

Risk Characterization of Hazardous Materials Truck Safety

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1. INTRODUCTION

A significant concern within the trucking industry is the shipment of hazardous materials. Incidents involving the loading/unloading and enroute transport of dangerous cargo can lead to severe consequences characterized by fatalities, injuries, evacuation, property damage, environmental degradation and traffic disruption.

To better address this concern, the paper analyses risks posed by trucks carrying hazardous materials (HM). Within hazardous materials shipments, risks differ depending on hazards associated with material being transported and the level of transport activity. An analysis of the types of HM accident consequences can provide important insights into HM truck transportation risk. The paper specifically analyzes the comparative impacts of spill accidents, accidents with a fire only and accidents with a fire and explosion. The paper also examines the association of these accident consequences with the major classes of HM materials. With an understanding of the comparative risks across these groupings, policymakers can make safety investment decisions that offer a high return on investment.

This paper reports the HM risks component taken from a comparative risk assessment of HM and non-HM truck shipments conducted for the Federal Motor Carrier Safety Administration (FMCSA) by a team led by Battelle. The paper describes the methodology and presents the analysis results along with interpretations of these findings and consideration of their implication on public policy and practices associated with truck safety.

In this research, an incident is defined as an event involving the transportation of hazardous material that leads to an emergency response due to the release or potential release of the cargo. An accident is an incident that occurs when the vehicle transporting the goods is involved in a collision. The study included both HM truck accidents with a release, HM truck accidents where no release occurred and HM truck releases that occurred due to loading/unloading or enroute leaks not caused by a truck accident. Non-spill truck accidents warranted consideration in this study because severe consequences (e.g., injuries and fatalities) can occur. Safety officials often treat any HM accident as a potential spill even if no release of material is apparent.

2. RISK ASSESSMENT METHODOLOGY

The methodology used to perform this risk assessment consisted of the following steps:

1. Arrange HM classes (and divisions) into categories based on similar incident impact potential and data quality considerations.
2. Determine truck incident likelihood for each HM category
3. Estimate the per incident economic impact by HM category and truck incident type
4. Calculate the annual risk by truck incident type, HM category and for HM shipments overall

A description of each step and the corresponding results are presented in the following discussion.

2.1 HM Categories

The U.S. Department of Transportation (DOT) places each hazardous material being shipped into a specific class and, for some materials, divisions within a class. In the interest of establishing analysis consistency and to satisfy data quality considerations, HM classes (and divisions) were grouped into categories based on similar material properties and the potential impacts associated with a transport incident. This led to the following category distinctions:

<u>Category</u>		<u>Class/Division</u>
1	Explosive	1.1, 1.2, 1.3
2	Explosive	1.4, 1.5, 1.6
3	Flammable Gas	2.1
4	Non flammable gas	2.2
5	Poisonous gas	2.3
6	Flammable liquid	3
7	Flammable solids	4.1, 4.2, 4.3
8	Oxidizer	5.1, 5.2
9	Poison	6.1, 6.2
10	Radioactive	7
11	Corrosive	8
12	Miscellaneous	9

2.2 Incident Likelihood

Truck incident data for the period of 1990-99 contained in the Hazardous Materials Information System (HMIS) were used for identifying enroute non-accident leaks, loading/unloading incidents and accidents in which a release occurred [1]. The Motor Carrier Management Information System (MCMIS) supplied the data used to estimate HM truck accidents enroute for which a release did not occur [2].

Truck incidents were segmented by HM category and then further segmented according to whether the incident was: 1) an accident enroute, 2) a non-accident leak enroute or 3) a loading/unloading event. The incident frequencies were normalized into annual counts and then modified to account for known incident under-reporting inherent in both the HMIS and MCMIS systems, based on a previously-developed methodology [3, 4].

Enroute truck accidents that result in a release can create inhalation problems or lead to fires and explosions. These more serious events warrant special consideration due to their potential for large economic impact. To address this concern, enroute accidents were segmented according to whether they resulted in: a) fire, b) fire and explosion, c) release only or d) no release.

