Analysis of Large Truck Rollover Crashes

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ABSTRACT – The Large Truck Crash Causation Study undertaken by the Federal Motor Carrier Safety Administration describes 239 crashes in which a truck rolled over. In-depth analysis revealed almost half resulted from failing to adjust speed to curves in the road, (mostly on-and off-ramps), the load being carried, condition of the brakes, road surface, and intersection conditions. A second major crash contributor involved attention: simply being inattentive, dozing or falling asleep, and distraction, all leading to situations where a sudden direction change resulted in a rollover. The third large crash contributor involved steering: over-steering to the point of rolling over, not steering enough to stay in lane, and overcorrecting to the point of having to counter-steer to remain on the road. Finally, loads are a frequent problem when drivers fail to take account of their weight, height or security, or when loading takes place before they are assigned. Instruction in rollover prevention, like most truck driver training, comes through printed publications. The use of video would help drivers recognize incipient rollovers while currently available simulation would allow drivers to experience the consequences of mistakes without risk.

INTRODUCTION

When a truck travels along a curved path, centrifugal force causes it to lean away from the direction of the curve. The result can be a "rollover" in which the truck overturns. Tractor-trailers are particularly vulnerable because of the trailer's high center of gravity and frequently unstable loads. The Large Truck Crash Causation Study (LTCCS) was undertaken in 2002 by the Federal Motor Carrier Safety Administration. A nationally representative sample of large-truck fatal and injury crashes was investigated from 2001 to 2003 at 24 sites in 17 States (FMCSA 2006). Each crash involved at least one large truck and resulted in at least one fatality or injury. Data were collected on up to 1,000 elements in each crash. The total sample involved 967 crashes, which included 1,127 large trucks, 959 non-truck motor vehicles, 251 fatalities, and 1,408 injuries. An estimated 9% of all large truck crashes involve rollovers, defined as an event involving "one or more vehicle quarter turns about the longitudinal axis." When projected nationally, an estimated a total of 141,000 large trucks would have been involved in fatal, incapacitating, and non-incapacitating injury crashes during the period of the FMCSA analysis, 13,000 of which would have been rollovers.

Garcia, Wilson, and Innes (2003) studied the response of a five-axle tractor-trailer unit carrying various weight loads along roadway curves with varying radii under normal operating conditions. Although the vehicle traveled at or below the posted speed limit in the majority of cases, lateral accelerations recorded for the trailer exceeded expected lateral accelerations under all load configurations. Green (2002) concluded that rollovers are the deadliest crashes, occurring with particular frequency on freeway ramps and inclines and suggested the use of sensor activated warning signs that detect unsafe approaches. Khattak and Schneider (2002) reviewed police-reported crashes in North Carolina between 1996 and 1998, 30% of which were rollovers. Dilich and Goebelecker (1997) listed the range of rollover causes. The great majority were driver errors, including excessive speed in curves, often misjudging sharpness, drifting off road, often counter-steering abruptly, not adjusting to the trailers high center of gravity, being impaired physically (e.g. fatigue, drowsiness) or emotionally (reckless, angry). Vehicle-related problems include top heavy and badly distributed or unsecured loads, poorly maintained brakes or suspension and under-inflated tires, many of which were the driver's responsibility to check.

The present paper describes research undertaken to identify causes underlying the 239 rollover incidents drawn from the Large Truck Crash Causation Study (LTCCS). The analysis was undertaken to isolate the specific causes of rollover crashes, which could be expected to vary significantly from those that prevail across the full array of large tuck crashes. The differences could well call for preventive approaches that are aimed specifically at reductions in rollovers.

METHODS

The analysis of rollover crashes made use of data collected under the LTCCS. The following sections will summarize the methods by which data were collected and the means by which crashes were analyzed to identify the causes from collected data.

