Development and Evaluation of a Curve Rollover Warning System for Trucks[1]

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Abstract

Truck accidents involving rollover have extremely high fatality rates. About half of all truck drivers killed in accidents last year were involved in a rollover. Freightliner's Rollover Stability Advisor alerts drivers to potential rollover situations, training them to avoid excessive rollover risk. In this paper, we describe work that extends the Rollover Stability Advisor to predict rollover situations in advance, giving drivers time to slow down before they are in danger. In an empirical evaluation of the rollover prediction accuracy on a sharp curve, we found that 50% of the dangerous passes could be predicted 5 seconds or longer in advance of the maximum rollover risk, and only 10% of the safe passes wrongly predicted a rollover risk. We feel that these are encouraging first results, and further refinement of the algorithms will yield even better results.

1 Introduction

Truck rollover is a serious problem in the transportation community. Statistics from National Highway Traffic Safety Administration (NHTSA) show that vehicle rollovers kill 10,000 people yearly in the USA alone, injure another 27,000, and cause tremendous economic damage. Freightliner LLC has developed a Rollover Stability Advisor that warns truck drivers to slow down when they are already nearing the stability limits of their truck. An extension of this system would predict upcoming situations and warn the driver ahead of time. In this paper, we report on some of the results of a study conducted with funding from the Intelligent Vehicle Initiative, starting with some background on the RSA system. In the following section, we cover the test data generated by the project. We summarize the experimental effectiveness of our system on one likely rollover site in the next section. We conclude with a discussion of next steps and future work.

2 Background

The RSA system computes truck "Rollover" scores in real time when the truck is running [1]. The score is computed as

$$RSA\_score = \frac{a_N(Actual)}{a_N(Critical)} \times 100$$

where a_N is the lateral acceleration of the truck. The critical lateral acceleration is inversely proportional to the mass of the truck and was determined experimentally with a tilt table. The system computes the RSA score every half second, and once it generates a high score, it delivers a warning message to the driver after the perceived risk subsides, since another distraction at that critical moment might be too much for the driver to handle. The intent is to improve driving behavior by letting the driver learn from his or her past mistakes.

For RSA score prediction, we need to project the lateral acceleration ahead in time. The lateral acceleration of the truck, a_N, on a flat road at a time t is related to the speed of the vehicle s(t), the curvature of the road K(t), and the crosselevation of the road E(t) by:

$$a_N(t) = \frac{s^2(t)K(t)}{g} - E(t)$$

where s is speed in m/s, K is curvature in m^{-1}, g is 9.81 m/s^2, E is the crosselevation as a slope, and a_N is the measured lateral acceleration in g. We find the curvature and crosselevation of the road from a digital map we generate from a probe vehicle data set. We project the

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vehicle speed using a model of driving behavior generated from the same data set.

3 Data Collection

We generated the data set in a one-year Field Operational Test (FOT) period [3]. During the FOT, a Roll Stability Advisor (RSA) system and a global positioning system (GPS), among others, were mounted on each of six heavy trucks (Freightliner century class). The six trucks run daily to deliver liquid nitrogen from La Porte, Indiana, as part of Praxair's commercial operation, so the FOT occurred in a real world environment. An on-board computer recorded GPS, RSA, and other types of data during the run, and the data were uploaded to a server for storage and analysis after the truck stopped, normally at the end of the day. The FOT data covered about 10,000 hours of driving, or 773,000 kilometers in Indiana, Michigan, Illinois, and Wisconsin. Among the data collected are vehicle position GPS data (latitude, longitude, altitude, time stamp), GPS error estimate (GPS fix, differential age, DOP, etc), vehicle speed, measured lateral acceleration, vehicle operational parameters (brakes, acceleration pedals, wiper movement, etc), and lane-tracker information (offsets to lane marks). Due to the nature of the commercial operations, the roads were not traveled evenly. Figure 1 shows the road map and number of travel times in the FOT area.

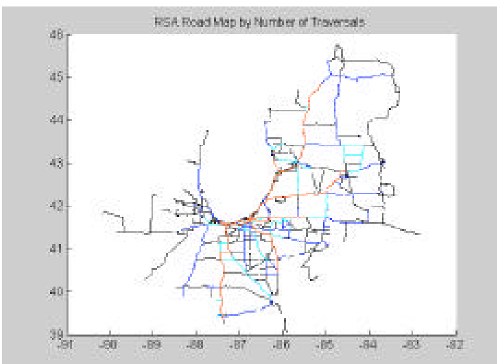

Figure 1: FOT data coverage with the number of traversals. Color code: black 0-5, blue 6-15, cyan 16-50, red >51.

Figure 2 is a plot of several types of recorded truck data over time to illustrate the relationships between RSA, lateral acceleration, vehicle speed and road curvature. It is obvious that the RSA score increases with curvature.