To assess the potential for these high consequence/low probability truck accidents, the study extended the empirical database containing low probability/high consequence accidents to consider a 50-year period. This modified database was assembled by examining a longer historical period of HMIS data, augmented by information collected from a systematic literature search. Event trees were constructed for each HM category, to which probability of occurrence (of enroute accident releases, fires and explosions) and expected outcomes could be assigned.

Table 1 provides an estimate of the annual number of HM truck accidents and incidents derived from applying this methodology. The table is segmented by HM category and incident type. Enroute accidents

are further sub-divided into release and non-release events. Several notable observations can be made from reviewing this information:

- Loading/unloading incidents comprise nearly 75% of all HM incidents.
- Of enroute accidents that occur, approximately 70% do not result in a release.
- Nearly one-half of all incidents involve Class 3 shipments; Class 3 and Class 8 together constitute nearly 80% of all incidents.

HM Category	Enroute Accident			Leak Enroute	Loading/Unloading	Total for All Hazmat Incidents	% of Total (by Class)
	Release	No Release	Release & NonRelease				
1.1, 1.2, 1.3	2	12	14	1	1	16.2	0.1%
1.4, 1.5, 1.6	9	23	32	3	3	38.1	0.3%
2.1	47	229	276	15	67	358.0	2.4%
2.2	26	152	178	19	126	323.0	2.2%
2.3	2	10	12	5	20	37.0	0.2%
3	490	889	1,379	587	4855	6,821.0	46.4%
4.1, 4.2, 4.3	8	25	33	13	92	138.0	0.9%
5.1, 5.2	29	32	61	50	372	483.0	3.3%
6.1, 6.2	15	35	50	125	760	935.0	6.4%
7	6	6	12	4	4	20.0	0.1%
8	73	184	257	539	4130	4,926.0	33.6%
9	60	119	179	94	316	589.3	4.0%
All Categories	767	1,716	2,483	1455	10,746	14,684.6	100.0%
% of Total Incidents	5.2%	11.7%	16.9%	9.9%	73.2%	100.0%	
% of Total Enroute Accidents	30.9%	69.1%	100.0%				

11.7% of all release accidents result in an outcome of a fire or an explosion (not in Table). However, for Division 2.1 and Class 3, the percentages are 19.2% and 14.7%, respectively. These findings are important because of their association with greater consequences.

The estimated number of annual truck incidents (and accidents) can be converted into rates by using annual vehicle miles of HM operation. The 1997 Commodity Flow Survey (CFS) and the Vehicle Inventory and Use Survey (VIUS) were used for this purpose [5, 6]. These rates are shown in Table 2, segmented by HM category. Note that the incident rate always exceeds the accident rate since accidents have been defined as a sub-set of incidents.

The average HM truck accident rate is 0.32 accidents per million vehicle-miles and the average HM truck incident rate is 0.51 accidents per million vehicle-miles. When comparing across HM categories, Class 9 has the highest accident and incident rates, and Division 2.2 has the lowest. However, the HM category accident and incident rates are all within the same order of magnitude.

Table 2. HM Truck Accident and Incident Rates			
HM Category	Hazmat Miles	Hazmat Accident Rate (Acc./Mile)	Hazmat Incident Rate (Inc./Mile)
1.1, 1.2, 1.3	23,072,451	6.15E-07	6.59E-07
1.4, 1.5, 1.6	45,800,537	7.01E-07	7.66E-07
2.1	805,172,414	3.43E-07	3.61E-07
2.2	1,368,275,862	1.30E-07	1.44E-07
2.3	50,344,828	2.39E-07	3.38E-07
3	2,777,962,963	4.96E-07	7.08E-07
4.1, 4.2, 4.3	48,122,066	6.86E-07	9.56E-07
5.1, 5.2	200,768,246	3.04E-07	5.53E-07
6.1, 6.2	217,792,793	2.30E-07	8.04E-07
7	30,411,449	3.95E-07	5.26E-07
8	1,945,365,854	1.32E-07	4.09E-07
9	250,193,299	7.17E-07	1.09E-06
All Categories	7,763,282,762	3.20E-07	5.07E-07