Data Collection

At each site truck researchers operating under the National Automotive Sampling System (NASS) collected data including physical evidence at scenes, vehicle inspections, driver and witness statements, medical and police reports. NASS has no authority to require drivers, witnesses or company representatives to furnish information. All reports are voluntary and often withheld, primarily for concern over litigation. The role of the truck researchers was limited to data collection; inferences as to cause came from senior truck accident specialists on the project staff. The chief data source used in identifying causes in the present analysis was the set of lengthy narrative descriptions, generally running several hundred words, prepared by the on-site research staff. Although no strict format was employed the descriptions generally occurred in the following order: (1) location of crash, (2) the nature of the crash, (3) effect upon involved vehicles, including where they came to rest, (4) injuries and medical care, and (5) identification of contributing conditions and events, to occupants and others. The narratives are accompanied by diagrams showing movement of trucks and any other involved vehicles along with roadway and relevant off-road characteristics. Several photographs of the crash scene are also provided, although their use proved unnecessary to the analysis of most rollovers. The specification of unsafe acts revealed through on-site investigation comes in identification of the "Critical Event" and "Critical Reasons" for that event found at the end of the narrative, elements of crash analysis introduced by Perchonok (1972). Analysis of the lengthy narratives revealed crash causes beyond the critical event, including driver errors leading to the event. Most important, the LTCCS effort has provided a data base from which the research community can carry out analyses aimed at identifying the full range of causes.

Data Analysis

Accident causes have been classified into two categories by Reason (1990): 1) Unsafe acts, the specific conditions and behaviors that directly cause accidents as identified through investigation of individual accidents and 2) Latent Factors, the predisposing conditions that raise the probability of a crash as identified through statistical comparisons of accident-involved and accident-free samples. A paper describing the analysis of unsafe acts as causal factors in large truck crashes is provided by McKnight (2004) while Craft and Blower (2001) describe the analysis of latent factors. The present analysis of rollover crashes addresses the unsafe acts revealed through in-depth investigation of the 239 rollovers drawn from the cases making up LTCCS sample. Through the narratives and diagrams provided for each crash, a total of 279 unsafe acts were identified, meaning that many crashes had more than one cause (excluding any predisposing latent factors). Clearly such a number is too large to be addressed individually, making it necessary to group them into causal factors having sufficient homogeneity to become targets of highly similar preventive measures. As is usually the case, this was a step-by-step undertaking, gradually combining categories into a workable number yet preserving an acceptable degree of homogeneity. The result was 30 distinct categories grouped into seven major areas.

The source data analyzed included a subset of 239 rollover crash cases involving 290 large truck occupants (drivers or passengers). A total of 21 of these occupants died as a result of the crash, 4 had non-fatal critical or serious injuries. Based on the Abbreviated Injury Scale (Greenspan et al. 1985) these were occupants whose maximum injury severity was AIS 4 or 5. A total of 42 large truck occupants sustained moderate or serious injuries (AIS 2 or 3). Some 172 sustained AIS 1 (minor) injuries and 51 had no documented injuries as a result of the crash. The majority of rollover crash cases, 70%, involved Class 8 tractor-trailers or tractors without a trailer attached (commonly known as bobtails) and 30% involved single unit trucks. Of all rollovers, 56% occurred on divided highways which are typically higher speed roads, 42% occurred on two-way non-divided roads and 2%occurred on one way streets. The majority of the large truck rollover crashes, 77%, were single vehicle events. The remaining 23% involved contact with another vehicle before or after the large truck rollover.

RESULTS

The direct cause of any rollover is something that increases the roll moment about the longitudinal axis of the vehicle, generally either turning too quickly or allowing one side of the vehicle to drop or rise suddenly. However each of these is primarily due to an error on the part of the driver, less often some other driver or condition of the truck. It is these underlying causes that can become the object of preventive measures. The seven categories into which these causes were combined are Speed, Attention, Control, Search, Pre-Operation, Other Drivers and Vehicle Truck Components. Each will be addressed individually.

