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The Reconstruction of Eastern Kentucky Rear Coal Truck Crashes

by Roy Crawford, P.E. (NAFE 475F)

Introduction

This paper proposes a method for reconstructing a certain type of collinear, front-to-rear vehicle crash, Eastern Kentucky single-unit coal truck underrides. The crashes discussed are those in which a following vehicle gains rapidly from a long initial distance on a leading slowly moving vehicle that is not sufficiently conspicuous for crash avoidance. The results of these analyses provide insight into the details of what occurs in these types of crashes, show that inattention and/or speeding by the victims are not necessarily causes of the crashes, and can support or refute independent human factors evidence.

Discussion

The author has performed reconstructions of several Eastern Kentucky crashes that occurred because of slow speed and insufficient rear conspicuity of vehicles on high-speed highways, usually at night and/or sometimes in difficult sight conditions. The trucks involved are usually black or another dark color, are coated with mud and dust, and have only two tail lamps that are spaced just eighteen inches apart. See Figure 1. It is likely that the close spacing of the tail lamps causes some following motorists to mistake them for vehicles with tail lamps of normal spacing but three or four times farther away. When these lamps become covered with the mud and dust that is common to dirt and gravel Eastern Kentucky coal mine haul roads, there can be very little if any practical rear conspicuity. These crashes typically involve overloaded coal trucks traveling up and down the steep hills of this region of the country.

Many people envision these types of crashes as occurring when an assumed inattentive driver suddenly sees a truck in his or her path, hits the brakes too late, and slides into and strikes the truck. They are usually surprised to learn that while this sequence happens in only a few seconds, the vehicles involved are initially widely separated and cover significant distances between the beginning of perception of the following driver and impact.

Analysis

In the author's experience, inattention is always listed as a causative factor in these crashes, and speed is often listed as well. Inattention is expected

Roy Raymond Crawford, P.E., P.O. Box 929, Whitesburg, Kentucky 41858-7474

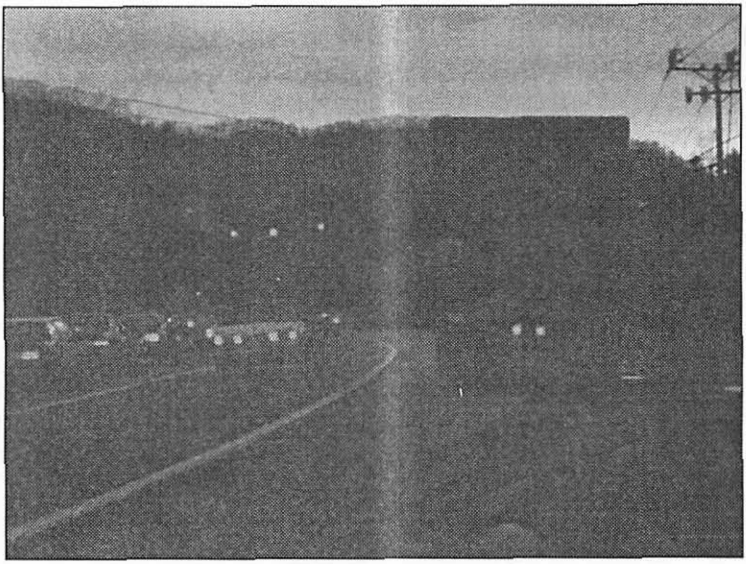


Figure 1

This truck has only two rear lamps and no reflectors or reflective tape. Its tail lamps resemble one side of the automobile adjacent to it. Even with some remaining daylight, it begins to blend into the background.