2.3 Economic Impact Estimation and HM Risk Calculation

The average cost per incident was determined by taking into consideration: 1) cleanup cost, 2) product loss, 3) carrier damage, 4) property damage, 5) environmental damage, 6) injury cost, 7) fatality cost, 8) evacuation cost and 9) incident (traffic) delay. A detailed description of the methodology used to perform this step can be found in Abkowitz, et. al. [3].

Tables 3 through 6 present the economic impact estimation results. Table 3 provides a summary of the economic impacts for truck *enroute release accidents*, segmented by HM category and impact component.

- On an annual basis, enroute release accidents “cost” over \$400 million.
- Class 3 enroute release accidents are responsible for the majority of these costs, with Division 2.1, Class 8 and Class 9 also being significant contributors.
- Fatalities are the most important impact component, contributing over 40% of the total cost.
- Injuries and fatalities combined contribute over 78% of the total cost.
- Incident delay, carrier damage and cleanup costs are also notable impact cost contributors.

Table 4 provides similar information for truck *enroute non-release accidents*. On an annual basis, enroute non-release accidents cost over \$600 million, roughly 1.5 times that of enroute release accidents. This is due to 1,716 enroute non-release accidents occurring on an annual basis compared to 767 enroute release accidents. Across HM categories and impact components, the patterns of both enroute release and non-release accidents are similar, with the exception of the following:

- The omission of cleanup costs as a significant contributor to enroute non-release accident cost, as the methodology assumed that non-release accidents do not involve cleanup of HM.
- The addition of Division 2.2 as a notable contributor to enroute non-release accident cost.

Truck *leak enroute incidents* are a small economic impact contributor, with an annual cost of approximately \$72 million. However, the number of incidents is relatively high, at 1,455 per year.

Truck *loading/unloading incidents* contribute the lowest annual cost, slightly over \$53 million, despite the fact that the number of incidents, 10,746, is far greater than any other type.

Table 3. HM Truck Enroute Release Accidents: Impact Components

HM Cat.	No.	Cleanup Costs	Product Loss	Carrier Damage	Property Damage	Env. Damage	Injury Costs	Fatality Costs	Evacuation Costs	Delay Costs	Total Costs	% Total (by Class)
1.1, 1.2, 1.3	2	\$28,571	\$4,000	\$63,628	\$689,714	\$4,858	\$381,778	\$1,750,706	\$709,500	\$87,998	\$3,720,755	1.0%
1.4, 1.5, 1.6	9	\$21,581	\$13,460	\$241,016	\$232,978	\$5,585	\$1,651,347	\$1,404,736	\$180,781	\$335,948	\$4,087,436	1.0%
2.1	47	\$67,810	\$53,589	\$1,202,355	\$147,927	\$128,884	\$10,618,919	\$11,143,930	\$199,774	\$1,979,966	\$25,543,157	6.1%
2.2	26	\$24,086	\$62,212	\$979,550	\$14,090	\$24,720	\$4,511,926	\$2,981,536	\$31,833	\$997,316	\$9,627,271	2.3%
2.3	2	\$606	\$2,456	\$23,880	\$200,400	\$106,708	\$1,147,071	\$1,448,598	\$46,000	\$75,091	\$3,050,811	0.7%
3	490	\$15,619,634	\$1,571,888	\$16,177,167	\$7,860,578	\$1,799,147	\$95,555,842	\$131,450,045	\$66,108	\$20,196,846	\$290,297,260	69.8%
4.1, 4.2, 4.3	8	\$131,557	\$24,647	\$95,511	\$36,020	\$4,264	\$1,388,284	\$991,832	\$35,875	\$293,328	\$3,001,320	0.7%
5.1, 5.2	29	\$150,750	\$52,230	\$543,413	\$28,521	\$29,559	\$5,365,866	\$3,313,153	\$23,629	\$1,107,314	\$10,614,438	2.6%
6.1, 6.2	15	\$533,584	\$124,401	\$233,962	\$36,934	\$15,046	\$3,430,307	\$1,765,606	\$2,088,214	\$571,990	\$8,800,046	2.1%
7	6	\$5,483	\$3,619	\$40,382	\$5,564	\$10,815	\$1,041,213	\$770,754	\$500	\$220,166	\$2,098,499	0.5%
8	73	\$1,137,622	\$358,421	\$1,864,499	\$226,619	\$53,011	\$15,812,585	\$8,176,873	\$883,281	\$2,720,618	\$31,233,532	7.5%
9	60	\$814,146	\$111,839	\$1,667,559	\$266,995	\$48,131	\$11,738,061	\$6,788,758	\$3,474	\$2,248,359	\$23,687,327	5.7%
All Cat.	767	\$18,535,435	\$2,382,765	\$23,132,928	\$9,746,344	\$2,230,730	\$152,643,205	\$171,986,533	\$4,268,972	\$30,834,943	\$415,761,858	100.0%
% of Total Costs		4.5%	0.6%	5.6%	2.3%	0.5%	36.7%	41.4%	1.0%	7.4%	100.0%	