Speed

Speed is the biggest contributor to rollover crashes, being involved in 45% of the crashes making up the LTCCS sample. This greatly exceeds the 23% of all large truck crashes attributed to "Traveling Too Fast for Conditions" (FMCSA 2006). Speed-related causes are listed in Table 1.

Table 1. Speed-Related Rollovers

CAUSE	N	DESCRIPTION
Speed	**108**	**Speed excessive to circumstances**
Curves	77	Curves taken at excessive speed
Misjudge	67	Misjudged speed at which the curve could be taken
Hurry	13	In a hurry and disregarded speed limitation
Anger	3	Loss of temper in response to other road users
Oversight	3	Failure to notice speed signs
Loads	26	Not adjusting speed to stability, weight, height
Brakes	15	Not adjusting speed to known bad brakes.
Road	11	Not adjusting speed to road conditions
Intersect	10	Not adjusting speed to sharp turn at intersection
Vehicles	5	Not adjusting speed to vehicles ahead
Tires	3	Not adjusting speed to worn tread
Sight Distance	2	Not adjusting speed to limited sight distance

Two aspects of the conditions under which the crashes occur help explain the role of speed. First, rollovers occur when the front wheels are turning the truck more quickly than the cargo it is carrying; the faster the speed of the vehicle, the greater the difference. Second, large trucks operate chiefly on Interstates and other high speed roadways. As with speed related incidents in general, it is not the very high speeds associated with "reckless" driving but rather speed that exceeds what is safe for the particular combination of vehicle and road characteristics. As noted earlier, many crashes have multiple causes, as is evident in the fact that the number of specific causes adds up to 149 where speed related crashes total only 108.

Curves. It is in handling curves, mostly on- and off-ramps, that excess speed becomes the biggest factor, accounting for 77 rollovers, two-thirds of all those that are speed-related. Semi-trailers appear the most vulnerable to curves in that straight trucks, which make up a third of the trucks involved in rollovers, have only 10% of those occurring on curves. This largely reflects the relatively lower roll stability of the trailer. Because the reasons drivers exceeded safe speeds on curves differ substantially, they are further sub-categorized.

Misjudgment. The single biggest cause is simply misjudging the speed at which the curve can be safely entered. Over four-fifths of the crashes occurring on curves are attributable to misjudgment. The judgment problem is aggravated in many locations by posted speed limits that are too high for loaded tractor-trailers. One proposed solution is to post lower limits for semis at such locations.

Hurry. Being in too much of a hurry is the second biggest antecedent to rollovers on curves, being a factor in 13 rollovers. Although in four cases it combined with misjudgment of safe speed, in most instances the desire for speed prevailed over any judgment as to how fast a curve could be safely taken. Reasons for haste included being late, having some outside commitment, chronic impatience and trying to beat another vehicle to some merge point.

Anger. While it happened only three times within the cases analyzed, the actions of other road users triggered anger and an overly aggressive response by truck drivers, the result of which was to place them in situations that ultimately led to a rollover.

Oversight. Curves sharp enough to threaten roll stability are generally posted for maximum safe speed. While most speed related rollovers result from simply ignoring posted limits, in three cases drivers claimed not to have noticed them (excluding cases when signs were down and drivers were left to their own faulty judgment).

Loads. Some 26 rollovers were the result of loads that were too heavy, insecurely fastened or mounted

too high in the truck. The effect of loads is evident in the fact that they have twice the effect on rollovers as they do on other truck crashes. The effect of cargo improperly loaded is experienced most often on ramps and curves, although some occurred in a lane change or when a wheel dropped off the pavement. In 18 cases the overloads were combined with misjudgment; had speed been adjusted to the overload the rollover might have been avoided. As with misjudgment, the high incidence of load-induced rollovers suggests the need for means of acquainting drivers with the possible effects of loads on vehicle stability.