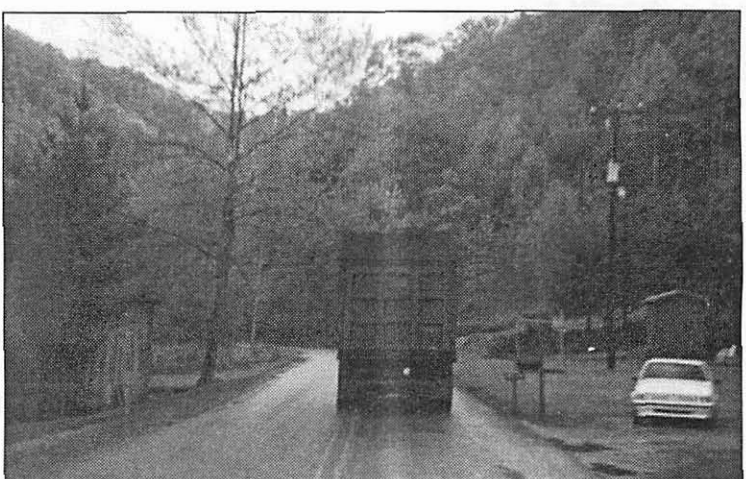


Figure 2

The rear of an Eastern Kentucky single unit coal truck. It has no identification or clearance lamps and no reflectors. Its turn, running, and brake lamps are combined and located six feet or more forward of and under the rear of the dump body. These lamps are spaced only 18" apart and, on this truck, one is broken or completely obscured.

because many people cannot believe that a driver could fail to see something as large as a truck, misunderstanding the difference between seeing and perceiving as a hazard. Speeding is listed whenever there is some evidence of high speed with the understanding that high speed reduces available perception, reaction, and avoidance maneuvering times and distances. However, the author argues that in these cases neither of these factor is necessarily causative.

Studies have shown that when trucks travel at speeds well below the flow of traffic, crash rates rise dramatically, and unlike most Eastern Kentucky coal trucks, the trucks studied had proper rear conspicuity. See Figure 2. The author has never had a case in which one vehicle closed rapidly on another from a large distance and struck it from behind when the lead vehicle was traveling at a normal speed nor a case in which this has happened to a vehicle encountering another with the proper level of rear conspicuity. He knows of no similar cases in his area involving any types of trucks other than coal trucks.

See Figure 3 for an example of a reconstruction of an Eastern Kentucky rear coal truck crash. In this set of calculations, the inputs necessary from the reconstructionist are listed under the heading Assumptions. These include coefficient of friction, grade, closing speed of the vehicles at impact, braking distance, if any, leading vehicle speed, and perception and reaction times of the following driver. The values of these inputs are gathered by standard methods outside the scope of this paper.

These types of reconstructions must be calculated in reverse chronological order from impact to the beginning of perception. There are four sections of results on the spreadsheet. The first section describes the scenario at impact, at which a time of zero has been assigned in this case and the rear of the leading vehicle and the front of the trailing vehicle are at the same point in space. These calculations can be performed with a leading vehicle accelerating or decelerating, but the leading vehicle speed in this example is assumed to be constant throughout the scenario, so it is the same as originally input for all four sections.

Following vehicle speed is the sum of the leading vehicle and closing speeds based on the simplifying assumption that because of the overwhelming difference in masses between the vehicles, usually about a 40:1 ratio, and the lack of permanent crush damage to the coal truck, the truck is treated as a moving barrier. Because truck delta-v's are usually less than one mile per hour in these crashes, their drivers often state that they did not feel any impact and were not aware there had been a crash until they were notified by someone else who saw the wrecked victim vehicle behind the coal truck involved.

Collinear, Same-Direction, Front-to-Rear Crash Scenario Calculations						
Assumptions:			**Standard example**			
Coefficient of friction		0.7	Dimensionless			
Grade		5	Percent, uphill positive			
Impact closing speed		20	Miles per hour			
Braking distance		50	Feet			
Leading vehicle speed		25	Miles per hour			
Perception time		1.75	Seconds			
Reaction time		0.75	Seconds			
Time	**0.00**	**Both vehicles at point of impact**				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		45	Miles per hour		
Time	**-0.72**	**Beginning of braking of following vehicle**				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		56	Miles per hour		
	Distance of leading vehicle from point of impact				27	Feet
	Distance of following vehicle from point of impact				50	Feet
	Separation between vehicles				23	Feet
Time	**-1.47**	**Beginning of reaction time**				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		56	Miles per hour		
	Distance of leading vehicle from point of impact				54	Feet
	Distance of following vehicle from point of impact				112	Feet
	Separation between vehicles				58	Feet
Time	**-3.22**	**Beginning of perception time**				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		56	Miles per hour		
	Distance of leading vehicle from point of impact				118	Feet
	Distance of following vehicle from point of impact				256	Feet
	Separation between vehicles				138	Feet

Figure 3

The second results section yields the products of calculations of the time and distance between impact and the beginning of braking by the victim vehicle, if any. It is not uncommon for there to be no skid marks at all. The point in time, the speed of the following vehicle, and the locations of both vehicles and the separation distance between them at the initiation of braking are all calculated using standard equations.