Table 4. HM Truck Enroute Non-Release Accidents: Impact Components

HM Category	No.	Carrier Damage	Property Damage	Injury Costs	Fatality Costs	Evacuation Costs	Delay Costs	Total Costs	% of Total (by Class)
1.1, 1.2, 1.3	12	\$178,004	\$15,154	\$1,776,000	\$1,344,000	\$2,253,000	\$439,992	\$6,006,150	1.0%
1.4, 1.5, 1.6	23	\$401,280	\$26,497	\$3,358,000	\$3,220,000	\$30,950	\$843,318	\$7,880,047	1.3%
2.1	229	\$3,983,634	\$490,112	\$34,746,389	\$32,979,624	\$488,924	\$8,396,514	\$81,085,199	13.2%
2.2	152	\$3,894,091	\$56,013	\$23,060,506	\$22,199,702	\$201,611	\$5,573,232	\$54,985,157	8.9%
2.3	10	\$74,392	\$1,360	\$1,534,883	\$1,302,325	\$130,000	\$366,660	\$3,409,621	0.6%
3	889	\$19,956,607	\$9,692,676	\$136,359,577	\$122,173,169	\$24,926	\$32,596,074	\$320,803,030	52.1%
4.1, 4.2, 4.3	25	\$202,962	\$76,542	\$3,504,672	\$5,233,644	\$112,109	\$916,650	\$10,046,582	1.6%
5.1, 5.2	32	\$407,747	\$21,401	\$4,042,105	\$2,021,052	\$28,005	\$1,173,312	\$7,693,624	1.2%
6.1, 6.2	35	\$371,221	\$58,602	\$5,409,090	\$2,545,454	\$95,535	\$1,283,310	\$9,763,215	1.6%
7	6	\$27,120	\$384	\$1,572,413	\$579,310	\$0	\$219,996	\$2,399,224	0.4%
8	184	\$3,195,701	\$388,419	\$29,055,043	\$26,946,949	\$345,406	\$6,746,544	\$66,678,063	10.8%
9	119	\$2,234,256	\$359,499	\$19,784,362	\$18,511,111	\$7,008	\$4,363,254	\$45,259,491	7.4%
All Cat.	1,716	\$34,927,020	\$11,186,664	\$264,203,045	\$239,056,344	\$3,717,477	\$62,918,856	\$616,009,408	100.00%
% of Total Cost		5.7%	1.8%	42.9%	38.8%	0.6%	10.2%	100.0%	

Summing the total costs across all four truck incident types results in an overall estimated HM incident impact of over \$1.1 billion annually. This is a significant impact when one considers that a 10% reduction in HM truck transport risk would save over \$100 million per year.

