1 of 2

SAND93-2580
Unlimited Release
Printed June 1994

Distribution
Category UC-722

A Statistical Description of the Types and Severities of Accidents Involving Tractor Semi-Trailers

David B. Clauss
Transportation Analysis Department 9614
Rodney K. Wilson
Verification and Monitoring Department 9241
Sandia National Laboratories
Albuquerque, New Mexico 87185-5800

Daniel F. Blower and Kenneth L. Campbell
Center for National Truck Statistics
University of Michigan Transportation Research Institute
Ann Arbor, Michigan 48109-2150

Abstract

This report provides a statistical description of the types and severities of tractor semi-trailer accidents involving at least one fatality. The data were developed for use in risk assessments of hazardous materials transportation. Several accident databases were reviewed to determine their suitability to the task. The TIFA (Trucks Involved in Fatal Accidents) database created at the University of Michigan Transportation Research Institute was extensively utilized. Supplementary data on collision and fire severity, which was not available in the TIFA database, were obtained by reviewing police reports for selected TIFA accidents. The results are described in terms of frequencies of different accident types and cumulative distribution functions for the peak contact velocity, rollover skid distance, fire temperature, fire size, fire separation, and fire duration.

MASTER
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *zp*

Acknowledgment

William Hartman, Jim Phillips, Toni Molina and John Lavasek of Sandia National Laboratories, and Dawn Massie, Bob Pichler, Amy Winn, and James Zamberlan of the University of Michigan Transportation Research Institute made significant contributions to the supplemental data collection effort. In addition, Clint Shirley, Robert Klett, and Robert Winchester of Sandia reviewed the document and provided helpful comments and suggestions.

Contents

Preface	8
1.0 Executive Summary	9
2.0 Introduction	11
2.1 Background	11
2.2 Report Organization	12
3.0 Accident Data Needed in Risk Assessments	13
4.0 AT/SST Surrogate Definition	15
5.0 Review of Existing Heavy Truck Accident Files	17
5.1 NASS	17
5.2 OMC	17
5.3 TIFA	18
5.4 GES	21
5.5 State of Michigan Police Accident Reports	21
6.0 Supplemental Data	23
6.1 Collision Severity Data	23
6.2 Fire Severity Data	28
7.0 Compilation of Accident Files	31
7.1 Main Accident File Constructed from TIFA	31
7.2 Accident File Constructed from GES Data	33
7.3 Fire Severity Data - TIFA	38
7.4 Fire Severity Data - Michigan Police Reports	38
7.5 Collision Severity Data - TIFA	39
7.6 Collision Severity Data - Michigan Police Reports	41
8.0 Discussion and Analysis of Accident Types	43
8.1 MHE	43
8.2 Impact Direction	46
8.3 Other Vehicle Involved	50
8.4 Impact Location	50
8.5 Rollover Occurrence	54
8.6 Fire Occurrence	56
9.0 Discussion and Analysis of Accident Severities	59
9.1 Collision	59
9.2 Rollover	65
9.3 Fire	66
10.0 Application of Accident Data in Risk Assessment	83
11.0 Summary	85
12.0 References	87
Appendix A: Supplemental Data for Rollover Accidents	89
Appendix B: Supplemental Data for Immersion Events	93
Appendix C: On-going Accident Severity Data Collection	95

Appendix D: Sensitivity of Analytical Simulation for Fire Surface Area and Duration to Weighting Factors and Leak Area Distributions	103
Acronyms	109
Nomenclature	111

Figures

4-1 The AT/SST	16
6-1 Definition of Impact Angle.....	24
6-2 Supplemental Data Form for Fire Severity.....	30
9-1 Peak Contact Velocity Distributions: Collision with a Medium/Heavy Truck	61
9-2 Peak Contact Velocity Distributions: Collision with a Fixed Object	61
9-3 AT/SST Peak Contact Velocity Distributions by MHE.....	63
9-4 Distribution for Skid Distance Associated with Rollover.....	65
9-5 Distribution for Fire Temperature--Object Being Heated is In the Fire.....	68
9-6 Fire Temperature vs. Fire Diameter--Object Being Heated is Out of the Fire	68
9-7 Distributions for Separation Distance by MHE	70
9-8 Fire Size Distributions.....	76
9-9 Comparison of Distributions for Fire Surface Area--Simulation vs. Accident Data.....	78
9-10 Fire Duration Distributions (Other Vehicle Involved is Truck).....	79
9-11 Fire Duration Distributions (Other Vehicle Involved is Car).....	79
9-12 Fire Duration Distributions (Other Vehicle Involved is Tanker)	80
9-13 Fire Duration Distributions (No Other Vehicle Involved).....	80
9-14 Fire Duration Distributions (Other Vehicle Involved is Train).....	81
9-15 Comparison of Distributions for Fire Duration--Simulation vs. Accident Data	82
C-1 Codes for Contact Area on Tractor and Trailer.....	99
C-2 Supplemental Data Form for Fire Severity--On-going Study	101
D-1 Overall Distribution of Fire Surface Area: Case 1	105
D-2 Overall Distribution of Fire Duration: Case 1.....	105
D-3 Overall Distribution of Fire Surface Area: Case 2	106
D-4 Overall Distribution of Fire Duration: Case 2.....	106
D-5 Overall Distribution of Fire Surface Area: Case 3	107
D-6 Overall Distribution of Fire Duration: Case 3.....	107
D-7 Overall Distribution of Fire Surface Area: Case 4	108
D-8 Overall Distribution of Fire Duration: Case 4.....	108

Tables

6-1 Spreadsheet for Supplemental Collision Severity Data	25
6-2 Cell Formulas used in Spreadsheet for Collision Severity Data.....	25
6-3 Estimates for Coefficient of Friction Based on Road Surface and Road Condition	26
6-4 Relative Hardness Values.....	27
7-1 List of Variables in Main Accident File.....	34
7-2 List of Variables in Accident File Constructed from GES	35

7-3	List of Variables in the TIFA Fire Severity File	39
7-4	States Selected for Review of Collision Severity Data.....	40
7-5	List of Variables in the TIFA Collision Severity Data File	41
8-1	Definition of MHE.....	44
8-2	Weighted Number of Fatal Accidents by MHE and Operating Environment	45
8-3	Frequency of MHE by Operating Environment (Fatal Accidents)	45
8-4	Overall Frequency of each MHE for Different Accident Thresholds	46
8-5	Weighted Number of Fatal Accidents by Impact Direction and MHE	47
8-6	Frequency of Impact Direction by MHE (Fatal Accidents)	47
8-7	Overall Frequency of Impact Direction by MHE for Different Accident Thresholds.....	49
8-8	Comparison of Impact Direction Frequencies Based on TIFA and Michigan Data	49
8-9	Weighted Number of Fatal Accidents in Which a Collision Occurred by MHE and Other Vehicle Involved.....	50
8-10	Frequency of Other Vehicle Involved by MHE (Given a Collision).....	51
8-11	Weighted Number of Fatal Accidents by Impact Location, Direction and MHE.....	53
8-12	Frequency of Impact Location by Impact Direction and MHE (Fatal Accidents)	54
8-13	Weights for Estimating Impact Location Frequencies.....	54
8-14	Comparison of Impact Location Frequencies Based on TIFA and Michigan Data.....	54
8-15	Weighted Number of Fatal Accidents with Rollover by MHE and Impact Direction	55
8-16	Frequency of Rollover by MHE and Impact Direction (Fatal Accidents)	56
8-17	Overall Frequency of Rollover by MHE and Accident Reporting Threshold	56
8-18	Weighted Number of Fatal Accidents with Fire by Impact Direction and MHE	57
8-19	Frequency of Fire by MHE and Impact Direction (Fatal Accidents).....	57
8-20	Overall Frequency of Fire by MHE for Different Accident Reporting Thresholds	58
9-1	Computation of Effective Mass for the AT/SST.....	63
9-2	Weighting Factors Used to Construct Peak Contact Velocity Distributions	63
9-3	Distribution of Area Involved (All Accidents Involving Fire).....	66
9-4	Frequency of Separation Category by MHE (Fatal Accidents).....	69
9-5	Weighting Factors Used to Construct Distributions.....	76
9-6	Distribution of Fatal Involvements by Other Vehicle Involved and MHE Given a Fire Occurrence.....	77
10-1	Distribution of Tow-Away Accidents by Injury Severity and Damage Severity.....	84
A-1	Rollover Accident Data.....	89
B-1	Immersion Event; Trailer Submerged, Vehicle Fell Into Water	93
B-2	Immersion Event; Trailer Submerged, Vehicle Drove Into Water	94
B-3	Immersion Events; Trailer Not Submerged.....	94
C-1	Spreadsheet for Supplemental Collision Severity Data--On-going Study.....	96
C-2	Cell Formulas used in Spreadsheet for Collision Severity Data--On-going Study	96
C-3	Code Values for Road Surface and Corresponding Range for Coefficient of Friction.....	97
C-4	Code Values For Mass Elements.....	97
C-5	Estimated Weights of Selected Fixed Objects.....	98
D-1	Sensitivity Study for Simulation of Surface Areas and Durations of Fires	104

Preface

This report describes the accident data for tractor semi-trailers developed for use in the Defense Programs Transportation Risk Assessment (DPTRA) project sponsored by the U. S. Department of Energy. The objective of the DPTRA project was to quantify the risk from inadvertent dispersal of radioactive material associated with off-site transportation of Defense Programs cargoes. The DPTRA project was a multiple task effort which involved many organizations and individuals. The work included development of new databases in several different areas and developing or refining various tools required to quantify release probabilities and consequences to the general public of the transportation of these cargoes. Because of the scope of the work required, it was not feasible to produce a single report which fully documents all the supporting work and the results in a manageable format. Therefore, the results of the DPTRA project were documented in separate reports that cover the databases, models and risk assessment methodology, respectively. In this report, the focus is on the accident data, specifically the statistical description of the types and severities of tractor semi-trailer accidents.

1.0 Executive Summary

Risk assessments for hazardous materials transportation may require analysis of the response of the transport vehicle, the package and its contents to the abnormal environments associated with a severe traffic accident to determine the conditions under which the hazardous material may be released into the environment. Statistical descriptions of the types of accidents that occur and of the severity of each type of accident are needed to evaluate the probability of releasing hazardous material to the environment.

This report provides such a description of the types and severities of accidents involving tractor semi-trailers. The primary data are based on traffic accidents involving at least one fatality. The information presented in this report was specifically developed to support a probabilistic assessment of the risk of transporting certain radioactive materials in the Armored Tractor (AT)/Safe-Secure Trailer (SST) for the U. S. Department of Energy (DOE).¹ However, because the information is based on tractor semi-trailers used in general commerce, much of the information described in this report may be of interest to anyone evaluating the safety of transporting hazardous materials in tractor semi-trailers.

A number of previous studies have addressed transportation accidents involving heavy trucks with the same basic intent, purpose and approach as this report. The information on the types and severities of accidents in the current study is more recent and more than that presented in previous studies, and it is also stored electronically, which simplifies queries and retrieval of the information.

A large number of accident variables can be used to characterize an accident. In this study, the emphasis was on defining the minimum number of accident characteristics that would provide a sufficient definition of the accident environment to analyze the response of the hazardous materials packaging system and also provide reasonable differentiation of the collision, rollover and fire severities. The variables used to characterize accidents were selected based in part on specific features of the packaging system used by the DOE to transport Defense Programs cargoes.

This report provides distributions of accident types as defined by the types of vehicles and/or other objects involved, collision occurrence, angle of impact, location of principal impact, rollover occurrence and fire occurrence as discussed in Chapter 8. Distributions of peak contact velocity, skid distance, fire temperature, fire size, fire separation, and fire duration were developed to define the severity of the accident, as discussed in Chapter 9. The report also includes a discussion of the application of this data in risk assessments for transportation of hazardous cargoes in Chapter 10.

¹The project is known as the Defense Programs Transportation Risk Assessment (DPTRA).

--This page left almost blank intentionally--

2.0 Introduction

2.1 Background

Risk assessments for hazardous materials transportation may require analysis of the response of the transport vehicle, the package and its contents to the abnormal environments associated with a severe traffic accident to determine the conditions under which the hazardous material may be released into the environment. Statistical descriptions of the types of accidents that occur and of the severity of each type of accident are needed to evaluate the probability of releasing hazardous material to the environment.

This report provides such a description of the types and severities of accidents involving tractor semi-trailers. The primary data are based on traffic accidents involving at least one fatality. Accident rates are described in a separate report [1]. The information presented in this report and in Reference 1 was specifically developed to support a probabilistic assessment of the risk of transporting certain radioactive materials in the AT/SST for the DOE. The operating history with the AT/SST includes only limited accident experience. Although sufficient to describe an overall accident rate, the number of accidents in which AT/SSTs have been involved is insufficient to provide a meaningful statistical description of the types and severities of traffic accidents involving AT/SSTs. Therefore, it is assumed that, given an accident, the distributions of the types and severities of accidents involving tractor semi-trailers used in general commerce with characteristics similar to those of an AT/SST are representative of the distributions of the types and severities of accidents involving AT/SSTs. Consequently, much of the information described in this report may be of interest to anyone evaluating the safety of transporting hazardous materials in tractor semi-trailers.

There have been a number of previous studies that addressed transportation accidents involving heavy trucks and that had the same basic intent, purpose and approach as this report (e.g., References 2-4). The information in the current study has the following advantages:

- The data are more recent and may therefore be more representative of the current environment for truck transportation.
- A more detailed characterization of accident types is provided.
- Collision and fire severity data are more detailed and more comprehensive.
- The data are stored in a set of electronic databases that can be easily queried and analyzed to obtain information in formats other than those used in this study.

2.2 Report Organization

The executive summary appears in Chapter 1. The background, purpose, and objectives for this report are discussed in Chapter 2. Chapter 3 provides a discussion of the type of data needed to evaluate the response of the transport vehicle, package and package contents to severe transportation accidents. Chapter 4 provides a brief description of the AT/SST and identifies the features that a truck-trailer combination should have to serve as a useful surrogate. Chapter 5 provides a review of existing heavy truck accident data files. The procedures used to generate supplemental accident data are described in Chapter 6. The compilation of the accident data files used in this report, including the use of existing data files and the generation of supplemental data, are described in Chapter 7. The statistical descriptions of accident types and severities used in the DPTRA study appear in Chapters 8 and 9, respectively. The suitability of the accident data developed in this study for use in transportation risk assessments is discussed in Chapter 10. Chapter 11 provides an overall summary. References are listed in Chapter 12.

The report includes four appendices. Appendix A provides detailed information on accidents in which the most harmful event is rollover and Appendix B provides detailed information on accidents in which the most harmful event is immersion. Appendix C provides a brief description of on-going efforts to collect accident data applicable to transportation risk assessments. The sensitivity of the Monte Carlo simulation used to develop distributions of fire surface area and duration to the weighting factors applied to pool and spill fire models and to the assumed leak area distributions are described in Appendix D.

3.0 Accident Data Needed in Risk Assessments

One element of a risk assessment for transportation of hazardous materials involves evaluation of the probability that the hazardous material will be released into the environment. Hazardous materials are typically shipped in a packaging system designed to mitigate accident environments and to prevent releases to the environment. In general, normal transportation environments do not produce environments that threaten the integrity of the packaging system. However, the environments produced from very severe traffic accidents could exceed the capabilities of the packaging system and cause a release of hazardous material.

Transportation risk assessments typically consider impact, puncture, crush and thermal environments.² In traffic accidents, impact, puncture and crush environments are associated with collision and rollover events; thermal environments are associated with fires involving the fuel system, cargo or other elements of the vehicles and/or objects involved in the accident. The response of the packaging system to these environment is likely to be interdependent. For example, the response of the packaging system to a fire should reflect damage to the packaging system caused by collision and rollover.