Brakes. In 15 cases the condition of the brakes prevented slowing down enough to avoid the rollover. Instances were fairly equally divided among curves, intersections and steep downgrades. In four instances bad brakes combined with misjudgment of maximum safe speed to result in rollovers on curves. In all of these instances the truck had been driven long and far enough during the trip for the drivers to be aware of the brake problem and accommodate it by reducing speed.

Roads. Features of the road contributing to 11 rollovers were slippery surfaces (6) and long downgrades (5). In all cases, the drivers were aware of the safety threat posed and could have prevented the rollover situation by reducing speed, either by downshifting before starting downgrades or by earlier braking on slippery surfaces. Since nothing could be reasonably done to alter the condition of the road, the true cause lies with drivers rather than what they are driving on.

Intersections. The 10 intersection rollovers were a result of going too fast to make turns. These occurred when drivers were trying to beat a traffic light, when unexpectedly encountering a T-intersection, or when making a last second turn at a cross road (where a better choice would have been to keep going and then come back).

Vehicles. Five rollovers occurred when drivers failed to realize early enough that vehicles ahead had slowed and they were unable to stop in time. The primary cause was inattention, with one case due to insufficient following distance.

Tires. Three rollovers involved failure of the driver to adjust speed to account for worn tire tread, two in curves and one on a slippery surface.

Sight Distance. On two occasions, trucks approached the top of a hill and failed to reduce speed to accommodate the limited sight distance. Upon seeing stalled traffic they swerved sharply and rolled over.

Attention

Second to speed as a contributor to rollovers comes lack of attention. Table 2 shows 54 instances that were the result of attention lapses. Across all motor vehicles, lack of attention ranks along with lack of visual search and out-ranks speed as a cause of non-fatal crashes. Fortunately, the attention demands of open highways are minimal compared with city streets. Also, over a third of attention-related rollovers were due to sleep deprivation, a function of the long distances and hours of truck driving.

Table 2. Attention-Related Rollovers

CAUSE	N	DESCRIPTION
Attention	**54**	**Lack of sufficient attention to driving**
Inattentive	25	Not paying attention ahead necessitating sudden turns
Sleep	20	Being asleep or drowsy enough to be unaware
Distraction	13	Driver distracted by CBs, passengers, cell phones

Inattention. The chief attention problem, leading to 25 rollovers, was simply not being observant to what is going on ahead of the truck, necessitating a sudden change in direction leading to a rollover. In 12 of the cases, lack of attention was the only cause reported. The 10% of rollovers resulting from inattention is close to the 8.5% reported for all large truck crashes. However, it is a smaller degree of involvement than occurs with motor vehicles in general, a finding less likely attributable to the alertness of those who drive large trucks than to the reduced attention demands of driving primarily on open highways outside of city and suburban traffic.

Sleep. The second most frequent source of attention loss, 20 cases, was falling asleep at the wheel, or at least becoming sufficiently drowsy to render the driver unaware of what was happening. In some cases it could be attributed to the time of day (early morning) or length of time without sleep, but the source was difficult to pin down in most cases. The most frequent result was drifting off the road and overturning. However, in six instances the driver suddenly became aware of having left the road, attempted to steer back quickly and rolled over while on the road.

Distraction. The remaining attention problem, with 13 cases, was being distracted, mostly by passengers either talking to them or otherwise attracting their attention. Other sources included cell phones, CBs, tuning the radio, or hearing a strange sound. There were a few additional cases in which drivers reported a distraction but the rollover cause lay elsewhere.

Control

Errors in controlling the motion of the truck were a factor in 46 rollovers (Table 3). Of the responses needed to control the truck, steering was the most prone to errors resulting in rollovers. Although failure to steer in a way that would keep the truck on the road was a frequent problem an equal contributor to rollovers was overcorrecting, that is going in one direction and quickly turning in the other direction. Maintaining adequate following distance, downshifting and braking were smaller problems.

