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A Truck Rollover Warning System – Preliminary Results

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This paper describes a test-and-evaluation project to evaluate the performance of a warning system to mitigate the risk of truck rollover. The warning system, which includes both on-board instrumentation and cooperative infrastructure elements, has been deployed since early this year. The test fleet consists of three tractors and six trailers which run a dedicated route that includes all of I-75 in Tennessee. The project is a public-private joint venture led by trucking company U. S. Xpress Enterprises, and coordinated by Oak Ridge National Laboratory. Project objectives include testing of all components in a real-world, revenue-service environment, evaluation of the driver interface, and correlation of driver and vehicle behavior with highway geometry and functional characteristics.

The warning system includes on-board instrumentation that measures the roll stability of the trailer continuously and determines the location and probable near-term path of the vehicle. In addition, roadside beacons at selected curves on I-75 broadcast characteristics of the selected curves. Receivers on the trucks accept curve data, and an on-board computer estimates rollover risk based on roll stability, vehicle speed and acceleration, and the lateral acceleration demand of the upcoming curve. If estimated rollover risk exceeds a trucking-company-specified threshold, visible and audible warnings are presented to the driver in time for corrective action to avoid rollover.

1.0 INTRODUCTION

1.1 Background

Truck rollover is perceived to be a major highway safety problem, with serious consequences for truck drivers, trucking companies and the traveling public. Rollover crashes are much more likely to result in driver fatalities than crashes that do not involve rollover, and vehicle and cargo damage are significant trucking company expenses. Severe traffic disruption often results from truck rollover, and some hazardous cargos have the potential to cause environmental or human disaster if they are spilled as a result of truck rollover. Because of the severity of consequences of truck rollover accidents, it is important to seek ways to avoid such accidents. A public-private partnership led by the United States Federal Highway Administration (FHWA) and Oak Ridge National Laboratory (ORNL) has implemented a prototype integrated system that can warn truck drivers of impending rollover in time for them to take corrective actions.

1.2 Participants

The contributing partners in our project are U. S. Xpress Enterprises, a major 48-state truckload hauler with headquarters in Chattanooga, TN, Volvo Trucks of North America, Wabash National Corporation, a major manufacturer of trailers, Raytheon Control by Light, a division of Raytheon Corporation, and the Operations Division of the Tennessee Department of Transportation (TDOT). Significant subcontractors include the Texas Transportation Institute and the University of Michigan Transportation Research Institute (UMTRI). The University of Tennessee (UT) Transportation Center, in a concurrent collaboration with TDOT, is assisting in the procurement of roadside equipment and will be responsible for storage and some analysis of the data produced by our test-and-evaluation efforts.

Intellectual leadership and financial support for ORNL's participation have been furnished by the former Office of Technology Applications of the FHWA.

1.3 Concept of Operation

Our instrumented tractor trailer vehicles have a computer mounted in the cab, with a flat-panel display visible to the driver and audio output capability. The system software integrates roll warning functions with other existing and future vehicle functions and information systems. The computer is connected to a dedicated short range communications (DSRC) receiver and to various sensors on the vehicle, including accelerometers and roll sensors on the trailer.

In normal highway travel, the sensors on the trailer collect roll-vs-lateral acceleration data and send them to the computer, which builds a table of values that represent the instantaneous roll stability and behavior of the vehicle.

At curves or turns that present appreciable risk of truck rollover, roadside transmitters store pre-computed data about the lateral acceleration demand of the curve. When an instrumented vehicle approaches an equipped curve, the roadside equipment broadcasts curve data to it. The vehicle receives the data and derives a longitudinal reference location. In addition, the vehicle interrogates its internal control computer to derive instantaneous speed and longitudinal acceleration.

If the equipped curve is on the mainline highway (i.e., not a turn, but merely a continuation of travel), the onboard computer estimates the risk of rollover based on projected vehicle speed in the curve, lateral acceleration demand of the curve, and vehicle roll stability. If rollover risk is unacceptable, the computer raises an alarm and adjusts its urgency and duration to suit the estimated risk.

If, on the other hand, the curve is a turn, the onboard computer first attempts to ascertain whether the vehicle is likely to take the turn. If the vehicle is decelerating and has an appropriate turn signal on, it is assumed that the turn is intended to be taken, and an appropriate alarm is raised as above.

