithm to determine the maximum number of false alarms and missed vehicles. However, in reality these maximum values may never be reached due to the calibration of the WIM system. A weight / speed based system using a type II WIM system had 13 (8 percent) false alarms and 8 (5 percent) missed vehicles. To further increase the accuracy of the rollover system, a type I and type III WIM system can be used, which had 7 (6 percent) false alarms and 5 (3 percent) missed vehicles, and 5 (3 percent) false alarms and 3 (2 percent) missed vehicles, respectively. Incorporating weight into the rollover warning system dramatically increased the efficiency the rollover system, by decreasing the number of false warnings for vehicles that are in no danger of rolling over. It can be seen that even with the maximum values, the number of false alarms is nearly decreased by a degree of magnitude from the speed based system.

4 SUMMARY AND CONCLUSION

Commercial truck rollovers are strongly associated with severe injury and fatalities in highway accidents (3). In 1998, commercial vehicle rollovers resulted in 207 accidents involving fatalities and 10,582 non-fatal accidents in the U.S. (1). To help mitigate the rollover of commercial vehicle on sharp curves, three rollover safety systems were investigated in this study: static signing, speed based system and weight/speed based rollover warning system.

For a vehicle in danger of a potential rollover, it is important that the warning be given to provide an opportunity for the driver to react and prevent an accident. Failing to provide an effective warning does nothing to improve a dangerous situation. For a vehicle that is not in a potential rollover situation, the optimal situation is not to provide a warning to that vehicle. If a warning is provided when it is not required, it is considered an error and poses a threat of desensitizing the driver to rollover warnings. Therefore, false warnings can potentially reduce the overall effectiveness of the warning system.

This study identified that rollover accidents are complex events that require a large number of inputs to have an effective and efficient rollover warning system. The case study presented in the paper revealed that there is an added advantage of incorporating weight in addition to speed and classification when warning commercial vehicles of potential rollover. Including weight into an intelligent rollover system reduced the number of false alarms from the speed-based system by approximately 44 to 49 percent (depending on the type of WIM system that is used). As a result, there is a dramatic increase in effectiveness for the rollover system. In the long run, accurate system performance will ensure the public will continually respond to the message of the intelligent rollover warning system.

At a minimum, road agencies must show a reasonable degree of safety for vehicles that may be entering potential danger curve on the highways system. Conventional static signing may be sufficient for normal curves, but high-risk curves may require a rollover safety system to complement the static signing, so high risk vehicles can be warned. The use of proven intelligent rollover warning system will not only improve safety at high risk location, but will also reduce road agencies liability by displaying reasonable effort to improve the dangerous situation. By incorporating an accurate intelligent rollover system, it will ensure the public will continually respond to the message of the intelligent rollover warning system in the long-term.

Future evaluations of intelligent rollover warning systems may wish to consider installing additional tracking sensors at the point of curvature, which would allow a comparison between the predicted speed of the warning system with the actual speed of the vehicle. In addition, applications of a system using similar principles to those of the rollover warning system can be implemented in other commercial vehicle situations.

5 ACKNOWLEDGEMENT

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