The accident data needed to define the probability of packaging system failure include probabilities of various accident types and distributions of collision, rollover, and fire severity. The response of the packaging system and the collision, rollover and fire severity depend on the type of accident. There are a large number of accident variables that can be used to characterize the accident. In this study, the emphasis was on defining the minimum number of accident characteristics that would provide a sufficient definition of the accident environment to analyze the response of the packaging system and also provide reasonable differentiation of the collision, rollover and fire severities. As a result, the variables used to characterize accidents were selected based in part on specific features of the packaging system used by the DOE to transport Defense Programs cargoes.

The packaging system used by the DOE to transport Defense Program materials includes the cargo, containers and the SST. The most important features of the SST that protect the cargo in accident environments include the walls of the trailer (including the ceiling, floor and doors), which provide significant thermal protection in fire environments, and the cargo tie-down system, which provides a means of holding the cargo in place. In general, damage to the walls of a trailer in an accident depends on a number of factors. If the accident involves a collision, accident characteristics that may affect the response of the packaging system include the location of the principal impact, the impact direction, the collision energy absorbed, the peak contact velocity and the collision duration, which depends on the type of vehicles and/or

²For some cargoes, immersion environments may also be a concern. Immersion is not evaluated in detail in this report. However, the raw data on fatal accidents in which the most harmful event is coded as immersion is presented in Appendix B of this report.

objects involved.³ If the accident involves a rollover, the primary characteristic of the rollover that may affect response of the packaging system (primarily by damage to trailer walls) is the skid distance. If the accident involves a fire, additional accident characteristics that may affect the response of the packaging system include the fire temperature, the size of the fire, the separation between the fire and the trailer, the number of walls on the trailer that are directly heated by the fire, and the duration of the fire.

The types of vehicles and/or other objects involved, collision occurrence, angle of impact, location of principal impact, rollover occurrence and fire occurrence are factors that define the types of accidents. These factors are discussed in more detail in Chapter 8. The peak contact velocity, collision energy absorbed, skid distance, fire temperature, fire size, fire separation, the number of heated walls and fire duration are factors that define the severity of the accident. These factors are discussed in more detail in Chapter 9.

The accident characteristics identified in the preceding discussion represent a compromise between the accident data that was available or could be generated (see Chapters 5 and 6) and the rigor of the analysis used to analyze the response of the packaging system. Detailed engineering data are almost never available for vehicles involved in traffic accidents and so relatively simple, approximate methods of analysis are used.

³Specifically, damage to the trailer walls depends on the location of the principal impact, the impact direction and the collision energy absorbed, and damage to the container and cargo depends on the peak contact velocity and the collision duration.

4.0 AT/SST Surrogate Definition

As described in Section 2.1, the lack of sufficient accident data with the AT/SST necessitates the use of a surrogate for which sufficient data are available to develop a statistical description of the types and severities of accidents. The ideal surrogate for the AT/SST would be a tractor semi-trailer that has similar features, is operated in a like manner, and is widely used. The selection of the actual surrogate represents a compromise between the definition of an ideal surrogate, the nature of the available data, and the need for a large sample size.

Figure 4-1 is a photograph of an actual AT/SST. The AT/SST is a five-axle, tractor semi-trailer combination, consisting of a three-axle power unit pulling a two-axle, 40-foot van semi-trailer. The vehicle typically operates at a gross combination weight (GCW) of between 60,000 and 80,000 pounds.⁴ The AT/SST is a highly specialized vehicle with many features that set it apart from the general truck population, including its brake system, state-of-the-art suspension system, cargo tie-down system and automatic transmission.

AT/SSTs are operated in convoys with escort vehicles, and are driven mainly over interstate and other highways. Routes are chosen to avoid population centers and bad weather. If weather conditions create an unsafe driving environment, convoys seek "safe haven" until weather and road conditions return to a safe level. Shipments in AT/SSTs are made in accordance with all federal regulations on the transportation of hazardous materials at all times. The couriers who operate AT/SSTs are highly-trained, federal officers who must pass regular health, physical-fitness, and driving examinations. Their driving shifts are limited to four hours, and no courier may be on the road continuously for more than 32 hours. That is, every 32 hours, a courier must receive rest over night for eight hours to allow "bed rest."

The physical features and maintenance of the AT/SST, training of the couriers, and operating procedures have the effect of minimizing transportation risk; in particular by lowering the overall accident rate and, when there is an accident, by producing less-severe accidents. These factors accounted for in the overall accident rate for the AT/SST used in the risk assessment since the rate was based on the actual operating experience of the AT/SST. However, the distributions of the types and severities of accidents are assumed to be independent of the special features of the AT/SST. Similarly, we ignored operating procedures, maintenance, and driver training even though they are also factors in reducing accident severity. Consequently, the criterion used to define a surrogate for the AT/SST was based on the most basic, outward physical features of the AT/SST, i.e., any tractor semi-trailer combination involved in an accident was used as a surrogate for the AT/SST. For the most part, the data files actually allow for a more precise definition of the surrogate (e.g., trailer body style, axle count and GCW could also be considered) but the sample sizes become too small when the definition of the surrogate is further restricted.

⁴The weights of the AT and SST are 22,300 and 37,100 lbs, respectively, exclusive of cargo weight.

Figure 4-1 The AT/SST

5.0 Review of Existing Heavy Truck Accident Files

There are only a few publicly available, nationally representative accident data files that deal with truck accidents:

1. The Office of Motor Carriers (OMC) MCS 50-T file from the Federal Highway Administration (FHWA);
2. The National Accident Sample Survey (NASS) file from the National Highway Traffic Safety Administration (NHTSA);
3. The Trucks Involved in Fatal Accidents (TIFA) file from the University of Michigan Transportation Research Institute (UMTRI); and
4. The General Estimates System (GES) file from the NHTSA.

The following sections provide a description of each of these files and an indication of their utility in providing surrogate accident data for an AT/SST. In addition, computerized police-reported accidents for the state of Michigan that are available at UMTRI are discussed. This file was used to obtain supplemental information on the severity of non-fatal accidents.

5.1 NASS

The NASS file [5] is a probability based sample of police-reported accidents. Sample cases are drawn by means of a three-stage process: first, Primary Sampling Units (PSU) are sampled from approximately 1200 political jurisdictions; then, police jurisdictions are sampled from within each sampled PSU; finally, within the sampled police jurisdictions, police accident reports are sampled. The sampled cases are investigated in great depth by teams of accident reconstruction experts. Because of the great investigative depth, NASS includes relatively few cases. Moreover, the focus of the work has been primarily on passenger automobiles. Consequently, sample size for truck accidents is small. NASS includes about 500 cases per year between 1980 and 1986 that can be identified as a tractor semi-trailer. This is too few to support all data elements required in the risk assessment. In addition, since there are so few cases, sampling errors are large and the reliability of the estimates correspondingly small. Finally, in 1987 NASS dropped large trucks entirely in order to focus on passenger cars. Therefore, the NASS file was not used in the present study.

5.2 OMC

The OMC accident file [6] is compiled from reports submitted by involved parties. All interstate carriers, whether public or private, who operate medium or heavy trucks are required to file an MCS 50-T report on traffic accidents involving a fatality, injury, or property damage over a given amount (\$4,400 at the time this study was conducted). These reports are

completed by the carrier itself, typically by the safety director. The OMC file includes sufficient detail about the truck to identify an AT/SST surrogate with some specificity. The file includes variables about trailer type, cargo-body style, axle count for each unit, and GCW. However, fire is coded only as part of a hierarchical variable, so some fires cannot be identified. Similarly, rollover can be identified only for single-vehicle accidents. Finally, OMC cannot support identification of the collision types required in the risk assessment.

The OMC file has other problems as well, related to representativeness. First, only interstate carriers are required to file reports. Public and private carriers who operate only within a given state are exempt from the reporting requirement. Second, enforcement of the reporting requirement is weak. The comprehensiveness of the TIFA file (discussed in Section 5.3) makes it a good yardstick for measuring other files. Using the TIFA file as a standard, it can be shown that only about 60 percent of reportable fatal accidents, where reportable means the an interstate carrier was involved, are actually filed with the OMC. Since reporting is so low for the most serious accidents, it is believed that an even lower proportion of non-fatal accidents are reported.⁵ Because reporting is so low and because OMC covers only interstate operations, OMC is not a representative source for non-fatal accidents. As described in Section 5.3, information in the OMC file for fatal accidents is used to construct the TIFA file. Therefore, the OMC file was not used directly in this study.

5.3 TIFA

The TIFA survey data [7] provided much of the accident data needed in the risk assessment. TIFA includes all variables necessary to identify AT/SST surrogate vehicles. The file includes a large number of variables that can be used to categorize the types of accidents that occur, including most harmful event, impact direction, rollover occurrence, and fire occurrence. The file also includes all variables necessary to establish the operating environment.⁶ Finally, the TIFA is nationally representative in that it includes records for virtually all medium and heavy duty trucks involved in a fatal accident in the U.S. from 1980 to 1990, amounting to 33,363 tractor semi-trailer involvements. The primary drawback of the TIFA file is that it includes only accidents in which there was at least one death. Accidents involving only injury and/or property damage are excluded. Nevertheless, the TIFA file does include most of the accidents of concern. The goal of this study was to determine the probability of traffic accidents that pose a serious threat to the physical integrity of the AT/SST and its cargo. Such accidents generally involve high-speed collisions with massive vehicles or objects, or major fires. These

⁵Because of data and representation problems, the reporting requirement was dropped in March 1993.

⁶The operating environment is defined by the road type and population area. Accident rates and distribution of accident types depend on the operating environment. A more detailed discussion of the significance of operating environment and how it is defined can be found in Section 8.1 and Reference 1.

types of accidents are also the most likely to involve a fatality, so the set of accidents of concern is largely, although not necessarily entirely contained in the set of accidents involving a fatality. Chapter 10 provides a more detailed discussion of the significance of this limitation and how it can be addressed in a risk assessment.

TIFA is produced by the Center for National Truck Statistics at UMTRI. In 1981, UMTRI initiated a survey of all large trucks involved in fatal accidents in the continental United States. The first data year was 1980. The survey combines information from the Fatal Accident Reporting System (FARS) of the U. S. Department of Transportation NHTSA [8] with data from the OMC MCS 50-T reports, state police accident reports, and comprehensive follow-up telephone interviews conducted by UMTRI research staff. At the time this study was conducted, the file was complete through 1990.

The TIFA file covers all cases where a medium or heavy truck was involved in a fatal accident. Medium and heavy duty trucks cover non-passenger vehicles with a gross vehicle weight rating (GVWR) greater than 10,000 pounds. In essence, the file covers all trucks larger than a pickup. Cases for TIFA are originally identified by subsetting the appropriate vehicles from the FARS file. Police reports are obtained for all accidents from the states. Next an attempt is made to match FARS cases with their corresponding cases in the OMC MCS 50-T file. OMC reports provide extensive information on the physical configuration of the case vehicle, so OMC-matches are considered complete, except for checks on the completeness and consistency of the data. However, the matching process is only successful for about one-third of the FARS cases. For the remaining two-thirds of the cases, a follow-up telephone survey is conducted to collect a detailed physical description of the involved truck. The owner, driver, or some other involved party is contacted for information about the configuration of the truck, the number of trailers, cargo-body type, and many other details.

Every case produced by the telephone survey is subjected to extensive editing to ensure accuracy and completeness of the data. The VIN (vehicle identification number) is decoded to positively identify the vehicle, and the physical description from the phone interview is compared with the manufacturer's specifications. Inconsistencies or contradictions are resolved by further interviews, whenever possible. Computerized consistency checks are made on the entire file. Where problems are found with OMC cases, calls are made to resolve them. The result is a file with low missing data rates and high expectations of accuracy.

For data years 1980 through 1986, TIFA is a census file, meaning that it contains records for all medium and heavy trucks involved in a fatal accident. Data years 1987 through 1990 include some limited sampling. The purpose of the sampling was to reduce the number of cases requiring telephone interviews, while not compromising the quality and completeness of the data. The raw number of cases for the data years where sampling was done is about 1,000 records fewer than if all cases had been taken. Appropriate weights have been determined that allow national population totals to be estimated. The sampling procedure is described below. Statistical work has shown that sampling has had little effect on the accuracy of estimates from

the files [14]. The 1980-1990 TIFA file contains records on 33,363 tractor semi-trailer combinations, with a weighted total of 36,369 tractor semi-trailers.

The sampling algorithm is straightforward. All OMC-matched cases are included in the file with certainty and have a weight of one. The pool of cases to be sampled covers straight trucks with no trailer or tractors with one trailer, which are identified in FARS with the greatest accuracy. The cases to be sampled are sorted by state and month to ensure good annual coverage, and an interval selection procedure is employed, taking every other case. A weight of two is given to the cases thus selected. All other cases (non-OMC-matches and not a straight truck with no trailer or tractor with one trailer) are taken with certainty and have a weight of one. Thus, the sampling procedure is limited to cases with no OMC-match and that are either a straight truck with no trailer or a tractor semi-trailer. Interviewing on the sampled cases then proceeds normally.

FARS includes a long list of variables about the accident environment, the events of the accident, and the people involved, but the detail about the vehicles involved is limited. The FARS accident, vehicle, and person variables relating to the truck are all incorporated in the TIFA file. TIFA also includes the detailed physical description of the involved truck from the MCS 50-T report, where a match could be found, or, if not, the even greater detail of the telephone survey. Consequently, the TIFA file contains the most complete selection of variables and the most detailed physical description of the vehicles involved available. Virtually all of the data elements identified related to types of accidents are in the TIFA file. Information about the "other vehicle involved" is not included in TIFA, but it was reconstructed from the original FARS file, since FARS includes all vehicles, not just trucks, involved in a fatal accident. A version of the TIFA file has been built that incorporates this additional information. For each truck record in the TIFA file, variables have been added that record the number of passenger cars/light trucks/pickups, medium or heavy trucks, hazardous tankers, or other vehicles involved in the accident.

The TIFA file was also used for the fire and collision severity studies. At the time this study was conducted, UMTRI had the original interviewing material and police reports for all TIFA cases from 1984 through 1988. All fire cases were examined and samples of the collision cases were drawn and examined. This topic is described further in Chapters 6 and 7.

The primary drawback to using TIFA exclusively in the risk assessment is that the file is limited to fatal accidents only. There is no information about non-fatal accidents. This is not an insuperable problem since fatal accidents are typically serious accidents that involve high collision energies and severe fires, i.e., those that are likely to pose the greatest threat to the AT/SST. Evaluating the full range of threats to the AT/SST, however, requires some consideration of non-fatal accidents.

5.4 GES

The GES file [9] is another probability-based sample of police-reported accidents. The GES file was developed by NHTSA to overcome the sample-size limits of the NASS file and provide reliable national estimates of accident totals. While NASS provides detailed examinations of particular accidents, GES is coded entirely from police accident reports. The GES file allows some extension of the risk assessment to non-fatal accidents. GES includes a shorter list of variables but larger sample size, including large trucks. Sample sizes are not as large as would be desirable but they are adequate. The three years of GES available (1988-90) at the time this study was conducted contained records for 5,665 tractor semi-trailers.

GES uses a three-stage sampling protocol similar to that of NASS. The United States is divided into PSUs grouped by geographical region (Northeast, South, Central and West) and type (large central city, large suburban areas and other). Police jurisdictions are sampled within the geographical areas in the second stage. Finally, GES investigators periodically visit the sampled police jurisdictions and select cases for inclusion in the GES file. Accidents are filed into three groups (involving a towed vehicle, not involving a towed vehicle but including an injury, and other), and a random sample is drawn from each group. In 1990, changes were implemented to increase the sample of large trucks. The GES variables are then coded from the selected police reports. Unlike NASS, there is no further investigation of the cases.