The third results section yields the products of calculations of the time and distance during physical reaction of the following vehicle driver. The time is simply the previous time plus the reaction time used by the reconstructionist. In this example, the speeds of both vehicles are assumed to be unchanged before and until initiation of braking by the following vehicle driver, so they are the same in this and the fourth results sections. The distances covered during this time interval are added to the previous distances from impact, and the locations of both vehicles are calculated using standard methods. Finally, the separation distance is again the difference between these two figures.

The fourth and final results section is calculated in the same manner as the third. Total time is perception time added to the previous time. All distances and locations are again calculated by standard methods.

In this example, the entire crash sequence occurs in less than 3-1/2 seconds. At the initiation of braking, the vehicles are only separated by 23 feet and the following vehicle is still traveling at its full initial speed of 56 mph.

A key result of this analysis is the final figure in section four, the separation between vehicles. Since, for example, rear truck lights are required to be visible for at least five hundred feet under normal conditions, and in practice can be perceived much farther away than this, such a result indicates either that the truck's rear conspicuity was grossly insufficient, as is the case in most if not all Eastern Kentucky crashes; that environmental conditions made traveling even at normal speeds by the following vehicle unsafe and an unusually slow speeds by the truck even more unsafe; that there was some problem with the following vehicle that hampered its driver's sight distance; that the following driver was extremely inattentive; that the trailing vehicle was traveling at a very high speed; or a combination of these factors. It is typical for the separation distance at the beginning of perception in these crashes to be between 175 and 250 feet, much less than the legally required 500 feet.

The inattention issue is dealt with first; see Figure 4. The second example uses the same assumptions as the first example but with perception time increased to yield an initial separation between the vehicles of the minimum 500 feet that would be expected if the conspicuity required by law under normal conditions was being met. The perception time required is almost 10 seconds, an unreasonably long time to expect someone to be inattentive when driving a motor vehicle. Since sight distances are usually ample in these crashes, this is often considered proof of gross inattention. However, the argument can be made that ample sight distance proves the opposite: that drivers cannot properly guide vehicles along the roadway, often around curves, and keep them centered in their lanes for this much time and distance while being so inattentive as to not be able to see trucks even in their peripheral vision until it is too late to avoid a crash. In other words, that ample sight distance exists in these crashes is not proof of inattention by the victim but of insufficient rear conspicuity and the danger of violating the expectations of drivers by vehicles traveling much slower than the flow of traffic. Even in cases where there are two climbing lanes, one providing a way to pass the slow-moving truck, victim vehicles have remained in the rightmost lane, indicating they did not perceive the truck in time. This example shows that gross inattention is not only not necessary but also very unlikely to be a causative factor in this type of crash.

Collinear, Same-Direction, Front-to-Rear Crash Scenario Calculations						
Assumptions:			**Inattention question**			
Coefficient of friction		0.7	Dimensionless			
Grade		5	Percent, uphill positive			
Impact closing speed		20	Miles per hour			
Braking distance		50	Feet			
Leading vehicle speed		25	Miles per hour			
Perception time		9.68	Seconds		< Only change	
Reaction time		0.75	Seconds			
Time	0.00	Both vehicles at point of impact				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		45	Miles per hour		
Time	-0.72	Beginning of braking of following vehicle				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		56	Miles per hour		
	Distance of leading vehicle from point of impact				27	Feet
	Distance of following vehicle from point of impact				50	Feet
	Separation between vehicles				23	Feet
Time	-1.47	Beginning of reaction time				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		56	Miles per hour		
	Distance of leading vehicle from point of impact				54	Feet
	Distance of following vehicle from point of impact				112	Feet
	Separation between vehicles				58	Feet
Time	-11.15	Beginning of perception time				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		56	Miles per hour		
	Distance of leading vehicle from point of impact				409	Feet
	Distance of following vehicle from point of impact				909	Feet
	Separation between vehicles				500	Feet