Another way of presenting this information is through the use of average costs. Table 5 presents the average cost of HM truck incidents by HM category and incident type. As expected, the average cost of an enroute release accident, at \$536,000, is greater than any other incident type and roughly 1.5 times the average cost of an enroute accident where no release occurs. The average cost of a leak enroute is \$49,524: an order of magnitude lower than that is the average cost of a loading/unloading incident.

HM Category	Enroute Accident		Leak Enroute	Loading/Unloading
	Release	No Release		
1.1, 1.2, 1.3	\$930,000	\$500,512	\$79,693	\$53
1.4, 1.5, 1.6	\$372,000	\$342,610	\$47,999	\$23,594
2.1	\$543,471	\$354,083	\$51,972	\$14,636
2.2	\$370,279	\$361,744	\$77,018	\$16,715
2.3	\$1,017,000	\$340,962	\$408,756	\$115,498
3	\$590,000	\$360,858	\$44,445	\$2,585
4.1, 4.2, 4.3	\$375,165	\$401,863	\$57,420	\$7,442
5.1, 5.2	\$366,015	\$240,425	\$49,791	\$5,504
6.1, 6.2	\$586,669	\$278,949	\$45,468	\$8,433
7	\$300,000	\$399,870	\$38,787	\$1,140
8	\$427,856	\$362,380	\$51,818	\$5,849
9	\$388,000	\$380,000	\$47,372	\$6,781
All Categories	\$536,000	\$359,000	\$49,524	\$4,975

Divisions 1.1, 1.2, 1.3, and 2.3 are associated with the highest average costs of truck enroute release accidents, while the average cost of enroute accidents without a release is fairly consistent across classes. The average cost of Division 2.3 leaks enroute and loading/unloading incidents far exceed those of any other respective HM category.

Table 6 provides insight into the cost of enroute release accidents. The table segments the average cost of enroute release accidents by whether the release resulted in a fire or explosion. Explosions result in the greatest economic impact with an average cost of over \$2.0 million per accident. The average cost of an enroute accident resulting in a fire (without explosion) is nearly \$1.2 million, while enroute accidents that have a release without fire or explosion have an average cost of slightly over \$400,000.

There is considerable disparity among HM categories in how they contribute to these average cost figures. In the case of fires, Class 6 has an average cost in excess of \$2.8 million per truck accident, whereas releases in some HM categories (e.g., Division 2.3) will not cause a fire because of the material properties involved. Division 2.1 has a large average cost for each accident that results in an explosion (over \$3.8 million), as does Class 3 (over \$2.1 million). For enroute accidents that result only in a release, Division 2.3 has an average cost of over \$1 million, far exceeding any other HM category, presumably due to the ingestion effects of toxic release.

Table 6. Average Cost of HM Truck Release Accidents				
HM Category	Enroute Release Accidents			
	Fire	Explosion	Release-Only	Total Releases
1.1, 1.2, 1.3	\$710,000	\$1,820,000	\$593,240	\$930,000
1.4, 1.5, 1.6	\$710,000	\$18,200	\$373,020	\$370,000
2.1	\$637,071	\$3,862,022	\$351,568	\$543,471
2.2	\$403,940	\$0	\$367,474	\$370,279
2.3	\$0	\$0	\$1,020,000	\$1,020,000
3	\$1,272,562	\$2,190,000	\$416,664	\$592,418
4.1, 4.2, 4.3	\$0	\$0	\$375,165	\$375,165
5.1, 5.2	\$389,175	\$0	\$364,299	\$366,015
6.1, 6.2	\$2,828,324	\$0	\$426,551	\$586,669
7	\$0	\$7,200	\$348,547	\$300,000
8	\$1,426,840	\$0	\$399,716	\$427,856
9	\$380,849	\$130,000	\$392,762	\$392,824
All Categories	\$1,150,000	\$2,070,000	\$407,646	\$541,609