The GES file does not contain all the vehicle-level detail of TIFA so the most precise surrogate definition that can be used is a tractor semi-trailer. There is no information in GES for cargo-body type, axle counts, or GCW. GES includes many of the same variables as the FARS. Make/model, most harmful event, rollover, fire, and time of day are identical in the GES, TIFA and FARS files. With the make/model coding, the type of other vehicles involved can be identified. Unfortunately, the road type and area type variables in GES are unusable. The Interstate variable codes only roads that are explicitly identified as a numbered Interstate highway, so many named Interstates are not identified and of course other limited access roads are not included. The smallest population size distinguished in the urban/rural variable is a city of 25,000 people, far larger than the FHWA rural definition of 5,000 people. Consequently, the dependence of accident data on road type and area type cannot be determined using GES.

5.5 State of Michigan Police Accident Reports

Police accident report files can be readily acquired from the state of Michigan by UMTRI and consist of all reportable traffic accidents. The data are collected by police officers; additional information is sometimes coded subsequently from the police report. At the time this study was conducted the reporting threshold in Michigan was \$200 of property damage.

The primary limitation of the state of Michigan file [10] is that it may not be representative of the national experience. In addition, the amount of detail on truck configuration is limited. Only tractor semi-trailers can be identified. There is no information about cargo-body style,

axle count, or GCW. Rollover can be identified for single-vehicle accidents. Michigan has a usable fire variable, which includes information on the source of fire. "Object Struck" variables are reasonably complete; and, since the files are census files, there are a large number of cases available. In this study, the Michigan file was used to gain insight into the severity of non-fatal accidents, as compared to fatal accidents. The Michigan file was used primarily as a source of hard copies of police reports that were studied for information on accident severities, for example, the duration of fires. With this focus, the question of national representativeness is less of an issue.

6.0 Supplemental Data

The computerized databases that are available contain variables that can be used to determine the frequencies of most of the accidents types that are needed to define the accident environment in transportation risk assessments (see Chapter 3). However, describing the severity of accidents, fire and collision severity in particular, requires information not contained in these databases. Therefore, procedures for gathering supplemental information on collision and fire severity were developed. Cases of interest were identified from the TIFA and Michigan Police Accident Report data files for which police reports were available.⁷ Data were entered into a spreadsheet for collision severity and onto a data form for fire severity based on a review of the information available in the police reports for the selected cases. The data obtained from the police reports were independently reviewed and checked for accuracy. The data were eventually imported into Paradox⁸ database files.

Section 6.1 describes the information entered into the spreadsheet, the procedures used to obtain this information and the spreadsheet calculations for the collision severity data. Section 6.2 describes the information entered onto the fire severity data form and the procedures used to obtain this information. Chapter 7 provides a description of the cases selected from the TIFA and Michigan Police Accident Report data files and the resulting Paradox database files.

In addition to the data collected on collision and fire severity, police reports were reviewed for selected cases from the TIFA file in which the most harmful event was coded as a rollover or immersion. This information was not imported into a database, nor was it independently reviewed for accuracy. The raw data generated from the review of police reports for rollover and immersion events appear in Appendices A and B, respectively.

A follow-on study, which provides improvements in the data collection procedures that are expected to reduce the number of unknowns and includes refinements in the metrics, is currently underway. A brief description of this on-going effort is provided in Appendix C.

6.1 Collision Severity Data

Supplemental data for collision severity were collected from police reports. The data obtained from police reports were entered into a spreadsheet, which was then used to compute measures of collision severity. Table 6-1 shows the format of the spreadsheet used to enter

⁷Police reports were not readily available for cases in the other computerized accident data files described in Section 5.0 (NASS, OMC, and GES).

⁸Paradox Version 4.0, Borland International, 1800 Greens Hill Road, P.O. Box 660001, Scotts Valley, CA 95067-0001.

these data. The year (Yr), state code (St), case number (Case) and vehicle number (Veh) were input so that the data could be combined later in the analysis with data in the existing computerized databases. The travel speed (Trav Spd, mph), skid distance (Skid Dist., ft) and coefficient of friction were used to calculate the speed at impact (Impct Spd, mph), using the spreadsheet formulas indicated in Table 6-2.⁹ The derivation of the formulas used for impact speed is described in Reference 11. The impact angle (Ang, degrees), which is the angle subtended by the velocity vectors of the case vehicle and the other vehicle or object, was used to calculate the relative velocity (Rel Vel., mph) between the case vehicle and the other vehicle or object. Figure 6-1 provides clarification of how impact angle is defined. The weights of the case vehicle and the other vehicle or object are specified in lbs and are used in the calculation of collision severity (Coll Sev.), which is a measure of the total energy absorbed by the vehicles and objects in the collision, along with a relative hardness factor (REH) and the relative velocity. The derivation of the formulas used for relative velocity and the total energy absorbed in a collision can be found in Reference 12. The cells labeled 'struck on this' and 'struck on other' are used to identify the impact location.

Rows 4, 7 and 10 of the spreadsheet contain information on the case vehicle; rows 5, 8 and 11 contain information on the other vehicle or object involved in the collision. For each case vehicle, only one event was coded.

Accidents in which there was no single collision that caused a sudden, large change in velocity were considered sideswipes. Sideswipes are characterized by glancing impacts and a decrease in velocity over an extended time and distance. These types of collisions do not constitute a threat to the integrity of the trailer or the cargo restraint systems since there is no significant change in kinetic energy that would damage the trailer walls (in severe collisions, kinetic energy is converted into work that is used in crushing and deformation), nor is there any significant deceleration that would load the cargo restraint system. Travel speed was coded as -1 for the case vehicle if the accident was considered to be a sideswipe, which effectively classifies the collision event as non-threatening. For accidents classified as sideswipes, the skid distances, coefficient of friction, impact angle and weights are not used.

Figure 6-1 Definition of Impact Angle

⁹The spreadsheet and formulas were developed using Quattro Pro, Version 4.0, Borland International, 1800 Greens Hill Road, P.O. Box 660001, Scotts Valley, CA 95067-0001.

Table 6-1 Spreadsheet for Supplemental Collision Severity Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	(-1 for sideswipe)					1=trac		2=trlr		3=fixed obj		4=unfixed obj			
2	LOW ESTIMATES				Trav	Skid	Coef.	Impct		Rel.		Coll.			
3	Yr	St	Case	Veh	Spd	Dist.	Fric	Spd	Ang	Vel.	Weight	Sev.			REH
4	0	0	0	0	-1	0	0.5	-1.0	0	0.0	0	-1.0			1
5	0	0	0	0	0	0	0.5	-1.0			0				
6	HIGH ESTIMATES														
7	0	0	0	0	-1	0	0.4	-1.0	0	0.0	0	-1.0			1
8	0	0	0	0	0	0	0.4	-1.0			0		Struck	Struck	
9	AVERAGE												on this	on other	
10	0	0	0	0	-1	0	0.45	-1.0	0	0.0	0	-1.0	0	0	1
11	0	0	0	0	-1	0	0.45	-1.0			0		0	0	

Table 6-2 Cell Formulas used in Spreadsheet for Collision Severity Data

H4=@IF(E4=-1, -1, @SQRT(E4^2-30*F4*G4))
H5=@IF(E5=-1, -1, @SQRT(E5^2-30*F5*G5))
J4=@SQRT(H4-H5*@COS(I4*@PI/180))^2+(H5*@SIN(I4*@PI/180))^2
L4=@IF(E4=-1, -1, @SQRT((.0334*(K4*K5)/(K4+K5))*J4^2/1000))/O4)
H7=@IF(E7=-1, -1, @SQRT(E7^2-30*F7*G7))
H8=@IF(E8=-1, -1, @SQRT(E8^2-30*F8*G8))
J7=@SQRT(H7-H8*@COS(I7*@PI/180))^2+(H8*@SIN(I7*@PI/180))^2
L7=@IF(E7=-1, -1, @SQRT((.0334*(K7*K8)/(K7+K8))*J7^2/1000))/O7)
H10=@IF(E10=-1, -1, @SQRT(E10^2-30*F10*G10))
H11=@IF(E11=-1, -1, @SQRT(E11^2-30*F11*G11))
J10=@SQRT(H10-H11*@COS(I10*@PI/180))^2+(H11*@SIN(I10*@PI/180))^2
L10=@IF(E10=-1, -1, @SQRT((.0334*(K10*K11)/(K10+K11))*J10^2/1000))/O10)

If the case vehicle was involved in more than one collision, the collision producing the greatest change in velocity was coded. Travel speed, skid distance and/or impact speed, and the impact angle are generally provided in a coded field, the narrative description, or an accident diagram in the police report. Police reports typically report travel and impact speeds as a range; estimating skid distances and impact angles from accident diagrams, as was done in many cases, is approximate at best. The use of upper and lower bound estimates in the spreadsheet was an attempt to accommodate information in this format. If impact speed was explicitly specified in the police report, the skid distance and/or travel speed were adjusted such that the formula for impact speed gave the value indicated in the police report. The upper bound, lower bound and average estimates for the coefficient of friction were based on the road conditions described in the police report, as indicated in Table 6-3.

Table 6-3 Estimates for Coefficient of Friction Based on Road Surface and Road Condition

Road Condition	Coefficient of Friction		
	Upper Bound	Lower Bound	Average
dry	0.4	0.5	0.45
wet	0.3	0.4	0.35
snow/ice	0.2	0.3	0.25

The weight of the vehicle or object used in the spreadsheet was the effective weight from the standpoint of momentum transfer. The following guidelines¹⁰ were used to evaluate the effective weight:

1. For tractor semi-trailers impacted in the front or rear, the GCW as given in the TIFA data was used.
2. For tractor semi-trailers impacted in the side of the tractor, the tractor weight as given in the TIFA data was used.
3. For tractor semi-trailers impacted in the side of the trailer, the combined trailer and cargo weight as given in the TIFA data was used.
4. The weight of large cars and pickups was assumed to be between 3500 and 4500 lb. depending on the model.
5. The weight of mid-size cars was assumed to be between 3000 and 4000 lb. depending on the model.
6. The weight of small cars was assumed to be between 2000 and 3500 lb. depending on the model.
7. The weight of motorcycles was assumed to be less than 1500 lb.
8. For fixed objects, the weight was set to an arbitrarily large number (1×10^{12} lb.) if the object remained in place to reflect the fact that the velocity of the fixed object does not change in the collision. If the object did not remain in place (e.g., a telephone pole could be snapped off at its base), the weight was estimated at ten times the estimated actual weight of the object.
9. For non-fixed objects, the effective weight was generally taken to be less than 1500 lb.
10. For trains, the effective weight was based on the number of locomotives and cars participating in the momentum exchange. In collisions in which the case vehicle was struck by the train; the effective weight was assumed to equal the total weight of all locomotives and cars in the train. In collisions in which the case vehicle struck the train, the effective weight was set equal to the combined weight of the locomotive or car struck and the locomotive(s) or car(s) immediately in front of and in back of the one struck (if present).

¹⁰The guidelines were not interpreted as rigid rules; the analysts that reviewed the data exercised considerable latitude to use information in the police report to estimate an effective weight consistent with the momentum change that occurred in the accident.

Locomotives were assumed to weight 400000 lb., empty box cars 60000 lb., loaded box cars 200000 lb., and passenger cars 100000 lb.

The relative hardness was set equal to one for all collisions except those involving fixed objects that remain in place. For fixed objects that remain in place a relative hardness factor of greater than one is used to account for energy absorbed by crush and plastic deformation of the object. Table 6-4 lists the relative hardness values for various targets. The relative hardness values are based on the ratio of the velocity into the specified target to the velocity into an unyielding surface that results in equivalent damage of a package as provided in Reference 13. The relative hardness was estimated as the square of this velocity ratio normalized by the velocity ratio for a concrete abutment, which was assumed to provide no significant energy absorption. The relative hardness values are difficult to justify, but ultimately they are not important since the collision severity metric calculated in column L of the spreadsheet (see Tables 6-1 and 6-2) was not used in the risk assessment. As described in Chapter 9, the peak contact velocity, which does not depend on the relative hardness, was used to characterize collision severity.

Table 6-4 Relative Hardness Values

Target	Velocity Ratio	Relative Hardness
Concrete Abutment	1.4	1.0
Hard Rock	2.2	2.5
Soft Rock	2.5	3.2
Hard Soil	3.4	5.9
Soft Soil	7.1	25.7
Water	4.5	10.3
Desert soil	2.3	2.7

The impact location was determined based on accident diagrams and/or the narrative description in the police report. In row 10, "struck on this" was coded as either 1 if the principal impact location was the tractor or 2 if the principal impact location was the trailer or left blank if unknown. In row 10, "struck on other" was coded as either 1 (if the other vehicle involved in the collision was a straight truck, car or train or a tractor semi-trailer and the principal impact location was on the tractor), 2 (if the other vehicle involved in the collision was a tractor semi-trailer and the principal impact location was on the trailer), 3 (if the collision involved a fixed object) or 4 (of the collision involved a non-fixed object) or left blank if unknown.

6.2 Fire Severity Data

Figure 6-2 shows the supplemental data form used for collecting fire severity data. This information was extracted directly from police accident reports, independently reviewed and checked for accuracy, and then key-punched into the existing data file.¹¹ The data fields included the year, state number, case number and vehicle number so that the data could be combined later in the analysis with data in the existing computerized databases.

Each fire in the accident was assigned a unique number (the fire source number). The number of fires coded for a specific case vehicle took into consideration how the nature of the fires might have differed if the case vehicle had been an AT/SST. Thus, if the cargo of the case vehicle was lumber and the lumber caught on fire, the lumber fire was disregarded. On the other hand, fires involving the tractor, fuel system, brakes or any other element of the tractor or trailer (excluding cargo) of the case vehicle were coded. In addition, all fires associated with other vehicles, objects or material not part of or carried by the case vehicle were coded. A data form was filled out for each case vehicle and each applicable fire; all other information on the form was coded in relation to that specific case vehicle and fire source.

For example, consider an accident involving a collision between two tractor semi-trailers (vehicles 1 and 2). Both of their fuel tanks rupture and catch fire. The fire spreads from the fuel tank of vehicle 1 to the cargo in the trailer of vehicle 1. The trailer and cargo of vehicle 2 are not involved in the fire. For vehicle 2, three fires are coded: the fuel tank fire of vehicle 2, the fuel tank fire of vehicle 1, and the trailer/cargo fire of vehicle 1. For vehicle 1, only two fires are coded: the fuel tank fire of vehicle 2 and the fuel tank fire of vehicle 1. The fire in the trailer/cargo of vehicle 1 is disregarded in considering the fire affecting vehicle 1 since the SST will not burn in this manner.

If the only fire in the accident involved the cargo of the case vehicle, the fire source number was assigned the number 98, meaning that the fire is not applicable. If a fire could not be identified from the police report, this field was coded 99, meaning that the number of fires and all other information with respect to the fire environment is unknown.

The source of the fire is self-explanatory. Since each applicable fire was coded separately for each case vehicle, only one box was checked. The "fire distance from this trailer" was defined as the shortest distance between the trailer of the case vehicle and the outside surface of the fire flame. If the location of the fire relative to the trailer could not be determined from the police report, the separation category was coded as 9 (unknown). If the fire was in contact with the one or more walls (including the floor and roof) of the trailer, the separation category

¹¹In at least one case in which there appeared to be a very serious fire, the police report did not contain all the information desired and additional information was obtained by conducting a telephone interview with police and fire department personnel that responded to the accident.

was coded as 1 (engulfed) and standoff LBE and UBE were not coded.¹² Otherwise, the separation category was coded as 2 (standoff) and a lower bound estimate (LBE) and upper bound estimate (UBE) for the standoff (i.e., the shortest distance between the outside surface of the fire and any point on the trailer of the case vehicle) were entered. Lower and upper bound estimates were used because considerable judgment was needed to interpret information from the narrative description and accident diagrams in police reports. As mentioned previously, the police reports and information entered into the fire supplemental information form were independently reviewed by at least two people. This process of independent review was intended in part to ensure the quality and accuracy of these types of judgments.

The information required on the data form for area involved, fuel tank capacity, type of cargo, and cargo weight is self-explanatory. These parameters represent an attempt to characterize the type and quantity of combustible material involved in the fire. Only one box could be checked for area involved and type of cargo. With the exception of the fuel tank capacity, which is rarely specified in police reports or other accident information, values for these parameters could be easily assigned based on information in the police reports.

