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TRACTOR/TRAILER ACCIDENT STATISTICS

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ABSTRACT
This paper describes the analysis that was performed to construct (1) a new truck accident event tree, including branch point probabilities and the fractional occurrences of route wayside surfaces, (2) new truck accident speed distributions and (3) new estimates of truck accident fire probabilities. The branch point fractions needed to construct the new event tree were calculated using truck accident data for the years 1996 through 2000 and vehicle mileage data for the years 1997 and 2000. Truck accident data were also used to estimate the fraction of bridge accidents that result in the truck falling off of the bridge. A count of bridges on Interstate 95 yielded a conservative estimate of the number of truck accidents that might lead to collisions with very large bridge columns. The occurrence frequencies of route wayside surfaces and surfaces under bridges were developed using Geographic Information System databases and methods of analysis.

INTRODUCTION
Estimation of the risks associated with the transport of spent nuclear fuel by truck is usually done by constructing a representative set of possible truck accidents and estimating the probability of each representative accident and the radiological consequences that would be caused should that accident occur. Construction of an accident event tree is an efficient and powerful way to describe a representative set of accidents. The Lawrence Livermore National Laboratory study (Fischer et al, 1987) usually referred to as the Modal Study, contains a truck accident event tree. The Modal Study event tree was constructed using truck accident data for the years 1973 through 1983. Figure 1 is the Modal Study truck accident event tree. Inspection of the Modal Study shows that the truck accident event tree first divides truck accident initiating events into two groups:

- Fires, mechanical failures, accidents in which the truck overturns, or jackknife accidents where the truck leaves the road and then runs into or hits something.
- Collisions in which the truck runs into another vehicle or impacts an on-road structure.

Next, so that an appropriate accident speed distribution can be selected to use in the estimation of truck accident risks, the tree indicates whether the accident occurred:

(1) At a highway/railway grade crossing,
(2) On level ground (i.e., not on a steep grade),
(3) Involved in a fall from a bridge, or
(4) A plunge down an embankment.

Finally the event tree specifies the type of object or surface that the truck runs into or hits, but does not indicate whether this impact initiates fire.

The NUREG/CR-6672 (Sprung et al, 2000) comments about a proposed follow-up to the Modal Study event tree suggested the event tree should be reconstructed using recent truck accident data (Sprung et al, 2002). This paper describes the analysis performed to construct a more current truck accident event tree, including the fractional occurrences of route wayside surfaces, and new truck accident speed distributions, and new estimates of truck accident fire probabilities.

NEW EVENT TREE STRUCTURE

Because truck casks are so massive and robust, only a high-speed impact into a massive object with a very hard surface (e.g., a train, a hard rock outcrop, a large steel reinforced concrete Interstate Highway flyover support column) can threaten the integrity of the cask's containment. Thus, the following collision accident paths (scenarios) on the Modal Study event tree pose an insignificant threat to the containment integrity of a spent fuel truck cask:

- A small and/or not very strong fixed object (e.g., small columns, barriers, walls, or trees),
- A small and/or relatively soft non-fixed object (e.g., cones, pedestrians, or automobiles),
- A yielding surface (e.g., soft rock, hard soil, clay, silt, soil, or water), or
- Several non-collision paths (e.g., mechanical failures, truck jackknifes, or overturns).

Consequently, as shown in Figure 2, the new truck accident event tree combines many of the non-threatening paths on the Modal Study event tree, and produces a simpler structure for the new truck accident event tree.

A comparison of the event tree structure in Figure 2 with the Modal Study event tree structure in Figure 1 shows several differences. The six sub-branches for collisions with a non-fixed object (paths 1 through 6 in Figure 1) have been restructured into four branches as follows:

1. Trains (the only non-fixed object large enough to threaten the containment integrity of a spent fuel cask during a collision)
2. Gasoline tank-trucks (not important for collisions but important for fire scenarios initiated by a collision)
3. Other vehicles (motorcycles, cars, other trucks)
4. Other small non-fixed objects (e.g., cones, animals, pedestrians)

All collisions with fixed objects are now part of a single branch, "Collision with a fixed object." The branches of "Collision with a fixed object" in the Modal Study tree (paths 7 through 18 in Figure 1) have been restructured. The bridge railing and column and abutment branches of the Modal Study event tree are now considered possible outcomes of bridge accidents, which are now divided into accidents that lead to falls from the bridge and accidents that lead to collisions with bridge components (columns, abutments), but not a fall from the bridge. Structures less massive than columns and abutments (e.g., buildings, walls) have been combined into a single path (path 12 in Figure 2), and all collisions with small fixed objects (trees, signs, barriers, posts, guard rails) have been combined into a single path (path 13 in Figure 2).