Because truck accidents enroute result in a release only 31% of the time and, of those, only 11.7% result in a fire or explosion, fire and explosion incidents are often considered low probability, high consequence events. This is reflected in Table 7, where the average cost per enroute release accident has been multiplied by the number of accidents per year to arrive at an overall economic impact. What emerges are far lower annual costs associated with fire and explosion accidents than for release only accidents. Because of the larger number of annual enroute release accidents that occur in their respective HM categories, Class 3 dominates overall cost, with Division 2.1 and Classes 8 and 9 also significant contributors.

Table 7. Estimated 1996 HM Truck Release Accident Impact Costs			
HM Category	Enroute Release Accidents		
	Fire	Explosion	Release-Only
1.1, 1.2, 1.3	\$712,032	\$1,822,240	\$1,186,481
1.4, 1.5, 1.6	\$71,000	\$18,222	\$3,357,181
2.1	\$4,459,499	\$7,724,044	\$13,359,613
2.2	\$807,880	\$0	\$8,819,391
2.3	\$0	\$0	\$3,050,811
3	\$63,628,107	\$52,503,379	\$174,165,773
4.1, 4.2, 4.3	\$0	\$0	\$3,001,320
5.1, 5.2	\$778,351	\$0	\$9,836,087
6.1, 6.2	\$2,828,324	\$0	\$5,971,721
7	\$0	\$7,215	\$2,091,284
8	\$2,853,680	\$0	\$28,379,851
9	\$380,849	\$133,503	\$23,172,974
All Categories	\$77,160,758	\$62,208,606	\$276,392,493

3. DATA ISSUES

This study represents a first attempt to quantify the economic impacts of HM truck risk, for the purpose of providing more effective management information from which improved safety policies can be developed. Effective risk assessments depend on high quality and reliable data.

In order to promote continuous improvement in HM truck safety data quality, the following recommendations are made:

- Incident/accident databases such as HMIS and MCMIS should be linked where feasible; contain standardized procedures to provide compatibility in defining an incident and accident, when it is reported and which attributes are included.
- Incident and accident databases should have common fields for sharing information.
- DOT should determine if it has the legal authority to audit the shipper's accounting records for the purpose of verifying the accuracy of HMIS reports.
- Quality control protocols should be included in MCMIS to ensure accurate data entry.
- The Commodity Flow Survey (CFS) should provide estimated mileage for each HM class.

4. CONCLUSIONS

This paper has presented the results of a study designed to better understand HM truck safety in the context of key risk contributors within the industry. The study approach and results allow for comparisons to be made by HM category and by HM incident type. These results are portrayed as estimates of annual economic impact.

- HM truck incidents in the U.S. cost society over \$1.1 billion on an annual basis.
- Injuries and fatalities comprise the largest components of this cost.
- Class 3 contributes the largest economic impact associated with HM truck incidents.
- Release-causing truck accidents enroute have the highest average cost, followed by truck enroute accidents in which a release does not occur; leaks enroute are considerably lower in average cost, with the average cost of loading/unloading incidents an order of magnitude lower than that.
- However, the greatest economic impact is associated with truck accidents enroute where a release does not occur, due to the higher frequency of these events.
- Of truck accidents enroute resulting in a release, explosions have the highest per incident cost, followed by fires (without explosions) and then releases where neither a fire or explosion ensue; however, the release only incidents contribute more to the annual economic impact because of the frequency of such events.

These findings and other insights gained from reviewing the study results can make an immediate contribution to more informed HM truck transport policy decisions. Hopefully, it will also serve as a stimulus for better incident/accident data collection so that more focused HM truck safety studies can be conducted in the future, with greater confidence in the results.

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