Table 3. Control-Related Rollovers

CAUSE	N	DESCRIPTION
Control	**46**	**Errors in controlling motion of the truck**
Steering	20	Over- or Under-steering
Over-Correct	19	Overcorrecting after error (off road, out of lane)
Following Distance	7	Failure to keep distance from vehicle ahead
Maneuver	6	Responding to vehicles/road incorrectly
Downshift	3	Failure to downshift for speed control
Braking	3	Improper braking, e.g. locked brakes

Steering. Poor steering control, including under-steering or over-steering, led to 20 rollovers. About half of these involved simple over-steering in the process of lane changes and swerving more sharply than necessary to avoid trouble. Most of the remainder involved marginal steering control, with difficulty staying in lane and two incidents of difficulty turning corners.

Overcorrection. Some 19 rollovers were the result of steering corrections, that is, turning too much in one direction followed by corrective turns that exceeded the stability of the truck, much like a curve taken at too high a speed. Situations leading to and coupled with overcorrection were falling asleep, inattention, steering errors, and distractions.

Following distance. Inadequate following distance is far less a factor in crashes among trucks than other vehicles. In three of the cases, one truck was following another.

Maneuver. Inappropriate responses included running into another vehicle when an alternative was available, and making a last-second sudden turn when it would have been wiser to continue ahead.

Downshift. These occasions involved failing to shift to a lower gear when starting down a long grade with known bad brakes.

Braking. Although locking the brakes caused three rollovers it is also frequently involved in other crashes of trucks and cars.

Search

Lack of adequate visual search, not looking in the right place at the right time, contributed to eight rollovers (Table 4). This is a far smaller problem as a rollover causal factor than in general trucking where it is involved in 13% of all crashes. Again, the difference is primarily attributable to the fact that most rollovers occur on interstates and other major highways where there is relatively little conflict with other vehicles. In city traffic the importance of maintaining a high level of visual search assumes far greater importance.

Table 4. Search Related Rollovers

CAUSE	N	DESCRIPTION
Search	**8**	**Inadequate visual search**
Side	6	Not looking sideways at intersections, lane changes
Ahead	2	Not looking far enough down road, along roadside

Search to the side. Six rollovers involving failure to search to the side were divided equally between initiating lane changes and crossing intersections. In one fatal incident a driver turned across a railroad track where a flashing light signaled an approaching train he apparently assumed was delivering to a local service area.

Search ahead. The two situations involved failure to look far enough ahead. One was a case where the driver's attention was diverted to the rear view mirror and the other was a case in which the driver's attention was focused on the road directly in front of the truck. In most cases the failure to respond to threats in the path ahead was the result of attention lapses rather than inadequate search.

Pre-Operation

Two categories of rollover resulted from conditions that existed before the time the truck was operated on the road: the way the truck was loaded and the driver's mental and physical condition before driving. (Table 5).

Table 5. Pre-Operation Rollovers

CAUSE	N	DESCRIPTION
Pre-Operation	**20**	**Lack of sufficient attention to driving**
Loading	15	Failure to assure the security of the load
Driver State	5	Unknown/ unpreventable condition of the driver

Loading. Some 15 rollovers could have been avoided by better securing of the load. Had the load itself not been allowed to shift, the truck would have remained upright. In these instances, it was the driver's responsibility to make sure the load was properly secured before starting out and this was not done. As noted earlier, in 26 additional cases the problem lay in the speed of the vehicle combined with the height, weight or stability (e.g. fluids) of the load itself.

Driver state. Five rollovers occurred when drivers lost consciousness due to a physical ailment or the medication used to treat it. One instance of falling asleep appears to have been the result of medication. All of these conditions had a history, and might not have become a rollover cause had drivers taken steps to prevent their arising when behind the wheel.

Other Drivers

In all of the rollovers that have been described up to this point the incident could be attributed to some mistake on the part of the person operating the truck. However, Table 6 shows that 32 rollovers were the fault of another driver. This represents a small proportion compared with other truck crashes, primarily collisions with other vehicles, less than half of which are attributed to operation of the truck.