Figure 4

It is the author's expectation that in most if not all of these cases glare from oncoming vehicles is very likely a contributing factor, although unfortunately rarely provable. The driver who caused the glare will ordinarily never know that his or her passing by was a factor, the truck driver may not remember or wish to acknowledge the oncoming vehicle, and the victim(s) are usually killed or have brain damage that causes them to be unable to remember the crash or the events leading up to it. An oncoming vehicle would also cause the following driver in these situations to dim his or her headlights, greatly reducing the distance at which those headlights can illuminate another vehicle.

It is also reasonable to expect that in some cases the victim driver looks away from the highway for at least a brief amount of time just before or upon entering a point in time and space in regard to the perception, reaction, and braking and/or steering time and distance necessary to avoid a crash and, by the time he or she looks back, it is too late to do so. This does not necessarily mean that the driver was negligently inattentive. He or she may merely be doing one of the many minor tasks that all drivers perform such as changing a radio station, talking with a passenger, looking in a mirror, reading a billboard, or lighting a cigarette.

For example, consider a coal truck that is perceivable at only 300 feet. A following driver may take his or her eyes off the highway for two seconds beginning at a separation distance of 400 feet, and look back too late to avoid a crash. If the driver is able to perceive a properly conspicuous vehicle at the 500 feet or more that is required by law and traveling at a normal speed, he or she will have enough notice to either complete the task quickly enough that a problem is avoided or wait until the situation is dealt with before performing it. The drivers who become victims of underride crashes may in many cases be the ones who have the misfortune to initiate one of these tasks just before or upon entering the minimum distance required to avoid such a crash. If glare from an oncoming vehicle occurs at the same time and/or there are environmental problems with sight such as fog, rain, or snow, the danger of the situation rises dramatically.

See Figure 5. To consider the possibility of high speed by the following vehicle being a contributing factor, the third example again shows most of the original factors but with a braking distance that yields a very high initial following vehicle speed and a leading vehicle that is perceivable for the required 500 feet. Closing speed is set to zero to represent the following vehicle coming as close as possible to the leading vehicle without striking it. These calculations show that in this example 500 feet is a sufficient sight distance to allow even most speeding following drivers to perceive the danger, react by braking or steering, and avoid crashes with ample time. In this case any speed less than 99

Collinear, Same-Direction, Front-to-Rear Crash Scenario Calculations						
Assumptions:			Speeding question			
Coefficient of friction		0.7	Dimensionless			
Grade		5	Percent, uphill positive			
Impact closing speed		0	Miles per hour		< Changed	
Braking distance		406	Feet		< Changed	
Leading vehicle speed		25	Miles per hour			
Perception time		1.75	Seconds			
Reaction time		0.75	Seconds			
Time	0.00	<u>Both vehicles at point of impact</u>				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		25	Miles per hour		
Time	-4.80	<u>Beginning of skid of following vehicle</u>				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		99	Miles per hour		
	Distance of leading vehicle from point of impact				176	Feet
	Distance of following vehicle from point of impact				406	Feet
	Separation between vehicles				230	Feet
Time	-5.55	<u>Beginning of reaction time</u>				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		99	Miles per hour		
	Distance of leading vehicle from point of impact				204	Feet
	Distance of following vehicle from point of impact				515	Feet
	Separation between vehicles				311	Feet
Time	-7.30	<u>Beginning of perception time</u>				
	Leading vehicle speed		25	Miles per hour		
	Following vehicle speed		99	Miles per hour		
	Distance of leading vehicle from point of impact				268	Feet
	Distance of following vehicle from point of impact				768	Feet
	Separation between vehicles				500	Feet

Figure 5

mph would allow the following vehicle to come to a stop without striking the lead vehicle. These last two examples point up the critical need for proper rear conspicuity, especially when a vehicle is traveling below the speed of the flow of traffic.