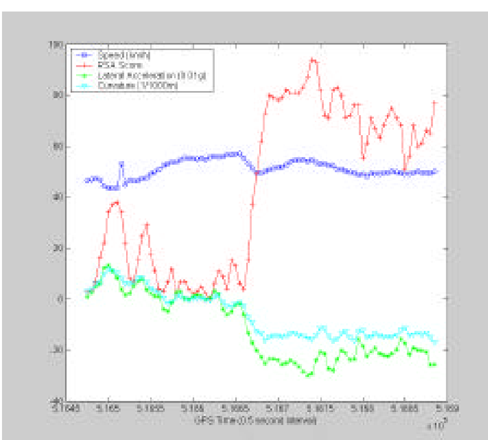

Figure 2: Sample trace for dangerous incident. RSA score rapidly accelerates when road curvature increases without significantly decreasing speed.

4 Making the Map

Current digital maps from commercial vendors, such as Navigation Technologies, are not suitable for RSA prediction because they normally lack such information, and they are also not precise enough.

At DaimlerChrysler Research, we have developed techniques of building refined digital maps from large amounts of GPS trace data [2]. We first map matched the GPS points with a digital map, and break the GPS trace into map segments from the NavTech digital map. Then we collect all GPS traces on each segment, and fit a B-Spline to them to get the centerline of the road. Notice the fitted centerline is not necessarily the center of the road; rather, it captures the average of the actual driving behavior. The vast amount of data from the FOT provides a very good resource for us to generate refined maps. The accuracy of our map increases with more traversals. Based on the "Bootstrap" statistics method, we have evaluated the accuracy of our map to be 0.01 meter for some segments where the number of traversals exceeds 200. We compute the curvature along each segment from the derivatives of the spline. Figure 3 shows the histogram of road curvature. As expected, most roads are straight with curvature 0.We also have calculated the bank for some high RSA areas. The super-elevation, or bank, of the curve

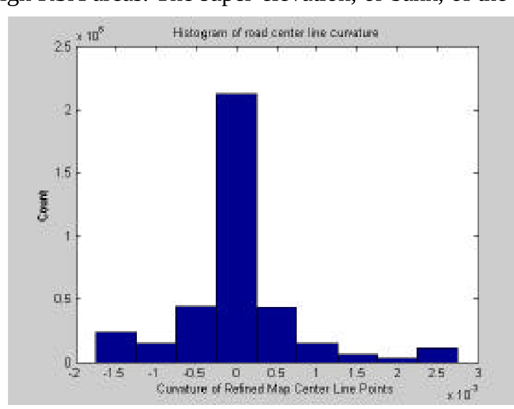

Figure 3: Histogram of road centerline curvatures.

lets the truck drive faster around the curve without increasing its lateral acceleration. We calculate the bank from the measured lateral acceleration, speed, and curvature.

Besides the curvature and crosselevation, the system needs to predict the speed of the truck to compute the lateral acceleration. After some analysis, we determined that the best way to predict upcoming speed is to assume that the driver will stay in the same position in the speed distribution as he moves around the curve. This comes from the observation that, although drivers change speed often, fast drivers tend to drive fast relative to other drivers throughout a curve. We estimate the speed distribution at every shape point along a curve from the speeds in the data set.

5 System Evaluation

For this evaluation, we used a fairly simple truck model that sets a threshold of 0.225 g lateral acceleration. This approximates the behavior of Freightliner's RSA system for fully loaded trucks. We evaluated the system on one particularly dangerous curve. An aerial photo of the curve is shown in Figure 4, and Figure 5 shows the comparison of our map's curvature and bank with ground truth and NavTech map. The ground truth for curvature is map obtained by fitting a circle to the aerial photo, and ground truth for banking is provide by the Indiana DOT. It is clearly shown that our map has significant improvements over normal commercial map in terms of map accuracy for road curvatures.

The object of the evaluation was to find how far in advance it is possible to accurately predict crossing the threshold. Figure 6 shows the accuracy of our prediction model for a sample incident. Figure 7 shows the results for this initial prototype. We found that 50% of passes with an incident had predicted the incident between 5 and 16 seconds before it occurred, and only 10% of passes without an incident falsely predicted an incident to occur within 16 seconds. We did a similar evaluation with less data to build the map and found significantly worse results.

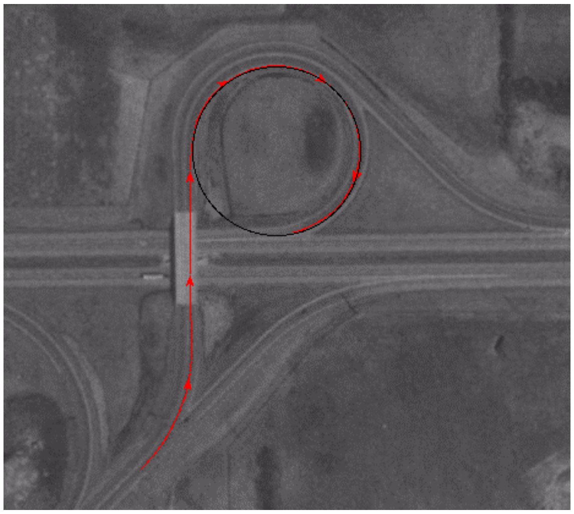

Figure 4: Aerial photo of a dangerous curve.