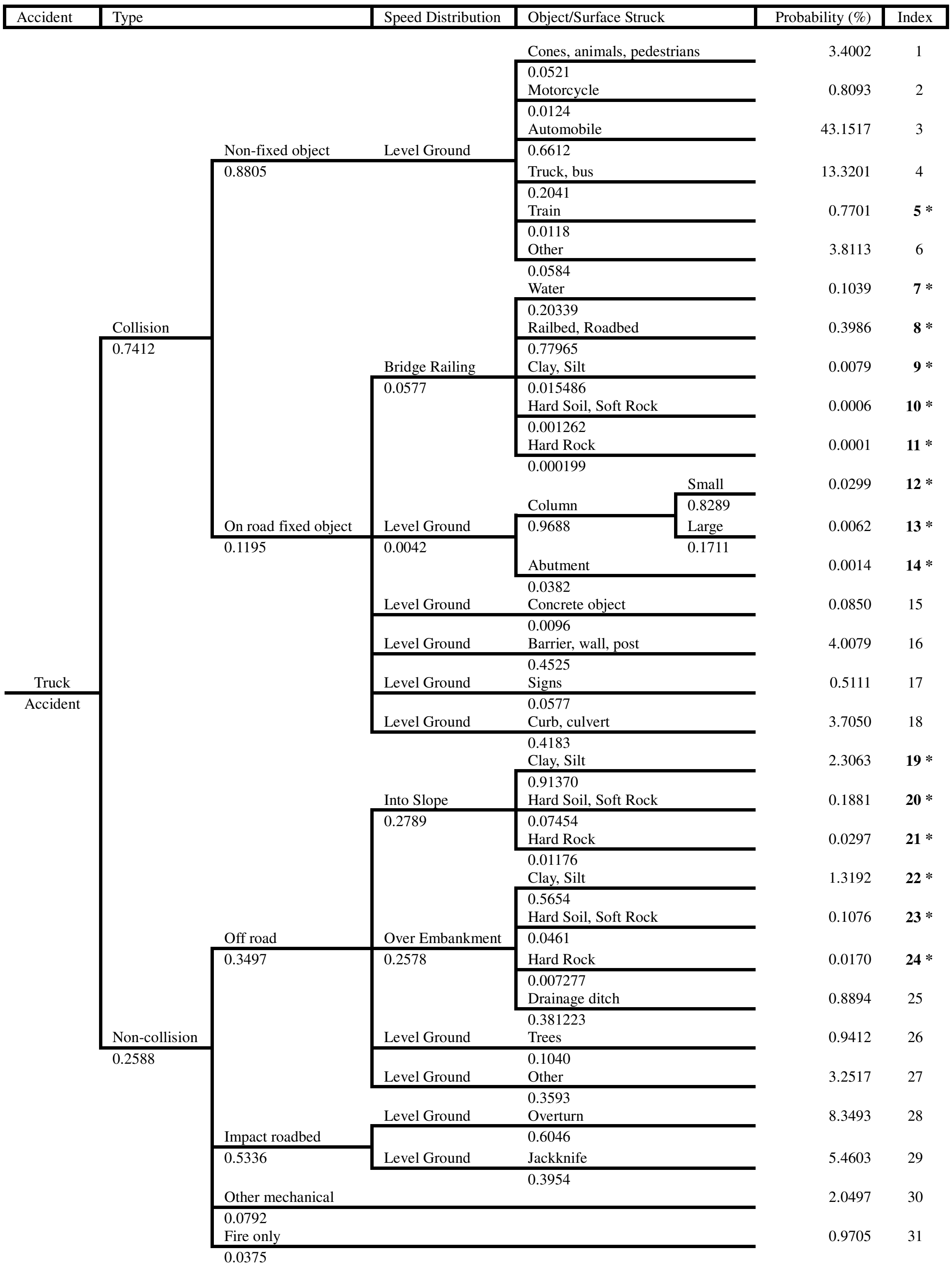

Figure 1: Modal Study truck accident event tree

*** Potentially significant accident scenarios.**

Accident	Type	Object Struck			Speed Distribution	Surface Struck	Probability	Index
Large Truck Accident On Interstate Highway	Collision w/ non-fixed object 0.820	Train 0.001			Train Grade Crossing Accident Speeds		0.00082	1 *
		Gasoline Tanker Truck 0.003					0.00246	2
		Other Vehicles (motorcycles, cars, other trucks) 0.938					0.76916	3
		Other smaller non-fixed objects (e.g., cones, animals, pedestrians) 0.058					0.04756	4
	Collision w/ fixed object 0.054	Bridge Accident 0.064	Fall off Bridge 0.02			Hard Rock 0.050	3.46E-06	5 **
						Soft Rock, Rocky Soil 0.046	3.18E-06	6 *
						Other Soils, Clay, Silt 0.817	5.65E-05	7
						Railbed, Roadbed 0.078	5.39E-06	8
						Water 0.009	6.22E-07	9
			Strike Bridge Structure 0.98	Large Column 0.03	Initial Accident Speeds		0.00010	10 **
				Small Columns, Abutments, Other 0.97	Initial Accident Speeds		0.00329	11 *
		Building, Wall 0.010			Initial Accident Speeds		0.00054	12 *
		Other fixed objects (trees, signs, barriers, posts, guard rails) 0.636					0.03434	13
		Slide on/into Ground, Culvert, Ditch 0.244					0.01318	14
		Into Slope, Embankment 0.046			Initial Accident Speeds	Hard Rock 0.055	0.00014	15 **
						Soft Rock, Rocky Soil 0.050	0.00012	16 *
						Other Soil, Clay, Silt 0.895	0.00222	17
	Non-Collision 0.126	Fire/Explosion 0.050					0.00630	18 *
		Other Non-Collision (jackknife, rollover, mechanical problems) 0.950					0.11970	19

Figure 2: New truck accident event tree

*** Accident scenarios that might lead to cask failure (loss of containment)**
**** Collision accidents judged to pose significant threats**

On the new event tree, accidents in which the truck slides along the ground, perhaps into a culvert or a ditch, have been combined into a single path (path 14 in Figure 2). All non-collision paths that don't involve fires (e.g., mechanical problems, truck jackknifes or overturns) have been combined into a single pathway (path 19 in Figure 2). The descriptors of the Surface Struck branches, called "Hard Soil, Soft Rock" and "Clay, Silt" in Figure 1 have been changed to "Soft Rock, Rocky Soil" and "Other Soils, Clay, Silt" in Figure 2 because even a very high speed impact onto hard soil poses no threat to a spent fuel cask, while after soil compaction has occurred impact onto rocky soil may lead to significant cask damage.