The Underride Protection Issue

The results of these crashes are often made much worse when the lead vehicle is a singe-unit truck with a dump body designed with a large rear overhang and either no or insufficient rear underride protection. See Figure 6.

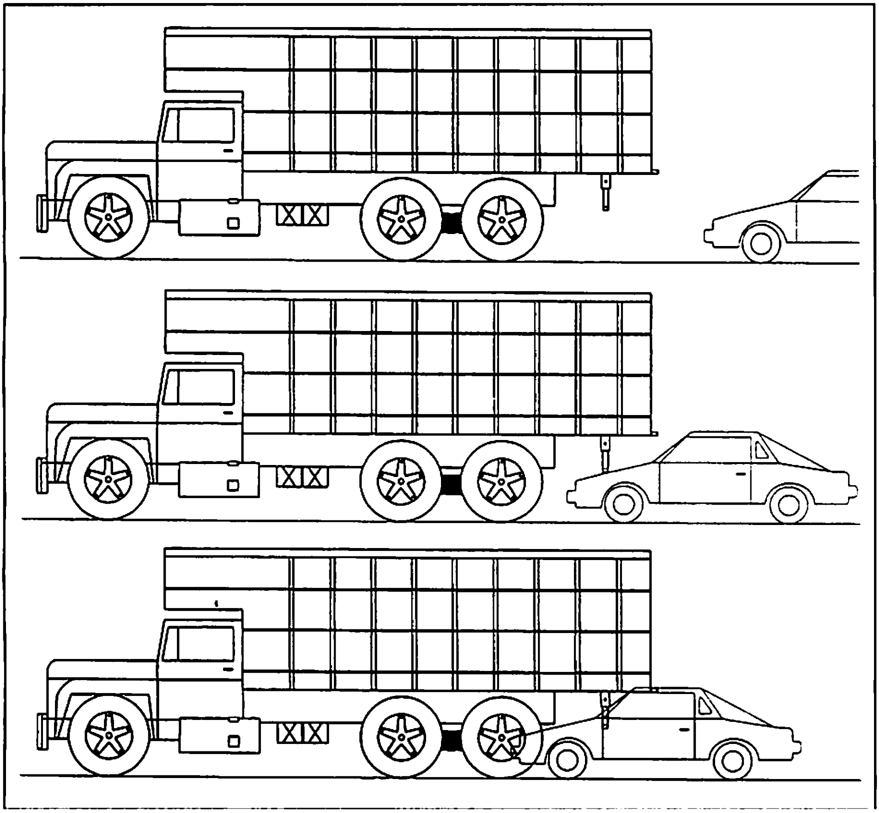


Figure 6

Because none of the occupant protection systems of a vehicle — such as air bags, seat belts, collapsing steering columns, and crumple zones — are able to perform as intended when the top of a vehicle is sheared off before the front of the vehicle strikes anything solid, front-seat victims characteristically suffer massive head and chest trauma, usually death, and often decapitation. Injuries are horrific when there are no underride guards because the heads of victims are directly struck by the unprotected tailboards of trucks, something that would not happen if occupant space intrusion were prevented by safe guards. This is how the actress Jayne Mansfield was killed in 1967.

To be able to haul 40 tons or more over the safe limit, Eastern Kentucky single-unit coal trucks typically have rear overhangs that create underride zones of six feet or more about four feet above the ground when the truck is unloaded. The overweight, conspicuity, and underride protection regulations that would prevent these crashes are not enforced, and as a result, there have been well over twenty such crashes in Eastern Kentucky causing over a dozen deaths.

The argument is often made that closing speeds at impact were so high that the victim(s) would have been killed by sudden deceleration alone even had underride guards been in place. This opinion presumes underride guards that are rigid and have insufficient energy absorbing abilities. That a victim would have been killed by delta-v upon striking an underride guard is a probability in some cases, especially if the guard were not sufficiently energy absorbing and/or when restraints were not used. However, this has been claimed even when frontal crush damage to the victim vehicle indicated an easily survivable delta-v and one of the two front-seat occupants survived the crash.

When it is not possible to make a sufficiently accurate estimation of closing speed in a case in which at least one of the occupants survived the crash, the highest delta-v the occupant(s) could be expected to survive may be used to calculate a worst-case scenario.