Efforts to extinguish the fire, if any, are entered into the form under the fire-fighting heading. Unfortunately, there was often no description of fire-fighting efforts. In many cases in which it was noted that a fire department responded it was not clear if the responders actually extinguished the flame or whether the fire was allowed to burn out. The large number of unknowns and the unknown effectiveness of the response in cases in which it was known that fire-fighting equipment was available limits the usefulness of these data.

The data form also includes room for upper and lower bound estimates of the fire duration and the estimated surface area of the fire. The fire duration was intended to represent the time period during which an energetic open flame existed (excluding any time that the combustibles were smoldering). In most cases, fire duration was not available in any of the accident information. The surface area of the fire was intended to represent the ground area covered by open flame. Although this information was not normally explicitly available, it could often be inferred from the narrative or diagrams in the police reports. For example, if the police report stated that a vehicle was engulfed in fire, the surface area of the fire was assumed to be approximately equal to the footprint of that vehicle.

The form also contained an area for comments by the reviewers, which was used to describe any unusual features of the fire. The comments were not keyed in and thus are not in the computerized data file. However, they are available on hard copy.

¹²The description of the trailer walls heated by the fire has been improved in the on-going effort to collect supplemental data, as described in Appendix C.

AT/SST Fire Supplemental Information Form			
Accident Year: _ _			
State: _ _		Case No.: _ _ _ _ FARS Vehicle No.: _ _	
Source of Fire:		Fire distance from this trailer:	
This vehicle	☐ 1	Sep category:	
Other, heavy truck	☐ 2	Engulfed	☐ 1
Other, tank truck	☐ 3	Standoff	☐ 2 Standoff LBE: _ _ _ ft
Other, car/pickup	☐ 4		
Object (building, structure, etc.)	☐ 5		Standoff UBE: _ _ _ ft
Grass, trees, pavement	☐ 6	Unknown	☐ 9
Other	☐ 7		
Unknown	☐ 9		
Area Involved:		Fuel tank capacity: _ _ _ gal	
Fuel system and not cargo	☐ 1	Type of Cargo:	
Cargo and not fuel system	☐ 2	diesel, gas, alcohol	☐ 1
Fuel system and cargo	☐ 3	propane	☐ 2
Tires/brakes only	☐ 4	other combustible liquid	☐ 3
Electrical only	☐ 5	lumber, wood	☐ 4
Cab only	☐ 6	other	☐ 5
Object struck	☐ 7		
Other	☐ 8	unknown	☐ 9
Unknown	☐ 9		
		Cargo weight: _ _ _ _ lbs	
Fire fighting:		Estimated fire duration:	
None	☐ 1	Duration LBE:	_ _ _ min
Hand equipment	☐ 2	Duration UBE:	_ _ _ min
Fire truck	☐ 3		
Other	☐ 4		
Unknown	☐ 9		
		Estimated surface area	
		Area LBE:	_ _ _ ft ²
		Area UBE:	_ _ _ ft ²
		Fire Source No.:	_ _
Comments on intensity, duration or other features of the fire:			

Figure 6-2 Supplemental Data Form for Fire Severity

7.0 Compilation of Accident Files

The AT/SST-surrogate accident files are created from existing accident data files and supplemental data obtained from police reports. The final accident data developed for this project are contained in several files. The first two files are derived from existing accident data files. They are used to determine frequencies of the most harmful event, impact direction, other vehicle or object involved, rollover occurrence, and fire occurrence. The other four data files were developed from the supplemental data collection efforts for collision and fire severity and are used to determine the frequency of impact location and distribution functions for peak contact velocity, fire separation, fire size and fire duration. The impact severity studies focused on most harmful events that posed the most serious threat to the AT/SST and its cargoes. The fire data were collected on all types of accidents in which fire occurred.

7.1 Main Accident File Constructed from TIFA

This file is a subset of the 1980-1990 TIFA file. Only tractor semi-trailers are included in the file (the TIFA file includes all medium and heavy duty trucks). The file includes forty-seven variables from the TIFA file and three variables generated for this study. The TIFA file variables include case identifiers and variables on the accident environment, the events of the accident, operator of the truck and the physical configuration of the truck. The added variables code the type of other vehicle involved in the accident, whether any truck in the accident suffered a fire, and the event tree category for the accident. A list of variables in this file appears in Table 7-1. The file has 33,363 records representing 36,269 vehicles. The file does not include all TIFA variables, nor does it include all TIFA records.

The coding of those variables copied directly from the TIFA database can be found in Reference 14. The coding of the three variables created for this study is described here. The 'other vehicle type' variable classifies the accident the case vehicle was involved in according to the following rules:

- Code level 0 is used if there is no other vehicle involved in the accident (i.e., the accident is a single-vehicle accident);
- Code level 1 is used if there is one other truck, no cars, and the other truck is not a hazardous tanker; or if there are two or more other trucks involved and neither is a hazardous tanker;
- Code level 2 applies if there is any number of cars and no trucks; or if there is one other truck (not a hazardous tanker) and any number of cars; and
- Code level 3 is used for any accident in which any of the other vehicles involved is a hazardous tanker.

The 'other vehicle type' field was generated in two steps. In the first step, variables containing counts of vehicle types involved in the accident were generated. Variable v2001 contained a count of the number of other trucks, buses, and fire trucks involved in the accident. Variable v2002 contained the number of passenger cars, motorcycles, and light trucks. Variable v2006 contained the number of tank trucks carrying hazardous commodities. Variable 2001 was generated from FARS using the 'body type' variable (v109). If v109 was coded 30-39, 70-76, 78, 79, 81, or 83 then the vehicle was counted as a truck. Variable 2002 was also generated from FARS using the 'body type' variable. If variable 109 was coded 1-49, 70-81, or 88-99, then the vehicle was counted as a car.

Variable 2006 was coded from the TIFA variables for 'straight truck body style' (variable 1027), 'straight truck hazardous cargo' (variable 1034), 'first trailer body style' (variable 1040), and 'first trailer hazardous cargo' (variable 1042). If (v1027=tank and v1034=yes) or (v1040=tank and v1042=yes) then the vehicle was counted as a hazardous tank.

With these variables, the following logic was used to generate the 'other vehicle type' field:

```
if v2001=0 and v2002=0 and v2006=0 then v2011=0
if (v2001>=1 and v2002=0 and v2006=0) or (v2001>=2 and v2006=0) then v2011=1
if (v2001=0 or v2001=1) and v2006=0 and v2002>=1 then v2011=2
if v2006>=1 and v1026<>1 then v2011=3
```

The 'fire on any truck' field records whether any truck in the accident is coded as having a fire. Even if the case vehicle did not have a fire, if another truck in the accident had a fire this field was coded yes (code level 1). If none of the trucks involved in the accident, including the case vehicle, experienced a fire this field was coded no (code level 0). To produce this field, a variable (v2012) was generated in the TIFA file, using variable 134 ('fire occurrence'), to count the number of trucks involved in the accident which had a fire. The 'fire on any truck' field was then produced as follows:

```
if v2012=0 then [fire on any truck]=no
if v2012>=1 then [fire on any truck]=yes
```

The 'event tree' field is developed based on TIFA Variable 139 (most harmful event) but includes some regrouping to improve differentiation of accident severities. The code levels are:

1. most harmful event is collision with heavy or medium truck (not a tanker)
2. most harmful event is collision with a light truck or car
3. most harmful event is collision with a tanker
4. most harmful event is collision with a high, hard object
5. most harmful event is collision with a high soft object
6. most harmful event is collision with an angled, hard object
7. most harmful event is collision with an angled, soft object

8. most harmful event is collision with a low, hard object
9. most harmful event is collision with a low, soft object
10. most harmful event is collision with a non-fixed object
11. most harmful event is collision with a train
12. most harmful event is rollover
13. most harmful event is fire
14. most harmful event is tank fire
15. most harmful event is immersion
16. most harmful event is other non-collision event
- most harmful event is unknown (blank)

The 'other vehicle type' field (v2011) was used in combination with the TIFA variable for most harmful event to produce the 'event tree' according to the following logic:

```

if v139 in(12,13) and v2011 eq 1 then [event tree]=1
if v139 in(12,13) and v2011 eq 2 then [event tree]=2
if v139 in(12,13) and v2011 eq 3 then [event tree]=3
if v139 in(19,21-22,30,56) then [event tree]=4
if v139 in(27-29,31,42,54,55) then [event tree]=5
if v139 in(32,35-37,51) then [event tree]=6
if v139 eq 34 then [event tree]=7
if v139 in(25,26,39,52,53,57) then [event tree]=8
if v139 in(20,23,24,33,38,40,41,43,44) then [event tree]=9
if v139 in(8,9,11,14-18) then [event tree]=10
if v139=10 then [event tree]=11
if v139=1 then [event tree]=12
(For non-collision events, where there is a fire, hazardous tank cannot
be the case vehicle)
if v139=2 and v1042<>1 then [event tree]=13
if v139=2 and v1040=3 and v1042=1 then [event tree]=14
if v139=3 then [event tree]=15
if v139 in(4-7) then [event tree]=16

```

7.2 Accident File Constructed from GES Data

This file is a subset of the 1988-90 GES file. Only tractor semi-trailers are included in the file. All variables from the accident and vehicle GES files are included, as well as five additional variables generated for this study. Two variables code the number of trucks and the number of cars involved in the accident. Another records the vehicle type class of the accident. There is also a variable which codes whether any vehicle in the accident was towed and another variable coding the event tree category for the accident. The full list of variables appear in Table 7-2. The file has 5,665 records representing 442,376 vehicles.

Table 7-1 List of Variables in Main Accident File

TIFA Variable No.	Description
9	Year
1	State
2	FARS number
104	Vehicle number
10	Hour
12	No. of vehicles
14	Land use
15	Roadway function class ¹³
17	Route signing ¹⁴
21	1 st harmful event
22	Manner of collision
27	Speed limit
29	Roadway profile
31	Roadway condition
35	Light condition
36	Weather
47	No. of drinking drivers ¹³
122	Rollover
124	Travel speed ¹³
125	Hazardous cargo ¹⁵
129	Initial impact
130	Principal impact
131	Extent of deformation
132	Vehicle role
134	Fire
137	1 st vehicle related
137	2 nd vehicle related
139	Most harmful event
223	1 st driver related
223	2 nd driver related
223	3 rd driver related
307	Driver age
1003	Area of operation
1004	Operating authority
1005	Carrier type
1019	Primary event
1020	Associated event

¹³Not coded for 1980.

¹⁴Not coded for 1981.

¹⁵Not coded for 1980 and 1981.

Table 7-1 (continued)

TIFA Variable No.	Description
1030	Power unit axles
1032	Power unit length ¹⁶
1039	Trailer axles
1040	Trailer cargo body
1042	Trailer hazardous cargo ¹⁵
1043	Trailer cargo weight ¹⁷
1045	Trailer length
1063	Combination code
1068	Gross combination weight
1098	Sample weight
2011	Other vehicle type
2012	Fire on any truck
2500	Event tree

Table 7-2 List of Variables in Accident File Constructed from GES

Variable	Description
V1	Case
V2	Month
V3	Year
V4	Day
V5	Hour
V6	Minute
V7	Number vehicles
V9	Number occupants
V11	Number non-motorists
V13	Land use
V14	Percent rural
V15	First harmful
V16	Manner collision
V17	Interstate
V18	Relation to junction
V19	Relation to roadway
V20	Traffic way flow
V21	Number lanes
V22	Roadway alignment
V23	Roadway profile
V24	Roadway surface
V25	Traffic control

¹⁶Available for survey cases only.

¹⁷Combines survey information from Variable 1043 with OMC information from Variable 1067.

Table 7-2 (continued)

Variable	Description
V27	Speed limit
V28	Light condition
V29	Weather
V30	School bus related
V31	Ped/cycle type
V32	Maximum injury accident
V33	Number injured accident
V34	Alcohol involved accident
V35	PSU
V36	Census region
V102	Driver presence
V103	Violations charged
V105	Driver vision obscured
V106	Driver avoid maneuver
V107	Hit and run
V108	Vehicle make
V109	Vehicle model
V110	Body type
V111	Model year
V112	VIN
V113	Special use
V114	Emergency use
V117	Travel speed
V118	Vehicle defects
V119	Vehicle trailing
V120	Jackknife
V121	Rollover
V122	Fire
V123	Damage area
V124	Damage severity
V125	Manner of leaving
V126	Most harmful
V127	Vehicle maneuver
V128	Vehicle role
V129	Accident type
V130	Maximum injury vehicle
V131	Number injured vehicle
V132	Driver drinking
V133	Coded vehicle number
V136	Weight
V2001	Number of trucks
V2002	Number of cars
V2011	Vehicle type
V2013	Vehicle towed
V2500	Event tree

Variables 2001, 2002, 2011, 2013, and 2500 were generated from the GES file. Variables 2001 and 2002 record the number of trucks and cars, respectively, involved in the accident. Trucks are identified using the body-type variable (v110) in GES. If v110 in(50-69,82,83) then the vehicle was identified as a truck. If v110 in(1-49,70-81,88-99) then the vehicle was identified as a car.

Variable 2011 has three code levels:

- Code level 0 is used if there is no other vehicle involved in the accident (i.e., the accident is a single-vehicle accident);
- Code level 1 is used if there is one other truck, and no cars; or if there are two or more other trucks involved;
- Code level 2 applies if there is any number of cars and no trucks; or if there is one other truck and any number of cars.

The following logic is used to generate variable 2011:

```
if v2001=0 and v2002=0 then v2011=0
if (v2001=1 and v2002=0) or v2002>=2 then v2011=1
if (v2001=0 and v2002<=1) or (v2001=1 and v2002<=1) then v2001=2
```

The 'vehicle towed' variable (2013) shows whether any vehicle in the accident was towed. This was generated from variable 123 (manner of leaving scene) in the GES file which records how a particular vehicle left the accident scene. Code level 2 of variable 123 records whether the vehicle was towed due to damage; code level 3 records whether the vehicle was towed for some other reason. Variable 2013 was generated by checking if any vehicle in the accident was coded 2 or 3 for variable 123.

The 'event tree' field, variable 2500, was based on variable 124 (most harmful event) and on the UMTRI-generated 'vehicle type' variable. The code levels are:

- 1 most harmful event is collision with heavy or medium truck
- 2 most harmful event is collision with a light truck or car
- 3 most harmful event is collision with a high, hard object
- 4 most harmful event is collision with a high soft object
- 5 most harmful event is collision with an angled, hard object
- 6 most harmful event is collision with a low, hard object
- 7 most harmful event is collision with a low, soft object
- 8 most harmful event is collision with an other fixed object
- 9 most harmful event is collision with a non-fixed object
- 10 most harmful event is collision with a train
- 11 most harmful event is rollover

- 12 most harmful event is fire
- 13 most harmful event is immersion
- 14 most harmful event is other non-collision event
most harmful event is unknown (blank)

The following logic was used to generate the 'event tree' variable in the GES file:

```
if v126=25 and v2011=1 then [event tree]=1
if v126=25 and v2011=2 then [event tree]=2
if v126 in(32,34) then [event tree]=3
if v126 in(37,45) then [event tree]=4
if v126 in(38,40) then [event tree]=5
if v126 in(36,42) then [event tree]=6
if v126 in(31,33,35,39,41,43,44,48) then [event tree]=7
if v126 eq 49 then [event tree]=8
if v126 in(21,22,24,26-29,46) then [event tree]=9
if v126 eq 23 then [event tree]=10
if v126 eq 1 then [event tree]=11
if v126 eq 2 then [event tree]=12
if v126 eq 3 then [event tree]=13
if v126 in(4-10) then [event tree]=14
```

7.3 Fire Severity Data - TIFA

This file contains supplementary data on the severity of fires in accidents involving AT/SST surrogates. Supplementary data were collected for all cases in which a surrogate vehicle was involved and at least one truck in the accident was coded as having a fire for data years 1984-88 (police reports for cases prior to 1984 had been destroyed and those for 1989-90 were not yet available at the time the supplementary data were collected). A total of 955 cases and 1,398 fires were coded. The variables in this file are listed in Table 7-3. A more detailed discussion of the variable listed in Table 7-3 can be found in Section 6.2.