A warning signal should be produced when it is estimated that the vehicle's risk of rollover exceeds a (predetermined) threshold if it is operated as projected, based on current speed and acceleration. Matching the type of signal and its urgency to the estimated risk of rollover in a given specific situation makes the system dynamic and hence more believable. It is important to produce the warning in time for the driver to take corrective action; if the vehicle is already tipping, it is too late, and the driver doesn't need any such distractions.

When risk of rollover has passed, alarms are abated, and the location and severity of the risk are recorded for subsequent evaluation by the driver and others.

2.0 SYSTEM COMPONENTS

2.1 Hardware

Onboard instrumentation includes components on both the tractor and the trailer. Of particular interest is the trailer instrumentation, since in almost all cases it is the roll stability of the trailer that determines the stability of the entire rig. The instrumentation includes a strain gauge, a two-axis accelerometer, a pressure gauge, and a temperature sensor. The trailer instruments operate under the control of a programmable trailer-mounted module (embedded computer) that provides excitation for the strain gauges, analog-to-digital conversion, and protocol generation for digital transmission of the data to the tractor cab.

Our trailers have air suspensions; such suspensions typically have leading or trailing arms on each side with air bags that support the load but provide little roll stiffness. The trailing arms are connected by torque tubes that provide the primary roll stiffness of the suspension. The assembly resists roll moment in a manner similar to that of an anti-sway bar in an automobile suspension. (For an excellent and more extensive discussion, see *Winkler, et al.* Our trailer instrumentation closely follows the example provided by the successful UMTRI project.)

Sensing of the strain in the torque tube as the trailer sways from side to side provides a signal proportional to the roll moment. Similarly, measurement of the air pressure in the suspension's air bags provides an output proportional to the total load of trailer and cargo. In addition, a two-axis accelerometer on the axle is mounted so that it measures lateral and longitudinal acceleration as the vehicle travels on the highway. Connections to leads for turn signal lights are included, to allow recording of turn signal actuations. A temperature sensor is included in the instrumentation to allow compensation for the temperature dependencies of the measurements provided by the rest of the sensors.

Instrumentation in the tractor includes a rugged computer with a VGA-capable liquid crystal touch screen display, a receiver for signals from Global Positioning System (GPS) satellites, a receiver for broadcasts from roadside DSRC beacons, and a number of other sources for advisory information to assist the driver. The various information sources are integrated into the display-based driver interface. We have emphasized the necessity of avoiding distractions that would diminish the attention that a driver must give to his primary task of vehicle control.

At a few sites along the route we have deployed DSRC beacons that broadcast information about a curve that the truck is approaching. The broadcast message contains information about the lateral acceleration demand of the curve. The beacons use 900 MHz broadcast technology that is derived from electronic toll collection and clearance product lines. The vehicle's position along the roadway with respect to the curve is derived from the timing of the receipt of the signal.

2.2 Software

Software installed on the trailer's embedded computer manages the collection of data from the trailer's sensors. In normal operation, air pressure, torque tube strain, and acceleration data are collected ten times a second; the embedded computer can be commanded to change that rate if a situation warrants a different collection rate. Turn signals are monitored, and times of actuation are recorded.

The main on-board computer, mounted in the cab, accepts messages from all of the installed equipment, monitors status of vehicle operating parameters, maintains a current estimate of vehicle roll stability, monitors vehicle location with respect to any stored hazard locations, and maintains a current display for the operator interface screen. If current data indicate that a warning to the driver is appropriate, the computer presents the warning; the saliency of the warning is adjusted to suit the timeliness and importance of the message. If current operational data exceed any established thresholds for severity of maneuver (for example, acceleration that indicates swerving or heavy braking), the relevant data including location are logged as a reportable incident.

During the initial revenue-service phase of this project, software to implement the driver interface was being written under a contract with Texas Transportation Institute. During that phase, when no warning to drivers was feasible, "before" data was collected by ad hoc software furnished by Volvo.

3.0 SYSTEM OPERATIONS

3.1 Route and Schedule

A potential problem for on-board systems that involve both tractor and trailer is that any particular tractor does not normally stay connected with a single trailer -- trailers often stay at a shipper's site as they are loaded, while tractors are usually in almost-continuous use. That problem is addressed in our project by instrumenting vehicles that U. S. Xpress has dedicated to a particular customer and route. Three tractors and six trailers are used to haul cargo from Atlanta, GA, to a suburb of Dayton, OH, primarily on Interstate 75. Typically, a driver will drop a loaded trailer in Ohio to be unloaded; a second already-loaded trailer is picked up in Ohio and driven to Atlanta, where the process is repeated. The usage pattern allows several traversals of the corridor and significant data collection along the route by each vehicle in a week.