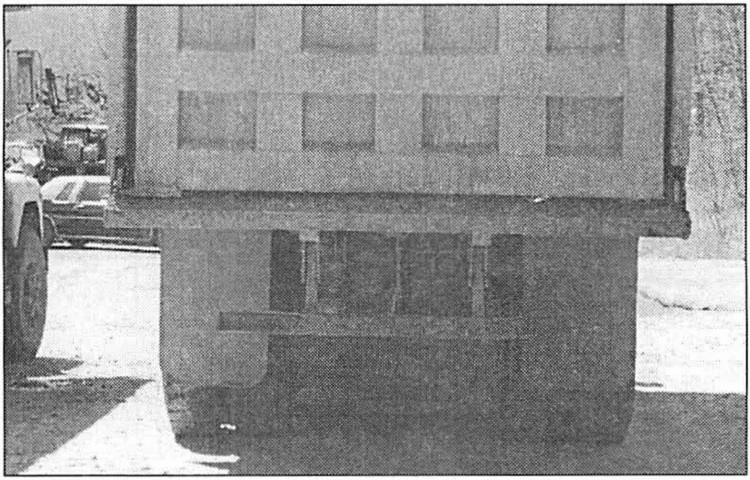
After some public attention was given to the underride guard problem after a crash in early 1994, nearly all single-unit coal trucks in Eastern Kentucky had underride guards installed. However, most of the ones presently being used are so flimsily designed and constructed that they collapse with relatively little effect upon impact. Crash tests have shown that minimally compliant guards cannot protect most victims, especially when the victims are in the newer, smaller vehicles with sloping hoods.

Safe underride guards should be full width, mounted flush with the rear of the vehicle, constructed as low to the ground as possible, and be energy-absorbing. Guards that are less than full width and not mounted flush with the rear allow people to be killed when the driver of the following vehicle swerves at the last moment, a common maneuver, causing part of his or her vehicle to pass under an unprotected rear corner of the truck.

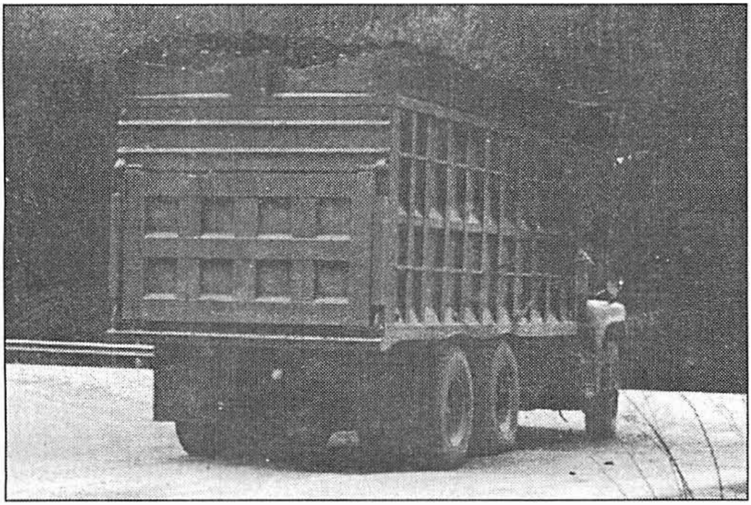
Underride guards should be able to stop an automobile with a closing speed of at least 40 mph, over as long a time interval as possible, and without any intrusion into the occupant compartment. As of the beginning of 1998, improved underride protection is required on newly built trailers, but existing trailers as well as all single-unit trucks are unfortunately exempt from these regulations.

Conclusions

The evidence in this paper debunks some of the myths surrounding rear vehicle crashes, namely that inattention and speed are always the causes of these tragedies. It also shows that even if such crashes are the fault of following drivers, their injuries and deaths could be greatly reduced by properly-designed and -manufactured underride guards.



The only lights on this truck are spaced 18" apart and covered with mud.
The hinged underride guard is minimally compliant.



A typical Eastern Kentucky single unit coal truck.
These trucks operate at around 120,000 pounds gross weight.