Table 6. Rollovers Caused By Other Drivers

CAUSE	N	DESCRIPTION
Other Drivers	**32**	**Truck driver was not the responsible party**
Struck By	28	Struck by another driver
Caused By	4	Caused by another driver

Struck by. Of all the rollovers, 28 resulted from the truck being struck by another vehicle. The incidents included oncoming or passing vehicles turning into the truck's lane, and vehicles coming from the side at crossroads and entrances. In none of these cases could the truck driver have been reasonably expected to avoid being hit.

Caused by. In four cases, the truck was not struck but rolled over in the process of avoiding a collision with another vehicle. The situations were largely the same as those in which the truck was struck, and here again the truck driver could not have prevented the rollover.

Vehicle

All of the rollover causes described thus far involved errors on the part of drivers, including drivers of vehicles other than the truck. Some 13 of the rollovers were the result of vehicle conditions for which the driver was not responsible (Table 7).

Tire failure. In addition to the three rollovers due to speed and worn tires, five were the result of blowouts that didn't involve any visible defects that could have allowed tire failure to be anticipated by drivers.

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Table 7. Vehicle Component Caused Rollover

CAUSE	N	DESCRIPTION
Vehicle	**13**	**Caused by condition of vehicle when assigned**
Tires	5	Caused by poor tread and blow-out
Loads	4	Caused by loading before truck assigned to driver
Brakes	2	Caused by sudden brake failure
Part	2	Part failure causing loss of control

Loads. Of the rollovers resulting from the way the truck was loaded while supervised by the driver, in four cases loading occurred before the truck was assigned to a driver and may be considered a condition of the vehicle for which the drivers were not responsible.

Brake failure. Two rollovers occurred when brakes suddenly failed on long downgrades. In neither case did drivers have reason to suspect a problem and possibly shift to a low gear before beginning the descent.

Part Failure. Two rollovers were caused by part failures, one in the steering mechanism and one in the rear axle.

DISCUSSION

The causes of rollovers emerging from the present analysis follow those identified by Dilich and Goebelecker (1997) but in greater detail. They form a pattern that is significantly different from those that characterize other truck crashes, which are primarily vehicle to vehicle collisions. Although the categories of cause are largely the same, many of the specific mistakes that cause the vehicle to crash are unique to rollovers.

Rollover Causes

Clearly the large truck's high center of gravity is a major factor contributing to the vehicle's likelihood of overturning. This occurs frequently in curves, such as on- and off- ramps, where the truck turns but the load tends to continue along the original path and the vehicle rolls over. In some cases the driver misjudges the speed at which a particular curve can be safely taken while in others it is simply a case of being in a hurry. A quarter of speed related rollovers result from failure to adjust to loads being carried. The higher and heavier the load, the greater the need to reduce speed during maneuvers. With loads, another rollover

cause is just failure to secure them fully, something drivers are supposed to assure is done before starting out. The second leading crash contributor is lack of adequate attention, a factor that figures more strongly in crashes involving other vehicles. Simply failing to pay attention to driving and being distracted are common to operation of automobiles. However, becoming drowsy and falling asleep are significant problems in trucking, due in great part to the length of time and hours of the day that much of it occurs. A third category of crash contributor that figures strongly in rollovers is control error. Most drivers of any vehicle learn how to steer, accelerate, and brake very quickly. However, in trucks steering can be a problem source. One problem is turning either too much and precipitating a roll moment or too little and running off the road, where the drop-off causes the rollover. The other problem involves overcorrecting for some path error and then having to swerve sharply to keep from going off the road. The remaining causes are those that figure heavily in all kinds of truck crashes, of which rollovers are just one type. They are primarily traffic related and relatively less of a factor in rollovers, which tend to occur on open roads. Lack of visual search, while a significant factor, is a greater contributor to other vehicle collisions, which tend to occur primarily in traffic. While the actions of other drivers figure in about half of all truck crashes, they play a relatively small part in rollovers, as do problems with the vehicle itself.