7.4 Fire Severity Data - Michigan Police Reports

With the exception of the variables used to identify the case, the structure of the Michigan fire severity data file is identical to that of the TIFA fire severity data. In the FARS file the case is identified using the year, state, FARS number and vehicle number; the Michigan file does not include a state code and a case number is used instead of the FARS number. Since these variables are only used to link the fire severity data file with the main accident file, this difference is unimportant. The same data collection procedures were used for both the TIFA and Michigan fire severity data files. The data in the Michigan fire severity data file were collected from Michigan police accident reports. All non-fatal accidents involving a surrogate vehicle and at least one truck with a fire were included. Two years of Michigan accidents

(1988-89) were taken to get a reasonable number of cases. A total of 58 cases were identified. The resulting file has data on 59 fires.

Table 7-3 List of Variables in the TIFA Fire Severity File

TIFA Variable No.	Description
9	Year
1	State
2	FARS number
104	Vehicle number
NA	Fire number
NA	Item burning
NA	Area involved
NA	Cargo
NA	Cargo weight
NA	Fuel tank size
NA	Separation category
NA	Standoff (lower bound estimate)
NA	Standoff (upper bound estimate)
NA	Fire fighting
NA	Fire duration (lower bound estimate)
NA	Fire duration (upper bound estimate)
NA	Surface area (lower bound estimate)
NA	Surface area (upper bound estimate)
1098	Sample weight
NA	Id

7.5 Collision Severity Data - TIFA

The focus of the data collected for the collision severity data file was on those accidents that pose the greatest threat to the integrity of the SST and its cargoes. The file contains data corresponding to six different types of accidents:

1. The most harmful event is a collision with a medium or heavy truck;
2. The most harmful event is a collision with a car or light truck;
3. The most harmful event is a collision with a train;
4. The most harmful event is a collision with a fixed, hard object;
5. The most harmful event is a fire and there is also a collision with a car or truck; and
6. The most harmful event is a fire and there is also a collision with a fixed object.

Data were not collected for accident types which either do not involve a collision or in which the collision is unlikely to threaten the integrity of the SST and its cargo. For example, severity data for cases for which the most harmful event is a collision with a non-fixed object (e.g., pedestrians, bicyclist and animals) were not obtained.

Cases in each of the six categories listed above were selected by different means, depending on the exigencies of the particular category, although there were some general considerations. At the time of case selection, police reports for accidents in the TIFA file were only available for the period between 1984 and 1988, so only these years were reviewed. In addition, estimating collision severity requires estimates of travel speed, impact speed and/or skid distances. Some states do not report this information and in others reporting is spotty. Overall, travel speed is not recorded for about 50% of the cases in the TIFA file. Missing data rates for travel speed were examined on a state-by-state basis; only sixteen states had reporting rates greater than 60%. Table 7-4 is a list of these state names. Except where noted, the cases for which collision severity data were generated come from these sixteen states. The sixteen states represent a reasonable geographic distribution for the continental U.S. Over 46% of all TIFA cases are from these states.

Table 7-4 States Selected for Review of Collision Severity Data

Arizona	Georgia	Nevada	Vermont
California	Louisiana	North Carolina	South Carolina
Delaware	Missouri	Ohio	Utah
Florida	Montana	Oklahoma	Virginia

A total of 432 records were developed for TIFA cases in which the most harmful event was collision with a medium or heavy truck. This includes all 388 TIFA cases in which the most harmful event was collision with a medium or heavy truck from 1984-88 in the sixteen states listed in Table 7-4. An additional 44 records from a pilot selection of cases used to test the collision severity data collection procedure are also included.

A total of 264 records were developed for TIFA cases in which the most harmful event was collision with a car or light truck. Because of the large number of TIFA cases in which the most harmful event is collision with a car or light truck (4,579 in the period 1984-88 in the sixteen states with high reporting rates for travel speed), it was not feasible to review all cases. Moreover, it was unnecessary to review large numbers of cases, since this type of accident is not likely to seriously threaten the integrity of an SST or its cargo. Thus, approximately 50 cases were selected randomly from each of five different collision orientations: head-on, truck side-on into car, car side-on into truck, truck rear-end into car, and car rear-end into truck.

All available TIFA cases (80) in which the most harmful event was collision with a train for the period 1984-88, regardless of state, were reviewed and are included in the collision severity data file.

A total of 154 records were generated for TIFA cases in which the most harmful event was collision with a fixed, hard object. All such cases from the available years and states with high reporting rates for travel speed were included.

A total of 69 records were developed for TIFA cases in which the most harmful event was fire and in which there was also a collision with either a truck or car. A total of 40 records were developed for TIFA cases in which the most harmful event was fire and in which there was also a collision with a fixed object. All cases meeting these criteria in the sixteen states with high reporting rates for travel speed for the period 1984-88 were included.

Table 7-5 is a list of the variables in the TIFA collision severity data file. These data were exported from the spreadsheet described in Section 6.1 and imported into a Paradox database. A more detailed discussion of the variable listed in Table 7-5 can be found in Section 6.1.

Table 7-5 List of Variables in the TIFA Collision Severity Data File

TIFA Variable No.	Description
9	Year
1	State
2	FARS number
104	Vehicle number
NA	Travel speed
NA	Skid distance
NA	Friction coefficient
NA	Impact
NA	Angle
NA	Relative velocity (best estimate)
NA	Hi relative velocity
NA	Low relative velocity
NA	Weight
NA	Severity
NA	Hi severity
NA	Low severity
NA	Other travel speed
NA	Other skid
NA	Other impact
NA	Other weight
NA	Strike this
NA	Struck that
NA	Low relative hardness
NA	Hi relative hardness
NA	Relative hardness
1098	Sample weight

7.6 Collision Severity Data - Michigan Police Reports

With the exception of the variables used to identify the case, the structure of the Michigan collision severity data file is identical to that of the TIFA collision severity data. In the TIFA file the case is identified using the year, state, FARS number and vehicle number; the Michigan file does not include a state code and a case number is used instead of the FARS number.

Since these variables are only used to link the collision severity data file with the main accident file, this difference is unimportant. The structure and procedures associated with this file are identical to those used for the TIFA collision severity data file. The same data collection procedures were used for both the TIFA and Michigan collision severity data files. The data in the Michigan collision severity data file were collected from Michigan police accident reports. For the Michigan file, cases from 1989-90 were selected. The cases selected were restricted to non-fatal accidents that involved either an injury or tow-away of at least one vehicle. Furthermore, since non-fatal accidents generally involve lower collision velocities than fatal accidents, only cases involving the most severe collisions (i.e., those for which the most harmful event was collision with a heavy or medium truck or collision with a fixed object) were examined.

A total of 266 records were developed for cases in which the most harmful event was collision with a medium or heavy truck. Truck-truck impacts were classified as head-on, rear-end, or side-on collisions. Variables 37 and 38 of the Michigan accident file [10] were used to classify the three groups. The following pseudo-code illustrates the method:

```
if v37=1 or v38=2 then impact=head-on
if v37 in(3-5) or v38 in(4-5) then impact=side-on
if v37=2 or v38=3 then impact=rear-end
```

The file includes all 1990 cases meeting this criterion. Head-ons and rear-ends from 1989 were included to increase sample sizes. A total of 102 records were developed for cases in which the most harmful event was collision with a fixed object. This total includes all 1990 cases where the fixed object is "hard" and one-third of the 1990 cases where the fixed object is "soft". Cases were sorted into "hard" and "soft" categories using variable 115 of the Michigan accident file [10]. The logic of the sort was:

```
if v115 in(5,7,11,15) then object="hard"
if v115 in(2-4,6,8-10,12-14,18) then object="soft"
```

8.0 Discussion and Analysis of Accident Types

The accident types used in the DPTRA study are defined by (1) the most harmful event (MHE),¹⁸ (2) the impact direction, (3) the type of the other vehicle or object involved, (4) the impact location, (5) rollover occurrence and (6) fire occurrence. The following sections provide a discussion of these six accident factors.

8.1 MHE

In the risk assessment for the DPTRA study, accidents are initially characterized by the MHE. The definition is based on the event tree variable in the main accident file constructed from the TIFA file, as indicated in Table 8-1. The MHE is used to differentiate accident events that have different accident severities, consistent with the information available in the databases. The key factors considered in selecting the MHEs used in the risk assessment were weight, crush characteristics and fuel capacity.

Note that fires and rollover can occur even when the MHE is a collision event and collisions may occur when the MHE is fire, rollover or immersion. These events are not mutually exclusive. Subsequent factors are used to evaluate the probability of multiple threats occurring in the same accident. This structure introduces some redundancy but is required by limitations of the databases used to quantify the questions. In the TIFA and GES databases, the MHE is generally coded based on the environment that is most harmful to vehicle occupants and/or pedestrians. There is no attempt to describe the sequence of accident events in these databases.

Table 8-2 shows the weighted number of fatal involvements by MHE and operating environment as determined from the main accident file constructed from the TIFA file. Four categories of operating environment are considered: limited access roads in urban population areas, limited access roads in rural population areas, other roads in urban population areas and other roads in rural population areas. TIFA variables 14 (land use), 15 (roadway function class) and 17 (route signing) were used to define the operating environment based on the following logic:

Operating environment = Limited/Urban:

$v14=1 \text{ and } ((v17=1 \text{ or } 2) \text{ or } v15=2 \text{ or } (v17=\text{blank and } v15=1))$

¹⁸Most harmful event as used in the risk assessment for the DPTRA study should not to be confused with variables in the accident data files by the same name. The acronym for most harmful event will only be used in the context applicable to risk assessment and/or the DPTRA study.

Operating environment = Limited/Rural:

v14=2 and ((v17=1 or 2) or v15=2 or (v17=blank and v15=1))

Operating environment = Other/Urban:

v14=1 and ((2<v17<10 and v15≠2) or (v17=blank and 2<v15<9))

Operating environment = Other/Rural:

v14=2 and ((2<v17<10 and v15≠2) or (v17=blank and 2<v15<9))

Operating environment = Unknown:

v14=blank or (v17=blank and v15=blank)

Table 8-3 indicates the frequency with which each MHE occurs given a fatal accident in the indicated operating environment. There are some significant variations in the frequencies of MHEs with the operating environment, notably for train collisions, which almost never occur on limited access roadways.

Table 8-4 provides a comparison of the overall frequencies of MHE based on TIFA data and GES data for different accident severity levels (i.e., all; fatal or tow-away; and fatal). The GES data do not allow hazardous tankers to be explicitly identified and so collision with trucks and hazardous tanker involvements are combined into the truck category in Table 8-4. Furthermore, immersion events are not explicitly identified in GES but there is an 'other non-collision' category in GES, so that is used in place of immersion in Table 8-4. Examination of Tables 8-3 and 8-4 shows that the overall frequencies of MHE are in general less dependent on the accident severity level than on the operating environment. Therefore, use of the fatal accident data to evaluate the frequencies of MHE does not introduce any significant error.

Table 8-1 Definition of MHE

MHE	Description
1. Truck	Collision with medium or heavy truck (event tree=1)
2. Car	Collision with light truck or car (event tree=2)
3. Tanker	Involvement with hazardous tanker (event tree=3 or 14)
4. Hard Object	Collision with hard, fixed object (event tree=4 or 6 or 8)
5. Soft Object	Collision with soft, fixed object (event tree=5 or 7 or 9)
6. Non-fixed Object	Collision with non-fixed object (event tree=10)
7. Train	Collision with train (event tree=11)
8. Rollover	Rollover (event tree=12)
9. Fire	Fire (event tree=13)
10. Immersion	Immersion (event tree=15)

Table 8-2 Weighted Number of Fatal Accidents by MHE and Operating Environment

MHE	Limited Urban	Limited Rural	Other Urban	Other Rural	Unknown	Total
Truck	237	782	105	861	15	2000
Car	2805	2825	4463	13847	178	24118
Tanker	20	29	12	87	1	149
Hard Object	142	218	47	296	11	714
Soft Object	166	242	53	438	8	907
Non-Fixed Object	639	704	1007	1020	19	3389
Train	0	1	49	149	1	200
Rollover	344	711	138	1655	15	2863
Fire	93	228	28	278	4	631
Immersion	14	20	6	31	0	71
Subtotal	4460	5760	5908	18662	252	35042
Unknown	126	260	166	623	52	1227
Total	4586	6020	6074	19285	304	36269

Table 8-3 Frequency of MHE by Operating Environment (Fatal Accidents)

MHE	Limited Urban	Limited Rural	Other Urban	Other Rural
Truck	5.31%	13.58%	1.78%	4.61%
Car	62.89%	49.05%	75.54%	74.20%
Tanker	0.45%	0.50%	0.20%	0.47%
Hard Object	3.18%	3.78%	0.80%	1.59%
Soft Object	3.72%	4.20%	0.90%	2.35%
Non-Fixed Object	14.33%	12.22%	17.04%	5.47%
Train	0.00%	0.02%	0.83%	0.80%
Rollover	7.71%	12.34%	2.34%	8.87%
Fire	2.09%	3.96%	0.47%	1.49%
Immersion	0.31%	0.35%	0.10%	0.17%

Table 8-4 Overall Frequency of each MHE for Different Accident Thresholds

MHE	GES-All	GES-Fatal or Tow-away	TIFA-Fatal	GES-Fatal
Truck (including Tanker)	6.65%	5.87%	6.13%	7.90%
Car	66.05%	71.58%	68.83%	74.88%
Hard object	1.94%	3.54%	2.04%	0.51%
Soft object	7.46%	2.70%	2.59%	0.43%
Non-fixed object	6.57%	1.83%	9.67%	4.94%
Train	0.18%	0.26%	0.57%	0.42%
Rollover	4.48%	9.23%	8.17%	10.03%
Fire	0.46%	0.82%	1.80%	0.39%
Other non-collision	6.20%	4.16%	0.20%	0.51%

8.2 Impact Direction

The impact direction defines the principal component of deceleration, i.e., longitudinal or lateral. The impact direction is an important accident characteristic for the AT/SST because the failure thresholds for the cargo tie-down system depend on the principal direction of deceleration. The impact direction for accidents involving collision angles between -30° and 30° and between 150° and 210° (where 0° is head-on) were classified as front/rear, for which the principal component of deceleration is assumed to be in the longitudinal direction. All other impacts were classified as side, for which the principal component of deceleration is assumed to be lateral. Because the strength of the AT/SST tie-down system in the longitudinal direction is more than twice that in the lateral direction, this classification results in a conservative treatment of tie-down system failure. Since some accidents do not involve a collision, non-collision events (in which the deceleration of the case vehicle is assumed to be small) must also be considered.

TIFA variables 129 (impact point - initial) and 130 (impact point - principal) were used to define the impact direction based on the following logic:

Impact direction=Front/rear:

(v130=1, 5, 6, 7, 11 or 12) or ((v130=blank, 15 or 16) and (v129=1, 5, 6, 7, 11 or 12))

Impact direction=Side:

(v130=2, 3, 4, 8, 9, 10, 13 or 14) or ((v130=blank, 15 or 16) and (v129=2, 3, 4, 8, 9, 10, 13 or 14))

Impact direction=Non-collision:

(v130=0) or ((v130=blank, 15 or 16) and (v129=0))

Impact direction=Unknown:

(v130=blank, 15 or 16) and (v130=blank, 15 or 16)

Table 8-5 lists the number of fatal involvements by impact direction and MHE as obtained from TIFA data between 1980 and 1990. Table 8-6 lists the frequency of each category of impact direction conditional on an accident in which the MHE is of the type indicated in the first column. For six of the ten MHEs, non-collision is precluded because the accident involves a collision by definition of the MHE. These cases are indicated by na (not applicable) in the column listing the frequency of non-collision.