3.2 Data Collection, Storage and Analysis

The on-board computer in the tractor collects a variety of data about the vehicle's operation. For example, trailer dynamic performance is monitored by the trailer's computer and data are sent to the tractor to record suspension torque-tube strain (surrogate for roll moment), suspension air pressure, lateral and longitudinal acceleration, presence of left or right turn signal voltage, and temperature, all as a time series data set.

The tractor's computer both stores these data for later off-line analysis and immediately uses the data to calculate and refine an estimate of the lateral acceleration threshold for lift-off of the inside wheels on a curve. The lift-off threshold calculation is initially performed at the start of a trip as soon as the vehicle's speed reaches a chosen lower bound (to eliminate spurious data from low-speed artifacts) and is continuously refined throughout the trip. The calculation is made with measurements taken on the as-loaded trailer; this is very significant, because the roll threshold can vary significantly under different loading conditions. (See Winkler for a discussion of the calculations and examples of the convergence of the calculations as data collection continues during a trip.)

In addition to trailer data, the tractor computer collects and stores -- as time series -- location data (from the GPS receiver), speed and some engine operating parameters (from the vehicle's internal data bus), and the time of occurrence and content of any messages received from roadside DSRC beacons. Warnings generated by non-rollover safety systems are also logged.

3.3 Warnings to Driver and Other Uses for the Data

The immediate objective of the on-board data collection and processing is to allow estimation of the risk of rollover as the vehicle (with calculated roll stability) approaches a curve (with just-received or previously-measured lateral acceleration demand) at a known (continuously measured) speed. If estimated risk of rollover exceeds a pre-chosen threshold, a warning is presented to the driver in time for corrective braking. [Author's Note: That's how it's going to work. The contract to produce the final software for risk estimation and driver warning was to be signed on the day before the submission deadline for this paper!]

An additional objective of the data collection is to allow later, off-line analysis of the data. Each vehicle will collect and store data during a round trip; the stored data will be transferred to a removable flash memory card in a PC Card slot in the on-board computer which is then transferred to a similar PC Card in a computer at the U. S. Xpress headquarters in Chattanooga. U. S. Xpress staff will validate the data and load them into a database for preliminary analysis; any data they consider proprietary will be "cleansed," and the data will then be made available -- probably by Internet file transfer -- to staff at the University of Tennessee - Knoxville (UTK) for storage in the Rollover Warning Project central data base.

Staff at UTK will subsequently analyze the data, looking in particular for geographical clustering of instances of emergency accelerations. Clusters of heavy braking events could indicate either highway design features that surprise drivers or perhaps traffic situations that require emergency maneuvers. This sort of analysis is particularly interesting to the Tennessee Department of Transportation, who are co-sponsoring the project. In addition, analysis of the data will allow construction of a relatively complete database of locations of high lateral acceleration demand on the route as normally driven. Such a "bad-curve" database could materially reduce the need for beacons to broadcast descriptions of curves.

4.0 PRELIMINARY RESULTS AND CONCLUSIONS

[Author's Note: At the submission deadline for papers for this conference, the Rollover Warning fleet was in final checkout before deployment into revenue service, and therefore there was no useful data to report in this section. By conference time, we should have data from several months of operation, which we will present and discuss. Generally speaking, we will report on the topics indicated below. We plan to bring a few preprint copies of the final paper to the conference for those who may want copies of the results.]

4.1 Performance of Hardware and Software

(functionality, reliability; phases, changes and upgrades)

4.2 Observed Influence of Highway Characteristics

(acceleration excursions vs location/geometry)

4.3 Implications for Truck Safety

(functionality vs requirements; cost – as-built, near-term future, and after a computer-systems learning curve)

References

Winkler, C.; Fancher, P.; Ervin, R. 1999. Intelligent systems for aiding the truck driver in vehicle control. Michigan University, Ann Arbor, Transportation Research Institute. 14 p. IVVehicle Navigation Systems and Advanced Controls (SAE-SP-1428). Warrendale, SAE, 1999. Pp. 165-178. Report No. SAE 1999-01-1301.