Rollover Prevention

Knowing the crash causes that are specific to rollovers will allow countermeasures to be directed specifically to their reduction. Some crashes might be overcome through changes to the vehicle or roadway. Examples include signs at freeway exits that impose lower speed limits on trucks, or devices in vehicles that advise drivers of dangerous load conditions. However, these seem unlikely, particularly in a generally tight economy. A more accessible route to crash reduction would be to include rollover prevention measures in training programs for drivers of trucks, particularly the tractor-trailers that are most vulnerable to rollover. As previously mentioned, 69% of the rollover cases sampled (166 out of 242) involved a tractor-trailer yet the number of registered single unit trucks outnumbers tractor-trailers by nearly 3 to 1. Most truck training programs list rollovers within their subject matter. However, the nature of instruction is not specified in descriptions of most curricula. One barrier to instruction as a means of preventing rollovers is the lack of any requirement that drivers be trained. Efforts of the past score of years to impose a training requirement have fallen short of complete success. The need to pass a Commercial Driver License (CDL) test is expected to provide the impetus to learn safe operating procedures, an aspect of driving that can be satisfied largely through printed materials. However the situations that lead to rollovers are far better presented visually than through the written word. In recent years a number of video programs providing instruction in various aspects of driving safety have been developed and would lend themselves to rollover prevention. The fact that most rollovers are the fault of the truck driver, and the cost must be borne entirely by the company, might provide the impetus to provide something more than printed material.

Simulation

Overcoming the three biggest causes of rollovers ─ speed, inattention and poor control ─ will be a challenge as it requires the ability to recognize and handle the specific conditions that could lead to a rollover. Unfortunately many drivers learn what can lead to a rollover only by failing to cope with such situations and experiencing them first hand. A clearly better alternative would be a form of simulation which duplicates the vehicle response to the speed, steering and load conditions that lead to rollovers. The application of simulation for this purpose in truck driver training has been addressed by the Professional Truck Driver Institute (PTDI 1999). While simulation has been widely offered as a means of developing skill in vehicle operation its use has been discouraged by the ready availability of trucks for training purposes. However, training in trucks is not likely to be successful for dealing with rollover situations, where the truck could be on its side before an instructor could intercede. Here is where simulation offers the only acceptable means of skill development. Learners can be presented with situations, experience the consequences and learn how to handle them. To serve as a rollover prevention device, a simulator must be programmed to convert vehicle control responses beyond merely the visual display of speed, direction and the effects of surface irregularities, but also the combinations that result in rollovers. This involves a highly complex set of equations that few truck simulators attempt to make part of their programs. The only aspect of rollovers that cannot be readily simulated is causing the simulator itself to rollover, with the learner at the controls. However, achieving this degree of fidelity is not essential to learning rollover prevention. What remains is a test of simulation's ability to reduce the incidence of rollovers. The ultimate test would involve a random experiment in which a large sample of drivers was divided between

simulation and non-simulation approaches to instruction, with actual rollovers as the effectiveness measure. However, given the relatively low incidence of rollovers, the size of the sample needed to carry out such an experiment would make it non-fundable. A realistic first step would be simply to see the extent to which instruction improves the recognition and handling of rollover situations in operating simulators.

CONCLUSIONS

1. The majority of rollovers occur in curves, primarily on- and off- ramps where misjudgment leads to speeds that are excessive to the vehicle's high center of gravity.
2. Inattention, dozing and distraction necessitate sudden course corrections leading to rollovers.
3. Three control errors that are relatively unique to truck rollovers are turning too sharply, turning too little to remain on the road and overcorrecting path errors.
4. A quarter of rollovers result from failure to adjust speed to the height and weight of the load being carried.
5. Commercial Driver License programs could improve safety through the use of video to expose truck drivers to the situations leading to rollovers.
6. Simulation can allow drivers to experience the results of rollover inducing errors without the consequences.

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