Table 8-5 Weighted Number of Fatal Accidents by Impact Direction and MHE

MHE	Front/Rear	Side	Non-collision	Subtotal	Unknown	Total
Truck	1659	320	0	1979	21	2000
Car	18524	5343	0	23867	251	24118
Tanker	104	31	12	147	2	149
Hard Object	567	126	0	693	21	714
Soft Object	683	170	0	853	54	907
Non-Fixed	2352	883	0	3235	154	3389
Train	86	111	0	197	3	200
Rollover	867	755	1194	2816	47	2863
Fire	445	97	72	614	17	631
Immersion	47	8	15	70	1	71
Unknown	832	215	126	1173	54	1227
Total	26166	8059	1419	35644	625	36269

Table 8-6 Frequency of Impact Direction by MHE (Fatal Accidents)

MHE	Front/Rear	Side	Non-Collision
Truck	83.83%	16.17%	na
Car	77.61%	22.39%	na
Tanker	70.75%	21.09%	8.16%
Hard Object	81.82%	18.18%	na
Soft Object	80.07%	19.93%	na
Non-Fixed	72.70%	27.30%	na
Train	43.65%	56.35%	na
Rollover	30.79%	26.81%	42.40%
Fire	72.48%	15.80%	11.73%
Immersion	67.14%	11.43%	21.43%

The GES data do not include variables that are directly comparable to those used to define impact direction in the TIFA data. For the GES data, variables 16 (manner of collision) and 123 (damage area) were used to determine the impact direction using the following logic:

Impact direction=Front/rear:

(v16=1, 2, 3, 5 or 6) or ((v16=0, 8 or 9) and (v123=1 or 4))

Impact direction=Side:

v16=4 or ((v16=0, 8 or 9) and (v123=2 or 3))

Impact direction=Non-collision:

(v16=0, 8 or 9) and v123=0

Impact direction=Unknown:

(v16=0, 8 or 9) and (v123=5, 6, 8 or 9)

Table 8-7 shows a comparison the overall frequencies of impact direction by MHE based on TIFA data and GES data for different accident severity levels (i.e., all, fatal or tow-away, and fatal). The variation with the database used and the reporting thresholds are significant in the case of impact direction. As the accident severity level becomes more severe, the estimates for the frequencies of impact direction by MHE obtained with the GES data come closer to those obtained with the TIFA data. Nevertheless, the estimates for the frequencies of impact direction by MHE made with TIFA and those made with GES, regardless of the severity level, are considerably different. The estimates obtained with GES suffer from two problems: (1) the sample sizes are small or even non-existent (as indicated by an asterisk in Table 8-7) in many of the cells of this two-way distribution, particularly for fatal accidents, (2) the variables used to define the impact direction for the GES estimates are not as descriptive of the impact location as those used for the TIFA estimates. TIFA provides a much larger sample size (such that all cells in this two-way distribution are reasonably well-populated) and variables that can be used to obtain a more precise description of the impact direction than those in GES. For these reasons, the estimated frequencies of impact direction by MHE from TIFA are considered to be more representative and more accurate than those from GES.

A comparison can also be made with Michigan non-fatal accidents, using the data gathered for the collision severity of accidents in which the MHE was a truck collision. As seen in Table 8-8, the Michigan data are in much better agreement with TIFA than the GES Fatal or Tow-away data is. This provides additional support for the claim that the frequencies for impact direction based on the TIFA data are more representative than those based on GES.

Table 8-7 Overall Frequency of Impact Direction by MHE for Different Accident Thresholds

MHE	Impact Direction	GES-All	GES-Fatal or Tow-away	TIFA	GES-Fatal
Truck (including Tanker)	Front/Rear	69.58%	67.56%	82.93%	84.47%
	Side	30.42%	32.44%	16.51%	15.53%
	Non-collision	0.00%	0.00%	0.56%	0.00%
Car	Front/Rear	50.46%	44.20%	77.61%	55.97%
	Side	49.45%	55.56%	22.39%	44.03%
	Non-collision	0.10%	0.24%	0.00%	0.00%
Hard object	Front/Rear	17.20%	23.53%	81.82%	*
	Side	60.03%	76.47%	18.18%	
	Non-collision	22.76%	0.00%	0.00%	
Soft object	Front/Rear	16.91%	17.53%	80.07%	100.00%
	Side	63.26%	61.21%	19.93%	0.00%
	Non-collision	19.83%	21.26%	0.00%	0.00%
Non-fixed object	Front/Rear	32.98%	48.33%	72.70%	100.00%
	Side	31.55%	51.67%	27.30%	0.00%
	Non-collision	35.47%	0.00%	0.00%	0.00%
Train	Front/Rear	0.00%	0.00%	43.65%	0.00%
	Side	100.00%	100.00%	56.35%	100.00%
	Non-collision	0.00%	0.00%	0.00%	0.00%
Rollover	Front/Rear	12.28%	12.47%	30.79%	31.71%
	Side	86.19%	87.53%	26.81%	68.29%
	Non-collision	1.53%	0.00%	42.40%	0.00%
Fire	Front/Rear	100.00%	100.00%	72.48%	*
	Side	0.00%	0.00%	15.80%	
	Non-collision	0.00%	0.00%	11.73%	
Other non-collision	Front/Rear	8.14%	7.34%	67.14%	*
	Side	29.55%	46.55%	11.43%	
	Non-collision	62.31%	46.11%	21.43%	

*Indicates value could not be calculated because database included no samples in these cells.

Table 8-8 Comparison of Impact Direction Frequencies Based on TIFA and Michigan Data

MHE	Impact Direction	TIFA	Michigan
Truck (not including Tanker)	Front/Rear	83.83%	80.70%
Truck (not including Tanker)	Side	16.17%	19.30%

8.3 Other Vehicle Involved

For cases in which the MHE is coded as a non-collision event, it is possible that the accident involved a collision as indicated in Table 8-7. For these cases, it is important to identify the other vehicle involved. The main accident file constructed from TIFA includes a variable ('other vehicle type', see Section 7.1) that was generated for this purpose. Table 8-9 indicates the number of fatal involvements in which either no other vehicle was involved or a truck, car or tanker was involved by MHE given that a collision occurred (impact direction equal to front/rear or side). Table 8-10 provides the percentage of fatal accidents in which a collision occurred for the indicated MHE that either do not involve another vehicle or involve a truck, car or tanker. Note that for those cases in which no other vehicle is involved, the collision could have involved a hard object, soft object, non-fixed object or a train.

A comparison with non-fatal accidents is not available since a description of the other vehicle involved comparable to that developed from the TIFA file was not available for the GES file.

Table 8-9 Weighted Number of Fatal Accidents in Which a Collision Occurred by MHE and Other Vehicle Involved

MHE	Other Vehicle Involved			
	None	Truck	Car	Tanker
Truck	0	1979	0	0
Car	0	0	23867	0
Tanker	20	1	14	100
Hard Object	533	24	136	0
Soft Object	581	34	238	0
Non-fixed Object	2834	81	316	4
Train	188	2	7	0
Rollover	982	79	559	2
Fire	209	120	203	10
Immersion	35	3	17	0

8.4 Impact Location

Given a collision, the impact location defines which transport element on the case vehicle was impacted directly by the other vehicle or object: either (1) the tractor only or (2) the trailer and/or the tractor. In the DPTRA study this information is used to determine the threat to the integrity of the SST. The trailer is likely to have greater damage if it is directly impacted in the collision. If the tractor is impacted first, collision energy is absorbed by crush and deformation of the tractor, which reduces the energy imparted to the trailer.

Table 8-10 Frequency of Other Vehicle Involved by MHE (Given a Collision)

MHE	Other Vehicle Involved			
	None	Truck	Car	Tanker
Truck	0.00%	100.00%	0.00%	0.00%
Car	0.00%	0.00%	100.00%	0.00%
Tanker	14.81%	0.74%	10.37%	74.07%
Hard Object	76.91%	3.46%	19.62%	0.00%
Soft Object	68.11%	3.99%	27.90%	0.00%
Non-fixed Object	87.60%	2.50%	9.77%	0.12%
Train	95.43%	1.02%	3.55%	0.00%
Rollover	60.54%	4.87%	34.46%	0.12%
Fire	38.56%	22.14%	37.45%	1.85%
Immersion	63.64%	5.45%	30.91%	0.00%

The supplemental collision severity data were used to determine impact location. The spreadsheet used to collect and store information obtained from the review of police reports included a cell labeled 'struck on this' in row 10 (see Table 6-1), which was imported into the collision severity database as a variable labeled 'strike this' (see Table 7-5). This variable was coded as 1 if only the tractor was impacted directly and 2 if the trailer and/or tractor were impacted directly. Thus, this variable is used directly to determine the impact location. The weighted number of fatal accidents by MHE, impact direction and impact location are listed in Table 8-11; impact location frequencies for fatal accidents with a given MHE and impact direction are indicated in Table 8-12. The procedures used to derive the impact location frequencies are based on the following observations and assumptions:

1. The data for impact location for truck and tanker collisions were combined (because the number of records in the supplemental TIFA data are small relative to the overall TIFA database) so that the estimated impact location frequencies are the same for accidents in which the MHE is coded as collision with a heavy truck or involvement with a tanker.¹⁹
2. Data for impact location for collisions with the three types of objects considered (fixed, hard objects; fixed, soft objects and non-fixed objects) were also combined. From these three categories only cases in which the MHE was collision with a fixed, hard object were selected for the supplementary data collection effort for collision severity. It was assumed

¹⁹Many of the characteristics of accidents involving heavy trucks and those involving tankers should be similar. The primary reason for differentiating these two types of vehicles in the event tree is that the amount of fuel carried in a tanker represents a much greater fire threat than that posed by an ordinary heavy truck. However, it is assumed that the characteristics of a collision event (i.e., distributions of IL and peak contact velocity) involving another heavy truck and those of collision event involving a tanker would be similar.

that impact location frequencies for cases in which the MHE was collision with a fixed, soft object or a non-fixed object are approximately the same as those for cases in which the MHE is collision with a fixed, hard object.

3. Cases in which the MHE was coded as rollover or immersion were not selected for the supplemental collision severity data collection effort, and therefore the impact location is unknown for all of these cases. Therefore, the impact location frequencies for rollover and immersion were estimated by weighting the impact location frequencies for truck/tanker, car, object, and train collisions by the frequencies with which these events occur given that rollover and immersion are the MHE. These weighting factors are listed in Table 8-13. The weighting factors for truck/tanker and cars were determined using the data in Table 8-10 directly. The weighting factors for objects and trains were determined from data in Table 8-10 and 8-11. It was assumed that if there was a collision and no other vehicle was involved the collision must have been with an object or a train and that the likelihood of an object or train involvement is in proportion to the frequency with which these events are coded as the MHE. Thus the weighting factor for objects was computed as the product of the frequency that no other vehicle is involved (from Table 8-10) and the ratio of fatal involvements involving a collision in which the MHE was coded as collision with an object and those in which the MHE was coded as either collision with an object or collision with a train (from Table 8-11). Because the weighting factors for rollover and immersion are comparable, the impact location frequencies for rollover and immersion were calculated by using the weighting factors obtained by combining the data for these two events.
4. The cases in which the MHE was coded as fire were selected for supplemental data collection for collision severity only if there was a collision involving a heavy truck or fixed object. These cases were selected because they were thought to represent the most severe collisions for cases in which the MHE was coded as fire. Using this data to estimate impact location frequencies would be inappropriate because it does not reflect a properly weighted sample of this class of accidents. Therefore, the impact location frequencies for cases in which the MHE is fire were estimated by weighting the impact location frequencies for truck/tanker, car, object, and train collisions by the frequencies with which these events occur given that fire is the MHE in the same way as cases in which the MHE was coded as rollover or immersion. The weighting factors for cases in which the MHE is fire are also listed in Table 8-13.

A comprehensive comparison with non-fatal accidents is not available since a description of the impact location comparable to that developed using supplementary data for the TIFA file was not available for the GES file. A limited comparison can be made using the collision severity data from Michigan police reported accidents. As described in Section 7.6, collision severity data for Michigan police reported accidents were only generated for non-fatal cases in which the most harmful event was coded as either collision with a medium or heavy truck or collision with a fixed object. Table 8-14 provides a comparison between TIFA and Michigan non-fatal data for the frequencies with which the tractor only is impacted on the case vehicle given a

collision. The frequencies with which the trailer is impacted are not listed, but since they are the complement of the frequencies with the tractors only is impacted they can be easily deduced from Table 8-14. The most significant difference is associated with side impacts, for which the Michigan data indicates a higher likelihood of striking the tractor only. Thus, with respect to impact location, the TIFA accident data represent a class of accidents that are in general more threatening to the cargo in a semi-trailer (because side impacts into the trailer are more threatening than side impacts into the tractor) than that associated with the Michigan data.

Table 8-11 Weighted Number of Fatal Accidents by Impact Location, Direction and MHE

MHE	Impact Direction	Impact Location				
		Tractor Only	Trailer	Subtotal	Unknown	Total
Truck/Tanker	Front/Rear	174	106	280	1483	1763
Truck/Tanker	Side	25	27	52	299	351
Truck/Tanker	Other	1	0	1	34	35
Car	Front/Rear	124	41	165	18359	18524
Car	Side	10	32	42	5301	5343
Car	Other	1	0	1	250	251
Objects	Front/Rear	95	2	97	3505	3602
Objects	Side	13	1	14	1165	1179
Objects	Other	8	0	8	221	229
Train	Front/Rear	30	6	36	50	86
Train	Side	30	15	45	66	111
Train	Other	1	2	3	0	3
Rollover/Immersion	Front/Rear	0	0	0	914	914
Rollover/Immersion	Side	0	0	0	763	763
Rollover/Immersion	Other	0	0	0	1257	1257
Fire	Front/Rear	63	3	66	379	445
Fire	Side	4	1	5	92	97
Fire	Other	0	0	0	89	89
Unknown	Front/Rear	0	0	0	832	832
Unknown	Side	0	0	0	215	215
Unknown	Other	0	0	0	180	180
Total		579	236	815	35454	36269

Table 8-12 Frequency of Impact Location by Impact Direction and MHE (Fatal Accidents)

MHE	Impact Direction	Impact Location	
		Tractor Only	Trailer
Truck/Tanker	Front/Rear	62.14%	37.86%
Truck/Tanker	Side	48.08%	51.92%
Car	Front/Rear	75.15%	24.85%
Car	Side	23.81%	76.19%
Objects	Front/Rear	97.94%	2.06%
Objects	Side	92.86%	7.14%
Train	Front/Rear	83.33%	16.67%
Train	Side	66.67%	33.33%
Rollover/Immersion	Front/Rear	87.97%	12.03%
Rollover/Immersion	Side	66.27%	33.73%
Fire	Front/Rear	80.60%	19.40%
Fire	Side	55.86%	44.14%

Table 8-13 Weights for Estimating Impact Location Frequencies

MHE	Truck/Tanker	Cars	Objects	Train
Rollover/Immersion	5.01%	34.35%	58.24%	2.40%
Fire	23.99%	37.45%	37.03%	1.53%
Rollover	4.99%	34.46%	58.15%	2.40%
Immersion	5.45%	30.91%	61.12%	2.52%

Table 8-14 Comparison of Impact Location Frequencies Based on TIFA and Michigan Data

MHE	Impact Direction	Impact Location--Tractor Only	
		TIFA	Michigan
Truck	Front/Rear	62.14%	55.95%
Truck	Side	48.08%	61.36%
Hard Object	Front/Rear or Side	97.30%	97.50%
Soft Object	Front/Rear or Side	na	94.34%

8.5 Rollover Occurrence

Accidents may involve a rollover even if the MHE is not coded as rollover. The main accident file constructed from TIFA includes a variable that indicates if the case vehicle experienced a rollover. This variable is used directly to determine rollover occurrence. The weighted

number of fatal involvements in which the case vehicle experienced a rollover are shown in Table 8-15 by MHE and impact direction. The rollover occurrence frequencies for a given MHE and impact direction are listed in Table 8-16. These frequencies were calculated as the ratio of the counts listed in Table 8-15 to the count in the corresponding cell of Table 8-5. For six of the ten MHEs, impact direction equal to non-collision is precluded because the event is a collision by definition. These cases are indicated by na (not applicable) in the column listing the frequency of rollovers given a non-collision.