The "Over Embankment" branch on the Modal Study tree (paths 22 through 25 in Figure 1) has been eliminated because; the cask impact speed for these accidents should be bounded by the initial speed of the accident. The initial accident speed should bound the sliding speed because sliding friction should cause the cask (or the truck that is carrying the cask) to slow down, rather than accelerate as it slides along the ground or down a slope. Therefore, since there is no good way to estimate the actual sliding speed of a truck or a cask, elimination of this event tree branch causes this set of accidents to be apportioned into branches 14 through 17 in Figure 2. For these branches in Figure 2, use of the initial accident speed to characterize the severity of the cask impact leads to an overestimate of cask damage.

DATABASE REVIEW

New heavy-truck accident statistics were developed from three primary highway accident databases maintained by the U.S. Department of Transportation (DOT):

- Fatality Analysis Reporting System (FARS) [4]
- General Estimates System (GES) [5] databases, maintained by the National Highway Traffic Safety Administration
- Motor Carrier Management Information System (MCMIS) crash file [6], compiled by the Analysis Division of the Federal Motor Carrier Safety Administration

The MCMIS crash file is often used to support truck safety analysis because it contains only truck accident data and allows accidents to be sorted by truck type (e.g., tractor/trailers) and by accident consequences (e.g., injuries, fatalities, property damage above a reporting threshold). The FARS database, which is constructed by state analysts, provides more detail about vehicle configuration and for accidents resulting in a fatality, information about crash circumstances and consequences than what is reported in the MCMIS crash file.

