



Evaluating the rollover propensity of trucks—A roundabout example



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ABSTRACT

The rollover propensity of SUVs and trucks has long been recognized as a potential safety issue. The propensity may increase with the growing number of roundabouts that are being built on high-speed roadways designed for 50 mi/h or higher. This paper presents a research methodology developed to evaluate the rollover propensity of trucks on existing roundabouts and other roads with tight curves and high-speed traffic. The research objective was accomplished by developing an advanced 3D model of rollover that is applicable to field observations of the undisturbed behavior of multiple vehicles. This model was supplemented with a nonintrusive method of data collection based on recording video from a remote location and a novel method of extracting the data from the video material and processing it to generate the input required by the rollover model. The method is demonstrated in this paper on an example roundabout by evaluating the rollover propensity of semi-trailers in daytime and nighttime conditions. The results indicate that the drivers observed in nighttime conditions compensated well for the challenging conditions by driving more cautiously, which led to their rollover propensity at night being lower than during the day. The method was found useful for timely detection of the potential rollover problem without waiting for crashes.

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1. Introduction

The rollover propensity of trucks on horizontal curves becomes an issue if drivers tend to drive excessively fast for the conditions. Highway on and off ramps that have sharp curves are a well-recognized example, as examined by Wang and Council (1999), Green (2002), and McKnight and Bahouth (2009), with the last of these studies using data from the Large Truck Crash Causation Study (LTCCS). Intersections also have been associated with a greater rollover risk for trucks (TRB Truck and Bus Safety Committee, 2007). In addition to causing injuries, truck rollovers may have significant impacts due to the associated congestion, detours, and environmental/health issues (Bill et al., 2011; Campbell, 2015).

The rollover risk may be further exacerbated by the increasing number of roundabouts installed on high-speed roads designed for 50 mi/h or higher even though these roundabouts may reduce the overall crashes. Rollover crashes have been observed at roundabouts across the United States, as well as in Australia and the United Kingdom (Arndt and Troutbeck, 1998; U.K. Highways

Agency, 2007). The state of Kansas in the U.S. has considerable experience with this issue. The Kansas Department of Transportation (KDOT) reported that half of the truck crashes at roundabouts on high-speed roads since 2000 were rollovers; and the common theme among these crashes was speed too high for the conditions. The Australian study, an extensive examination of 100 urban and rural roundabouts, found that articulated vehicles had a high number of single-vehicle rollover crashes (Arndt and Troutbeck, 1998). The U.K. Highways Agency (2007) also studied the causes of rollovers at roundabouts and concluded that the conditions for rollovers include approaches with high speeds, small entry deflection, no vehicles impeding entry to a roundabout, extraordinarily high visibility encouraging high speeds, a significant decrease in radius within the roundabout, and sudden superelevation changes.

The rollover threshold of trucks is affected by the vehicle's speed, center-of-gravity location, suspension, width, and tire characteristics (NZ Transport Agency, 2008). Furthermore, the rollover threshold is influenced by load factors such as the overall weight and longitudinal and lateral weight distribution (Harwood et al., 2003). Fully loaded semi-trailers tend to have a higher center of gravity height than empty ones; and the trucker is often unaware of the lateral rollover force acting on the trailer.

Researchers have explored “in-vehicle warning systems” to help quantify a truck's proximity to rollover (Wang and Council, 1999).

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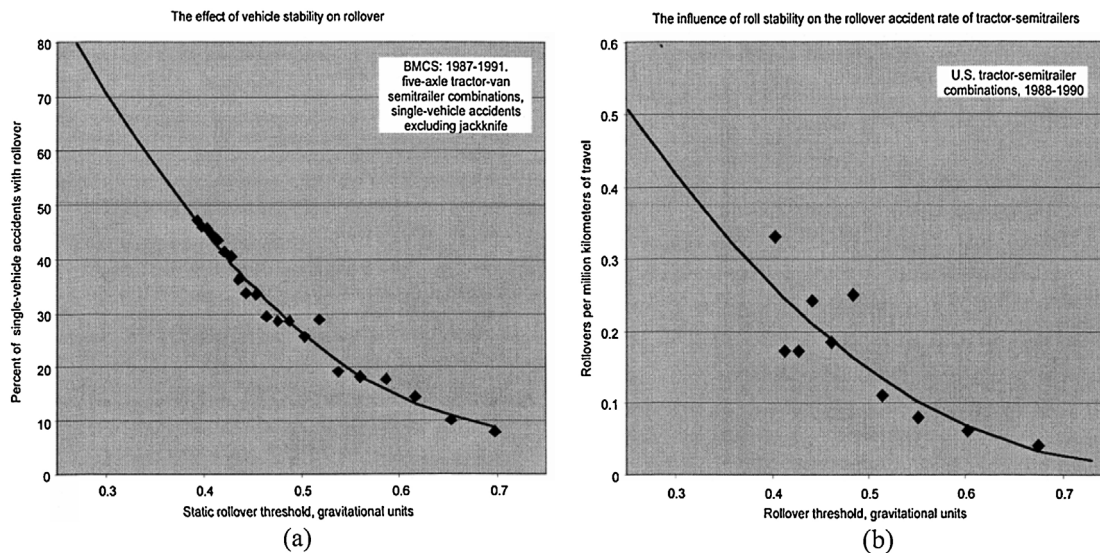