Table 8-17 lists the overall frequencies of rollover occurrence by MHE based on TIFA data and GES data for different accident severity levels (i.e., all, fatal or tow-away, and fatal). The estimates obtained with GES are not always reliable since the sample sizes are small or even non-existent (as indicated by an asterisk in Table 8-17) in many of the cells of this two-way distribution, particularly for fatal accidents. TIFA provides a much larger sample size, such that all cells in this two-way distribution are reasonably well-populated. Furthermore, the frequency of rollover occurrence for fatal accidents as obtained from the TIFA data is considerably greater than that for tow-away/fatal accidents as obtained from GES. This is consistent with the notion that fatal accidents generally impose a more severe environment on the cargo than do tow-away accidents.

Table 8-15 Weighted Number of Fatal Accidents with Rollover by MHE and Impact Direction

MHE	Impact Direction				Total
	Front/Rear	Side	Non-collision	Unknown	
Truck	100	55	0	2	157
Car	883	319	0	25	1227
Tanker	18	12	12	1	43
Hard Object	148	48	0	11	207
Soft Object	187	73	0	31	291
Non-Fixed	83	45	0	6	134
Train	7	8	0	0	15
Rollover	866	755	1194	47	2862
Fire	119	56	66	5	246
Immersion	23	5	7	0	35
Unknown	113	43	4	5	165
Total	2547	1419	1283	133	5382

Table 8-16 Frequency of Rollover by MHE and Impact Direction (Fatal Accidents)

MHE	Front/Rear	Side	Non-collision
Truck	6.03%	17.19%	na
Car	4.77%	5.97%	na
Tanker	17.31%	38.71%	100.00%
Hard Object	26.10%	38.10%	na
Soft Object	27.38%	42.94%	na
Non-Fixed	3.53%	5.10%	na
Train	8.14%	7.21%	na
Rollover	99.88%	100.00%	100.00%
Fire	26.74%	57.73%	91.67%
Immersion	48.94%	62.50%	46.67%

Table 8-17 Overall Frequency of Rollover by MHE and Accident Reporting Threshold

DPTRA tree	GES-All	GES-Fatal or Tow-away	TIFA	GES-Fatal
Truck (including tanker)	0.97%	2.86%	9.31%	*
Car	0.34%	0.85%	5.09%	*
Hard Object	3.86%	5.72%	28.99%	*
Soft Object	1.37%	1.29%	32.08%	*
Non-Fixed Object	0.00%	*	3.95%	*
Train	0.00%	*	7.50%	*
Rollover	100.00%	100.00%	99.97%	100.00%
Fire	5.68%	8.68%	38.99%	*
Immersion	1.00%	4.03%	49.30%	*

*No cases with the indicated description exist in the 1988-90 GES file.

8.6 Fire Occurrence

Accidents may involve a fire even if the MHE is not coded as fire. The main accident file constructed from TIFA includes a variable that indicates if any vehicle involved in the accident experienced a fire. This variable is used directly to determine fire occurrence. The weighted number of fatal involvements in which a fire occurred are shown in Table 8-18 by MHE and impact direction. The fire occurrence frequencies for a given MHE and impact direction are listed in Table 8-19. These frequencies were calculated as the ratio of the counts listed in Table 8-18 to the count in the corresponding cell of Table 8-5. For six of the ten MHEs, impact direction equal to non-collision is precluded because the event is a collision by definition. These cases are indicated by na (not applicable) in the column listing the frequency of fire given a non-collision. Although fire would seem to be precluded when the MHE is

immersion, this is not the case. Many of the cases in which the MHE is immersion involved ejection of a vehicle occupant into water; the vehicle itself is not immersed and fire is possible.

Table 8-18 Weighted Number of Fatal Accidents with Fire by Impact Direction and MHE

MHE	Impact Direction				
	Front/Rear	Side	Non-collision	Unknown	Total
Truck	306	80	na	1	387
Car	568	98	na	15	681
Tanker	46	15	12	2	75
Hard Object	44	9	na	4	57
Soft Object	51	10	na	7	68
Non-Fixed	41	10	na	0	51
Train	18	16	na	1	35
Rollover	62	42	50	2	156
Fire	445	97	72	17	631
Immersion	3	4	0	0	7
Unknown	40	7	1	1	49
Total	1624	388	135	50	2197

Table 8-19 Frequency of Fire by MHE and Impact Direction (Fatal Accidents)

MHE	Front/Rear	Side	Non-collision
Truck	18.44%	25.00%	na
Car	3.07%	1.83%	na
Tanker	44.23%	48.39%	100.00%
Hard Object	7.76%	7.14%	na
Soft Object	7.47%	5.88%	na
Non-Fixed	1.74%	1.13%	na
Train	20.93%	14.41%	na
Rollover	7.15%	5.56%	4.19%
Fire	100.00%	100.00%	100.00%
Immersion	6.38%	50.00%	0.00%

Table 8-20 lists the overall frequencies of fire occurrence by MHE based on TIFA data and GES data for different accident severity levels (i.e., all, fatal or tow-away, and fatal). The estimates obtained with GES are not reliable since the sample sizes are small or even non-existent (as indicated by an asterisk in Table 8-20) in many of the cells of this two-way distribution, particularly for fatal accidents. TIFA provides a much larger sample size, such that all cells in this two-way distribution are reasonably well-populated. Furthermore, the frequencies of fire occurrence for fatal accidents as obtained from the TIFA data are

considerably greater than those for lower accident reporting thresholds as obtained from GES. This is consistent with the notion that fatal accidents generally impose a more severe environment on the cargo than do towage accidents.

Table 8-20 Overall Frequency of Fire by MHE for Different Accident Reporting Thresholds

DPTRA tree	GES-All	GES-Fatal or Tow-away	TIFA	GES-Fatal
Truck (Including Tanker)	*	*	21.50%	*
Car	0.02%	0.04%	2.82%	0.81%
Hard Object	*	*	7.98%	*
Soft Object	0.02%	*	7.50%	*
Non-Fixed	*	*	1.50%	*
Train	*	*	17.50%	*
Rollover	*	*	5.45%	*
Fire	100.00%	100.00%	100.00%	100.00%
Other Non-Collision	0.89%	*	9.86%	*

*No cases with the indicated description exist in the 1988-90 GES file.

9.0 Discussion and Analysis of Accident Severities

This chapter addresses the severity of collisions, rollovers and fires in transportation accidents. Each of these events may occur separately or in any combination with the other two. The frequencies with which these events occur (separately and in combination) are defined by the factors used to characterize the accident, as described in Chapter 8.

9.1 Collision

Three factors are used to assess collision severity in the DPTRA study: (1) peak contact velocity, which is used to evaluate cargo damage from impact, puncture, and crush, (2) collision energy absorbed by the AT/SST, which is used to determine the extent of damage to the trailer, and (3) the maximum deceleration of the trailer, which is used to evaluate the response of the tie-down system. The collision energy and maximum deceleration depend on the peak contact velocity, as described later in this section. Thus, the collision severity depends only on the type of accident (as characterized by the six factors described in Chapter 8) and the peak contact velocity.

9.1.1 Peak Contact Velocity

The primary metric used to characterize collision severity is the peak contact velocity, which is a measure of the maximum relative velocity (ignoring effects of the tie-down system or other restraint systems) with which the cargo can strike the interior trailer walls. A more detailed discussion of peak contact velocity can be found in Reference 12. The peak contact velocity for a case vehicle involved in a collision is equal to its initial velocity minus the final common velocity, which, based on conservation of momentum, results in the following expression:

$$PCV = \frac{V_r}{1 + M/m} \quad (9-1)$$

where V_r is the relative velocity between the case vehicle and the other vehicle or object involved, M is the effective mass of the case vehicle and m is the effective mass of the other vehicle or object involved. Distributions for peak contact velocity for specific accident types were obtained from analysis of the supplemental TIFA collision severity data and from analysis of the collision severity data generated from the review of Michigan police reported accidents.

Figures 9-1 and 9-2 compare distributions of peak contact velocity for fatal (as obtained from the supplemental TIFA data) and non-fatal tow-away (as obtained from Michigan data) accidents in which the most harmful event was coded as a collision with another medium or heavy truck and in which the most harmful event was a collision with a fixed object, respectively. The upper bound and lower bound estimates were calculated using the high and low estimates, respectively, for the relative velocity in the databases. Note that the likelihood of a peak contact velocity greater than about 10 mph is consistently greater for fatal accidents

than it is for non-fatal, tow-away accidents (i.e., the collision severity of fatal accidents is in general more threatening than that of non-fatal tow-away accidents).

The results shown in Figures 9-1 and 9-2 are based directly on the data files and as such they represent a composite distribution for all vehicles that can be broadly classified as tractor semi-trailers. Obviously, there are significant variations in the tractor, trailer and cargo weights within this broad grouping. For a specific type of vehicle, such as the AT/SST, a better estimate of the distributions of peak contact velocity can be determined by substituting the effective mass of the vehicle of interest for the effective mass of the case vehicle (this is appropriate since the case vehicle is being used as a surrogate for the vehicle of interest). Section 6.1 provides a detailed discussion of how the effective mass of the case vehicle was determined. In essence, the effective mass is determined by identifying the elements of the case vehicle that participate in momentum exchange during the collision. For front/rear (head-on and rear-end) accidents, the effective mass is normally equal to the GCW. For side accidents, it is possible that only the tractor or only the trailer may participate in the momentum exchange depending on the impact location. The effective mass of the AT/SST for a particular case was determined according to which elements of the case vehicle participated in the momentum exchange, as outlined in Table 9-1. Figure 9-3 shows the peak contact velocity distributions obtained by substituting the effective mass of the AT/SST for the effective mass of the case vehicle according to the logic outlined in Table 9-1. The distributions are dependent on the MHE.

The distributions in Figure 9-3 were derived based on the following observations and assumptions:

1. The data for truck and tanker collisions were combined (because the number of records for tanker collisions in the supplemental TIFA data is small) so that the distribution of peak contact velocity is taken to be the same for accidents in which the MHE is coded as collision with a heavy truck or involvement with a tanker. Many of the characteristics of accidents involving heavy trucks and those involving tankers should be similar. The primary reason for differentiating these two types of vehicles in the event tree is that the amount of fuel carried in a tanker represents a much greater fire threat than that posed by an ordinary heavy truck. However, it was assumed that the characteristics of a collision event (i.e., distributions of impact location and peak contact velocity) involving another heavy truck and those of collision event involving a tanker are similar.
2. For cases in which the MHE was coded as collision with one of the three categories of objects considered, only those in which the MHE was collision with a fixed, hard object were selected for the collision severity data collection effort. The distribution of peak contact velocity for cases in which the MHE was collision with a fixed, soft object was assumed to be approximately the same as that for cases in which the MHE is collision with a fixed, hard object. As an approximation, the distribution of peak contact velocity for

cases in which the MHE was coded as collision with a non-fixed object was assumed to be the same as that for cases in which the MHE was coded as collision with a car.

Figure 9-1 Peak Contact Velocity Distributions: Collision with a Medium/Heavy Truck

Figure 9-2 Peak Contact Velocity Distributions: Collision with a Fixed Object

3. Cases in which the MHE was coded as rollover or immersion were not selected for the collision severity data collection effort, and therefore the peak contact velocity is unknown for all of these cases. Therefore, the distribution for peak contact velocity for rollover and immersion was estimated by weighting the distribution for peak contact velocity for truck/tanker, car/non-fixed object, fixed object, and train collisions by the frequencies with which these events occur given that rollover and immersion are the MHE. These weighting factors are listed in Table 9-2. The weighting factors for truck/tanker and car were determined using the data in Table 8-10 directly. The weighting factors for objects and trains were determined from data in Table 8-10 and 8-11. It was assumed that if there was a collision and no other vehicle was involved the collision must have been with an object or a train and that the likelihood of an object or train involvement is in proportion to the frequency with which these events are coded as the MHE. Thus the weighting factor for fixed objects was computed as the product of the frequency that no other vehicle is involved (from Table 8-10) and the ratio of fatal involvements involving a collision in which the MHE was coded as collision with a fixed object and those in which the MHE was coded as either collision with an object or collision with a train (from Table 8-11).
4. Cases in which the MHE was coded as fire were selected for collision severity data collection only if there was a collision involving a heavy truck or fixed object. These cases were selected because they were thought to represent the most severe collisions for cases in which the MHE was coded as fire. Using this data to estimate peak contact velocity distributions would be inappropriate because it does not reflect a properly weighted sample of this class of accidents. Therefore, the peak contact velocity distribution for cases in which the MHE is fire was estimated by weighting the peak contact velocity distribution for truck/tanker, car/non-fixed object, fixed object, and train collisions by the frequencies with which these events occur given that fire is the MHE in the same way as cases in which the MHE was coded as rollover or immersion. The weighting factors for cases in which the MHE is fire are also listed in Table 9-2.
5. The upper bound for peak contact velocity in collisions involving the AT/SST and trucks, tankers, fixed objects, or trains was assumed to be 90 mph even though the maximum value obtained from the data was approximately 80 mph. This assumed upper bound is intended to reflect accidents that could occur (albeit rarely) but have not yet been observed. For collisions between the AT/SST and cars or non-fixed objects the assumed upper bound was 60 mph.

The dependence of the peak contact velocity distributions on other accident characteristics (in addition to MHE) was also investigated. Somewhat surprisingly, the dependence on impact direction was not very significant. Therefore, the final distributions used in the risk assessments were dependent only on MHE as shown in Figure 9-3. By ignoring the apparent secondary dependence of other factors, a larger sample size was obtained, which reduces the uncertainties in the distribution.

Table 9-1 Computation of Effective Mass for the AT/SST

Impact Location	Effective Mass/GCW (Case Vehicle)	Vehicle Element Participating in Momentum Exchange	Effective Mass of AT/SST (lb.)
Tractor	<1	Tractor only	22,300
Tractor	≥1	Tractor and Trailer	60,100
Trailer	<1	Trailer only	37,800
Trailer	≥1	Tractor and Trailer	60,100
Not Tractor and Not Trailer		Tractor and Trailer	60,100
Tractor or Trailer	blank	Tractor and Trailer	60,100

Figure 9-3 AT/SST Peak Contact Velocity Distributions by MHE

Table 9-2 Weighting Factors Used to Construct Peak Contact Velocity Distributions

	Truck/ Tanker	Cars, Non- Fixed Objects	Fixed Objects	Train
Rollover	4.99%	73.81%	18.80%	2.40%
Fire	23.99%	62.51%	11.98%	1.53%
Immersion	5.45%	72.26%	19.76%	2.52%

9.1.2 Collision Energy

The energy absorbed in a collision is a measure of the work done, which is related to the deformation and damage of the vehicles. Based on conservation of momentum and conservation of energy laws and ignoring rebound, which is conservative, the total energy absorbed in a collision, E_a , can be expressed as:

$$E_a = 0.5 \{ M(PCV)^2 + m(pcv)^2 \} \quad (9-2)$$

where M , PCV and m are defined as before and pcv represent the peak contact velocity of the other vehicle or object involved in the collision, which is given by $\frac{V_r}{1 + m/M}$. The fraction of total energy that is absorbed by each vehicle depends on crush characteristics of the vehicles and objects involved and the impact locations. It is assumed that the collision energy absorbed by the AT/SST is:

$$E = 0.5 M(PCV)^2. \quad (9-3)$$

By substituting $pcv = \frac{M}{m} PCV$ into Eqn. 9-2 it can be shown that the fraction of the total collision energy absorbed by the AT/SST is:

$$\frac{E}{E_a} = \frac{m}{M + m}. \quad (9-4)$$

This provides a reasonable estimate if stiffness of a vehicle or object is proportional to its mass. The frame and body of the SST are considerably stronger and stiffer than most semi-trailers with comparable GCWs, so this assumption is certainly conservative when applied to the AT/SST. The appropriateness of this assumption for other makes and models of tractor semi-trailers is not addressed here.