The data in the GES database is extracted from a representative national sample of accidents from accidents described in police accident reports. The selected police accident reports describe accidents involving at least one vehicle traveling on a traffic-way that lead to injury, death, or property damage above a reporting threshold.

The annual number of truck accidents resulting in fatalities is available from both the FARS and MCMIS databases. The number of fatal truck accidents tabulated in the FARS database is usually larger than the number tabulated in the MCMIS crash file (about 23% higher on average), and the percent differences [100 × (FARS value − MCMIS value)/(FARS value)] vary greatly from one state to another. An analysis of FARS and MCMIS data by the DOT Volpe Center [7] concluded that the MCMIS data either is incomplete or, because of differing reporting methods, is inconsistent from state to state. Therefore despite the broader coverage of truck accidents, the MCMIS database may not provide a reliable picture of truck accident characteristics on a national perspective. The FARS database also may not provide a reliable picture of truck accident characteristics because the FARS database covers only accidents that involve a fatality and because many severe truck accidents do not involve fatalities. The most accurate data for this study were therefore statistical samples of truck accidents contained in the GES database.

Several other DOT traffic safety statistics tabulations, crash profiles and reports were reviewed for use in this study. However, the review revealed that each was incomplete with regard to some information important for the performance of this study. The University of Michigan Transportation Research Institute (UMTRI) [8] reports were also reviewed, but were found to be based primarily on fatal accidents and thus not a useful source of supplementary data.

CALCULATION OF BRANCH POINT FRACTIONS

The branch point fractions (conditional probabilities) needed to complete the event tree in Figure 2 were calculated as follows:

- All of the fractions in the column titled “Type” and all of the fractions for the first level branches in the column labeled “Object Struck” were calculated using GES data for the years 1996 through 2000 and vehicle mileage data for the years 1997 and 2000.
- GES data was also used to estimate the branch point fractions for the event tree branch labeled “Fall off of Bridge.”
- A count of bridges on Interstate 95 yielded a conservative estimate of the branch point fraction for the event tree branch labeled “Large Column.”
- The occurrence frequencies of route wayside surfaces and surfaces under bridges were developed using Geographic Information System (GIS) databases and methods of analysis.
- After values had been developed for all of the branch points, scenario probabilities were calculated as the product of all of the branch point fractions on each path.
- The branch point fractions and path probabilities produced the final version the event tree.

In Figure 2, the scenario probability values listed in the second-to-the-last column on the figure equal the product of all of the branch point probabilities that lie on that scenario pathway. All of these scenario probabilities are conditional on the occurrence of an accident on an Interstate Highway.

COMPARISON WITH MODAL STUDY RESULTS

Comparison of Figure 1 to Figure 2 shows that the frequencies of occurrence for several important accident scenarios have changed significantly. Table 1 provides a summary of the most significant scenario branch-points from both event trees to facilitate this comparison.

Table 1 shows impacts with small columns and abutments to be 11 times more probable than was found by the Modal Study. Although this is a large increase, it poses little significance for truck accident risks since small columns and abutments are soft targets for a spent fuel truck cask. The much smaller chance that a collision with a slope or embankment will involve “Soft Rock” or “Rocky Soil” is also of little significance as these surface layers are also relatively soft compared to a spent fuel truck cask.