Fig. 1. The frequency of rollover vs. the static rollover threshold (Winkler and Ervin, 1999).

Winkler et al. (1999) introduced a Roll Stability Advisor to determine the quasi-static rollover threshold. Such models represent a motion in a steady state where the focus is on the aspects of the motion that do not change with time. Winkler (2000) and Gertsch and Eichelhard (2003) used controlled experiments, such as a tilt-table, to determine the rollover threshold. However, few studies have been conducted to date using field-collected data to determine how close trucks encroach on the critical rollover threshold, especially in the context of roundabouts built on high-speed roads.

The objective of this study was to develop a new research methodology suitable for investigating the rollover propensity of trucks on roads with sharp curves, such as ramps and roundabouts. The method is demonstrated in this paper on a newly built roundabout in the state of Indiana in the U.S. The selection of Indiana was motivated by a plan to build 30 more roundabouts on Indiana high-speed rural and suburban roads. To evaluate the actual risk of rollover on a certain road, it was determined that observing the undisturbed behavior of truck drivers, which is affected by multiple factors such as fatigue and unfamiliarity with the road, was needed. Thus, nonintrusive observation of a sufficient number of truck drivers was an especially appealing approach.

The above research objective was accomplished by measuring the speeds and the paths of multiple trucks approaching and negotiating roundabouts using a nonintrusive method based on recording the video from a remote location. An advanced model of rollover is a critical component of the proposed method and is presented in the next section of this paper. The model requires only those inputs that could be extracted from the video. A novel method of extracting data from the video material and processing it to generate the required input for the rollover model also are described briefly and is demonstrated on an example roundabout in daytime and nighttime conditions. A discussion of the results, conclusions, and limitations close the paper.

2. Rollover condition

A quasi-static model provides a convenient means for considering rollover in road design (Gillespie, 1992) without requiring inputs difficult to attain in observational studies. In simplest form, the model involves the ratio (b/h), where b is half of the vehicle width and h is the height of the center of gravity. This ratio is sometimes referred to as the static stability factor or *static rollover threshold*.

In spite of the simplicity of a quasi-static model, this type of model may be useful for estimating safety if there is a connection between the results produced by the model and the actual rollover experience. In fact, Winkler and Ervin (1999) indicated a strong connection between the static rollover threshold of a vehicle and the frequency of rollover (Fig. 1). The propensity for rollover of various vehicles is expressed in Fig. 1a as the percent of single-vehicle crashes that were rollovers. Fig. 1b presents the propensity for rollover of semitrailers as the frequency of rollovers per million kilometers of travel. The crash and truck data were obtained from the Bureau of Motor Carrier Safety and other sources. These results are encouraging about the usefulness of a quasi-static model in reflecting the rollover conditions, particularly if this model is expanded to include the road geometry.

A version of the static rollover threshold that included the effect of road design was presented by Gillespie (1992) and later by Milliken and de Pont (2005). The improved version included roadway cross slope e :

$$a_r = \left(\frac{b}{h} - e \right) \times g \quad (1)$$

where: a_r = critical lateral rollover acceleration, b = half of the vehicle's width, h = height of the center of gravity, e = cross-slope or superelevation of the roadway, and g = acceleration due to gravity.

Eq. (1) is a 2D quasi-static approximation useful for considering road design matters if the following assumptions are met:

- The superelevation is uniformly applied along the curve,
- The driver follows the road curvature exactly,
- The vehicle body is parallel to the lane edge, and
- The vehicle moves at a constant speed.

The above conditions are violated by trucks negotiating tight curves, such as those on tight loop connectors and on modern roundabouts. For example, a roundabout paved surface may have a complex elevation design, trucks such as semi-trailers follow unique paths that are different from the circulatory road alignment, tractors and trailers rarely stay parallel to the travelled way edge, and drivers adjust their speed along their paths. These conditions need to be properly addressed in a 3D model that is more general and elaborate than Eq. (1). Such a model is presented in the following section for a semi-trailer, which is the type of vehicle most prone for rollover.

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