6 Conclusion

Overall we feel that this approach has promise and performance will improve with more development. Future work includes testing our system on other curves and incorporating more realistic truck and driver models. Even at 50% effectiveness, we hope some day to have an impact on truck safety.

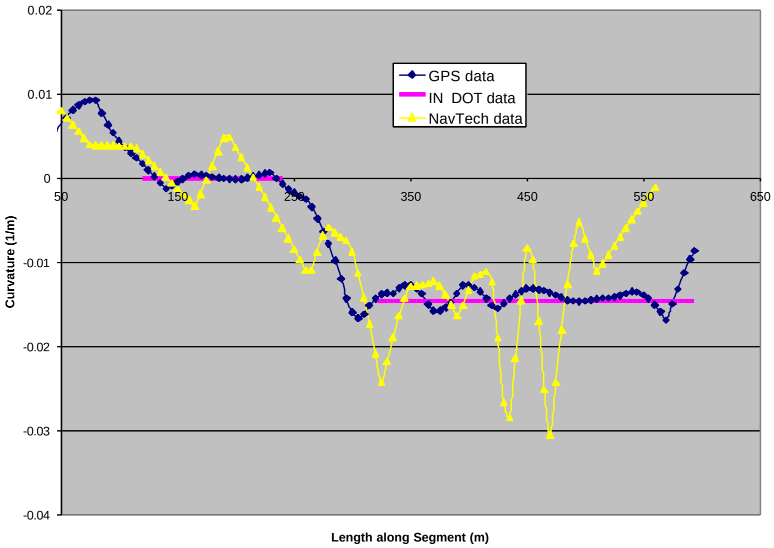

Figure 5: Comparison of curvature for Figure 4 using GPS data, highway authority data, and commercial map data.

References

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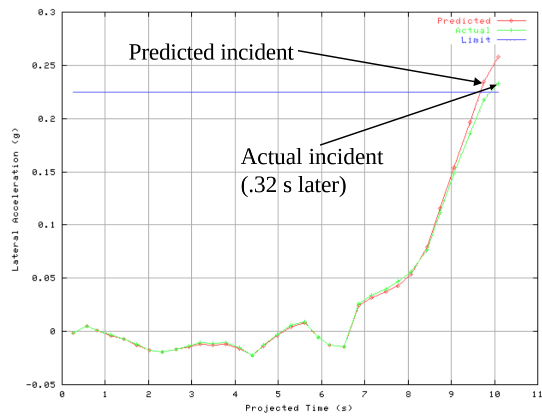

Figure 6: Projected lateral acceleration. The projected acceleration crosses the danger threshold 9.7 seconds into the projection, while the actual acceleration crosses the threshold 10.0 seconds into the projection. In this case, the driver would receive nearly ten seconds warning of an impending dangerous situation.

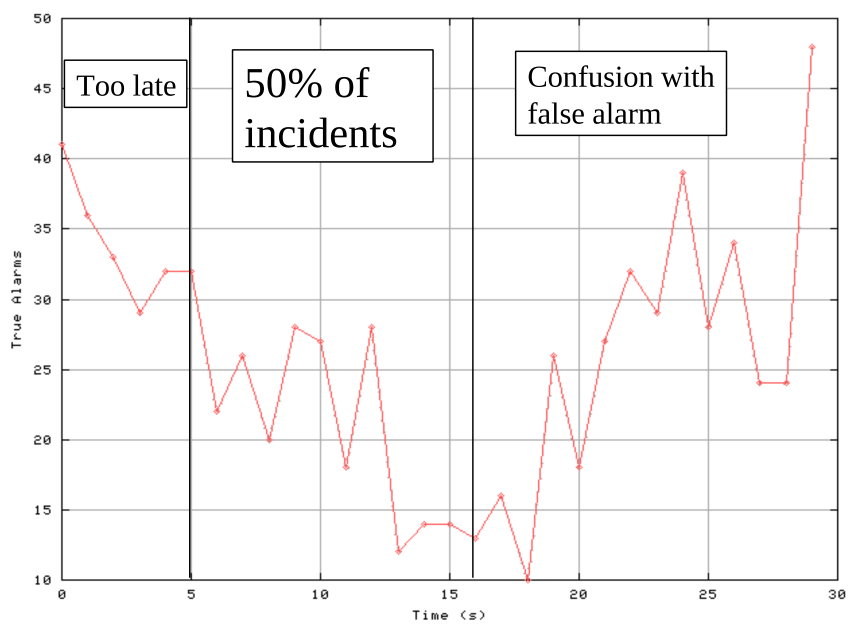

Figure 7: Alarm rate. Alarms occurring less than 5 seconds before the incident are probably too late for the driver to respond. Alarms occurring more than 16 seconds before the incident are probably false alarms. 50% of the passes with incidents, and 10% of the passes without incidents, generated a warning within this time window.