Table 1: Summary of End-Point Fractions for Significant Scenarios

Object Struck	Surface Struck	Modal Study (MS)	This Study (TS)	TS/MS
Train		7.70×10^{-3}	8.20×10^{-4}	0.11
Bridge	Hard Rock	1.00×10^{-6}	3.46×10^{-6}	3.46
	Soft Rock/Rocky Soil	6.00×10^{-6}	3.18×10^{-6}	0.53
Large Column		6.20×10^{-5}	1.00×10^{-4}	1.61
Small Column, Abutment		2.99×10^{-4}	3.29×10^{-3}	11.00
Building, Wall		8.50×10^{-4}	5.90×10^{-4}	0.69
Slope, Embankment	Hard Rock	4.67×10^{-4}	1.40×10^{-4}	0.30
	Soft Rock/Rocky Soil	2.96×10^{-3}	1.20×10^{-4}	0.04
Fire/Explosion		9.71×10^{-3}	6.30×10^{-3}	0.65

On the Modal Study tree, Figure 1, the chance of a truck having an accident that causes the truck to fall off of a bridge is:

$$P_{\text{collision}} \times P_{\text{on road fixed object}} \times P_{\text{bridge railing}} = (0.7412)(0.1195)(0.0577) = 5.1 \times 10^{-3}$$

On the new event tree, Figure 2, this chance is:

$$P_{\text{collision w fixed object}} \times P_{\text{bridge accident}} \times P_{\text{fall off bridge}} = (0.054)(0.064)(0.02) = 6.9 \times 10^{-5}$$

Thus, the Modal Study estimate for the chance that a truck falls off of a bridge is 74 times greater than the estimate developed by this study, most likely because the Modal Study assumed that whenever a truck strikes a bridge railing, the truck falls off of the bridge, while this analysis finds that only two bridge accidents in 100 result in a fall from the bridge [5]. Were this factor of 0.02 applied to the Modal Study estimate for the fraction of accidents that lead to a collision of a truck with a bridge railing, then the Modal Study estimate of the probability of a fall from a bridge would agree reasonably well with the value of 6.9×10^{-5} developed by this study.

Although only two bridge accidents in 100 lead to a fall from a bridge, the chance that an accident that occurs on a bridge leads to a fall off the bridge onto hard rock under the bridge is found to be about a factor of three larger than the Modal Study result. The new result is larger than the Modal Study result because the new estimate of the occurrence fraction for Hard Rock under bridges, 0.05, is 250 times larger than the Modal Study estimate of 0.0002 for this fraction. The Modal Study survey of surfaces under bridges simply tallied the principal feature that the bridge was crossing over (e.g., a highway, a railroad track, a stream) without accounting for the amount of ground that was under the length of the bridge on either side of the principal feature. In contrast, the present study considered all of the surfaces under bridges, including the ground on either side of the principal feature, and assumed that the occurrence of ground types ("Hard Rock", "Soft Rock", "Rocky Soil", "Other Soil, Clay, Silt") under bridges was the same as it was for route wayside surfaces. Therefore, as Table 2 shows, this study finds that rock layers and soil occur under bridges much more often than was found by the Modal Study.

Table 2: Occurrence Fractions for Ground Types under Bridges

Ground Types	Modal Study (MS)	This Study (TS)	Ratio (TS/MS)
Hard Rock	2.0×10^{-4}	5.0×10^{-2}	250
Soft Rock/Rocky Soil	1.3×10^{-3}	4.6×10^{-2}	35
Other Soils/Clay/Silt	1.5×10^{-2}	8.2×10^{-1}	55

Although impact with hard rock after a fall from a bridge is estimated by this study to occur about three times more often than was estimated by the Modal Study, this increase poses little risk since almost all of these impacts will occur at speeds below 30 mph and thus will not lead to cask failure (Mills et al, 2006).

CONCLUSIONS

The probabilities of severe accidents during the transport of spent nuclear fuel by truck have not been found to be significantly greater than those estimated in the Modal Study. While some branch-point fractions and scenario probabilities on the reconstructed truck accident event tree differ from corresponding fractions and scenario probabilities on the Modal Study event tree, none of the differences are expected to significantly alter the risks posed by spent fuel truck cask accidents. Truck/train collisions are estimated by this study to be about 100 times less probable than was estimated by the Modal Study. However, this large decrease will have little effect on truck spent fuel cask transportation risks since truck/train collisions are not likely to cause cask failure. Accidents that lead to cask collisions with large columns and hard rock slopes or embankments are respectively estimated to be somewhat more likely (70% increase) and about as likely as was estimated by the Modal Study. Finally, both studies find the chance of fire-only accidents to be about the same. Thus, both studies estimate similar probabilities for the few accident scenarios that might cause cask failure.

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