9.1.3 Maximum Deceleration

The response of the tie-down system or other restraint system may depend on the maximum deceleration arising from the collision. The maximum deceleration is strongly dependent on details of the vehicle design, the characteristics of the other vehicle or object involved, the impact direction and the impact location. For the AT/SST, a simple, empirically derived relationship between the maximum deceleration, a_{max} , and the peak contact velocity, PCV , was derived based on crash testing conducted on 1:4-scale models:

$$a_{max} = \frac{2 PCV}{t_d} \quad (9-5)$$

where t_d is the collision duration (i.e., the time elapsed between initial impact and the point at which a final common velocity is reached). For a specific vehicle, the collision duration can be

approximated as a constant given the type of the other vehicle or object involved, the impact direction and the impact location. Collision durations for the AT/SST were derived based on 1:4-scale model crash tests, but the discussion of those results is outside the scope of this report. The applicability of this approach to evaluating maximum deceleration to tractor semi-trailers other than the AT/SST is also not addressed in this report.

9.2 Rollover

For the AT/SST, the primary concern in a rollover event is the possibility of damage to the trailer walls. The maximum acceleration (or deceleration) generated in rollovers is not expected to threaten the functionality of the tie-down system in the SST. As an approximation, damage to the walls of the SST is related to the skid distance. A distribution of skid distance can be estimated using the data on rollover events in Appendix A, as shown in Figure 9-4. A curve fit using an exponential function (i.e., a Weibull distribution) was developed that closely matches the data.

Figure 9-4 Distribution for Skid Distance Associated with Rollover

9.3 Fire

In the DPTRA study, the MELTER computer code [16] was used to analyze the thermal response of cargoes in an SST to fire environments associated with transportation accidents. The fire characteristics that are important in such a simulation include the fire temperature, separation between the fire and the trailer, size, and the fire duration. The fire data collection effort included information that can be used to evaluate these characteristics, directly and/or indirectly. Unfortunately, the fire size and duration could not be determined for most of the cases reviewed, and as a result very little useful data were collected on these characteristics. As a consequence of this lack of data, the distributions for fire size and fire duration were obtained from an analytical simulation, in which the parameters were chosen to provide reasonable agreement with the limited data available. The fire temperature is derived indirectly based on the likely fuel source of fires involved in transportation accidents. Of the four fire characteristics needed, only the fire separation is derived directly and exclusively from the data collected on fatal accidents.

As shown in Table 9-3, fires associated with fatal accidents are more likely to involve the fuel systems and/or cargo than those associated with non-fatal accidents. Since tire and/or brake fires are generally of small size and short duration, they do not normally impose a severe environment on the cargo in the trailer. Therefore, in general terms, fires associated with fatal accidents are expected to be more severe than those associated with non-fatals.

Table 9-3 Distribution of Area Involved (All Accidents Involving Fire)

Area Involved	TIFA		Michigan	
	% of All	% of Knowns	% of Knowns	% of All
Fuel system and not cargo	1.65%	1.76%	0.00%	0.00%
Cargo and not fuel system	5.87%	6.27%	3.13%	1.69%
Fuel system and cargo	84.12%	89.91%	43.75%	23.73%
Tires/brakes only	0.21%	0.23%	34.38%	18.64%
Electrical only	0.07%	0.08%	6.25%	3.39%
Cab only	0.29%	0.31%	9.38%	5.08%
Object struck	0.57%	0.61%	0.00%	0.00%
Other	0.79%	0.84%	3.13%	1.69%
Unknown	6.44%			45.76%

The other conclusion that can be drawn from Table 9-3 is that for fires associated with fatal accidents the fuel of the involved vehicles is almost always involved. This suggests that there is a higher frequency of leakage and dispersion of fuel in fatal accidents, which is again consistent with the notion that collisions and resulting damage to vehicles associated with fatal accidents is more severe than non-fatal accidents. From a practical standpoint, this also suggests that it is not overly conservative to treat all fires associated with fatal accidents as if

they were (hydrocarbon) fuel fires. This is in fact the key assumption adopted in developing the models used to develop distributions for fire temperature, size and duration.

9.3.1 Fire Temperature

In this study, the fire temperature, T , is related to the emissive power of the fire, E_f , by the following expression:

$$E_f = \sigma T^4 \quad (9-6)$$

where σ is the Stefan-Boltzman constant, which is equal to $5.67 \times 10^{-8} \text{ W/m}^2\text{-K}^4$. The fire temperature depends on the fuel source, location of the object being heated relative to the fire, atmospheric conditions and other factors. As discussed previously, the fuel source for all fires associated with fatal accidents is assumed to be a liquid or gas hydrocarbon. Two cases are considered with respect to the location of the object being heated: (1) engulfed (in the fire) and (2) out of the fire.

Figure 9-5 shows distributions of fire temperature obtained from References 2 and 17. Reference 17 actually provides probability estimates at just a few discrete temperatures; the curve fit was developed separately.²⁰ These distributions are applicable when the object being heated is in the fire. In the DPTRA study, the curve fit to the data obtained from Reference 17 was used since the data in Reference 17 are based on actual measurements of temperatures for a number of different fuel fires. The variation in fire temperature is due to the type of fuel, atmospheric conditions, and other factors.

When the object being heated is out of the fire, the emissive power of the fire is reduced due to the effects of smoke and soot. Reference 18 provides a correlation between the emissive power of the fire, E_f , in W/m^2 and the diameter of the fire, d , in ft:

$$E_f = E_m e^{-Sd} + E_s (1 - e^{-Sd}) \quad (9-7)$$

where E_m is the emissive power of the luminous spots (equal to 140 kW/m^2), E_s is the emissive power of the smoke (equal to 20 kW/m^2), and S is an empirical coefficient (equal to 0.12 m^{-1}). Eqns. 9-6 and 9-7 can be used to solve for T in terms of d ; the result is shown in Figure 9-6. This correlation was used in the DPTRA study if the object being heated is out of the fire.

²⁰personal communication with M. K. Fuentes, May 4, 1994.

Figure 9-5 Distribution for Fire Temperature--Object Being Heated is In the Fire

Figure 9-6 Fire Temperature vs. Fire Diameter--Object Being Heated is Out of the Fire

9.3.2 Fire Separation

The fire separation is the closest distance between the outer perimeter of the fire and any surface of the trailer of the case vehicle. Distributions for the fire separation category and the separation distance were developed directly from the TIFA fire severity file.²¹ For cases involving multiple sources, only the fire with the shortest standoff was included in the data used to determine the distribution. The MHE was determined by linking the TIFA fire severity file and the main accident file constructed from TIFA. Table 9-4 shows the frequency of each separation category by MHE for fatal accidents. Figure 9-7 shows distributions of separation distance (both upper bound and lower bound estimates) by MHE given that the separation category is standoff. In the DPTRA study, the lower bound estimates for separation distance were used, which is a conservative approach since the threat posed by a fire is greatest when the separation is small.

Table 9-4 Frequency of Separation Category by MHE (Fatal Accidents)

Separation Category	MHE				
	Truck Tanker	Car	Objects	Train	Rollover/ Fire/Immersion
Engulfed	56.52%	86.60%	87.21%	75.00%	92.49%
Standoff	43.48%	13.40%	12.79%	25.00%	7.51%

9.3.3 Fire Size

Because fire size is rarely characterized in accident reports, an analytical simulation was developed to determine fire size distributions. The analytical model is a blend of pool and spill models. Certain parameters of the model were tuned using the limited accident data that were available. The uncertainty in the accident data on fire size is significant and can be accounted for by modeling uncertainty in the parameters of the analytical model. Information on the range of values for the tuned parameters that would be appropriate in an uncertainty assessment can be found in Appendix D. In this section, first the derivation of the analytical model and then a comparison of the analytical model with accident data is described.

For both pool and spill models, the fire can be represented as a right circular cylinder. Reference 19 documents several correlations that can be used to estimate the fire's height. For the DPTRA study, the height of the fire is taken to be three times its diameter, which is conservative.

²¹The Michigan Fire Severity File does not include a significant number of cases for which the separation category, standoff, surface area and fire duration are known. Therefore meaningful comparisons of fire separation, size and duration for fatal (TIFA) and non-fatal accidents (Michigan) cannot be made.

Figure 9-7 Distributions for Separation Distance by MHE

For pool fires, Reference 4 provides distributions for fire size that are dependent on the other vehicle involved in the accident, as indicated below:

Medium or heavy truck--fire size is uniformly distributed between 40 and 200 ft²:

$$P_1(A_p) = (A_p - 40)/160, \quad 40 \leq A_p \leq 200 \quad (9-8)$$

Light truck or auto--fire size is uniformly distributed between 25 and 125 ft²:

$$P_2(A_p) = (A_p - 25)/100, \quad 25 \leq A_p \leq 125 \quad (9-9)$$

Tanker--fire size is uniformly distributed between 50 and 500 ft²:

$$P_3(A_p) = (A_p - 50)/450, \quad 50 \leq A_p \leq 500 \quad (9-10)$$

No other vehicles--fire size is uniformly distributed between 25 and 125 ft²:

$$P_4(A_p) = (A_p - 25)/100, \quad 25 \leq A_p \leq 125 \quad (9-11)$$

Train--fire size is Weibull distributed between 500 and 1000 ft²:

$$P_5(A_p) = 1 - e^{-\left(\frac{A_p - 500}{252}\right)^{1.6}}, \quad 500 \leq A_p \leq 1000 \quad (9-12)$$

In Eqns. 9-8 through 9-12, A_p is the surface area of the pool fire in ft² and $P_i(A_p)$ is the probability that the size of the fire is less than or equal to A_p given that the other vehicle involved corresponds to that associated with index i .

The model for spill fires was developed by Marv Larsen based in part on Reference 20. The following description of spill fires borrows liberally from a quarterly progress report prepared by Larsen.²²

As a liquid fuel first begins to drain out, the rate at which the fuel burns is less than the spill rate. As a result, the fire spreads along the surface onto which it is spilled. Given a constant spill rate on a flat surface and assuming a constant fuel surface recession (burn) rate, there results an equilibrium fire size which has just enough surface area to consume the supplied fuel. That is:

$$Q = \pi R^2 \dot{y}, \quad (9-13)$$

²²M. E. Larsen, "2nd-1/2 Quarterly Report (Contract 18-8453): Sandia Risk Assessment," South Dakota School of Mines and Technology, March 5, 1992.

where Q is the spill rate, R is the diameter of the fire and $\dot{y}$ is the fuel surface recession rate. Rearranging Eqn. 9-13 to solve for R results in:

$$R = \sqrt{\frac{Q}{\pi \dot{y}}}. \quad (9-14)$$

The spill is idealized as an opening at the bottom of a tank. If the tank is vented to the atmosphere, the Bernoulli Equation can be used to define the spill rate:

$$Q = A_l v = A_l \sqrt{2gh}, \quad (9-15)$$

where A_l is the cross-sectional area of the opening through which the fuel spills (hereafter referred to as the leak area), v is the velocity of the fuel through the opening, g is the acceleration due to gravity, and h is the height of the free surface of the fuel above the opening, which is clearly a function of time. The spill rate can also be related to the time rate of change in the volume of fuel in the tank:

$$Q = -\frac{dV}{dt} = -A_l \frac{dh}{dt}, \quad (9-16)$$

where V is the volume of fuel in the tank, t is time, and A_l is the cross-sectional area of the tank (assumed to be constant). Equating the right hand sides of Eqns. 9-15 and 9-16, rearranging to permit integration by separation of variables, and integrating over the time necessary to completely drain the tank leads to:

$$\int_{h_0}^0 \frac{dh}{\sqrt{h}} = \sqrt{2g} \frac{A_l}{A_t} \int_0^{t_b} dt \quad (9-17)$$

where h_0 is the initial fuel height in the tank and t_b is the time required to completely burn the fuel (which is equal to the time it takes to completely drain the tank). Completing the integration and solving for t_b results in:

$$t_b = \frac{A_t}{A_l} \sqrt{\frac{2h_0}{g}} \quad (9-18)$$

Eqn. 9-18 can be simplified further for tanks of particular shapes. For example,

$$t_b = \frac{1.358V^{5/6}}{A_l \sqrt{g}} \quad (9-19)$$

for right circular cylinders of equal height and diameter (axis vertically aligned) and

$$t_b = \frac{\sqrt{2}V^{5/6}}{A_l \sqrt{g}} \quad (9-20)$$

for cubes. These examples suggest that the influence of tank geometry is relatively minor, and therefore Eqn. 9-20 is used to represent all tank geometries. The time-averaged spill rate, $\bar{Q}$, is given by:

$$\bar{Q} = V/t_b \quad (9-21)$$

Combining Eqns. 9-14, 9-20, and 9-21 leads to the following result for the time-averaged surface area associated with a spill fire:

$$\bar{A}_s = \frac{V^{1/6} A_l \sqrt{g}}{\sqrt{2} \dot{y}} \quad (9-22)$$

$\bar{A}_s$ is used to approximate the surface area associated with a spill fire (i.e., the variation of the area with time not considered). The acceleration due to gravity, g , and the fuel surface recession rate, $\dot{y}$, are treated as constants in Eqn. 9-22. The fuel surface recession rate is taken to be 0.16 in/min.²³ The volume of fuel, V , and the leak area, A_l , are treated as random variables with distributions that depend on the other vehicle involved. Given distributions for V and A_l , distributions for $\bar{A}_s$ can be obtained using a Monte Carlo simulation. Note that the correlation between $\bar{A}_s$ and V is relatively weak.

The distributions of V are based on Reference 3. The distributions of V when the other vehicle involved is a car, tanker, none and train are identical to those labeled car, tanker, single vehicle and train, respectively, in Reference 3. The distribution used for MHE equal to truck was modified from the corresponding distribution in Reference 3 to represent larger fuel tank capacities and the effect of combustible cargoes in the other truck.²⁴ The resulting distributions for volume of fuel are:

Medium or heavy truck:

$$P_1(V) = 1 - e^{-\left(\frac{V-50}{500}\right)^{0.8}}, \quad V \geq 50 \quad (9-23)$$

²³The fuel surface recession rate may vary depending on type of fuel, size of the fire, temperature of the fire, and ambient conditions, but the rate is typically between about 0.14 and 0.18 in/min for fires with diameters greater than 3-4 ft (see Figure 1 of Reference 19). This variability is considered relatively small and is neglected in the models developed in this report.

²⁴It is assumed that the cargo in the vehicle of interest is not flammable, and thus the correction for the combustible cargo is only necessary in the case where the vehicle of interest is involved with another medium or heavy duty truck.

Light truck or auto:

$$P_2(V) = 1 - e^{-\left(\frac{V}{166}\right)^{3.73}}, \quad V \geq 0 \quad (9-24)$$

Tanker:

$$P_3(V) = 1 - e^{-\left(\frac{V}{5718}\right)^{2.73}}, \quad V \geq 0 \quad (9-25)$$

No other vehicles:

$$P_4(V) = 1 - e^{-\left(\frac{V}{132}\right)^{3.68}}, \quad V \geq 0 \quad (9-26)$$

Train:

$$P_5(V) = 1 - e^{-\left(\frac{V-1000}{1415}\right)^{1.06}}, \quad V \geq 1000 \quad (9-27)$$

In Eqns. 9-23 through 9-27, V is the volume of fuel in gallons and $P_i(V)$ is the probability that the volume of fuel is less than or equal to V given that the other vehicle involved corresponds to that associated with index i .

Neither accident data nor analytical models that can be used to directly determine A_i exist. Therefore, Weibull distributions of A_i that depend on the other type of vehicle²⁵ are assumed; the parameters of these distributions were adjusted (within reasonable bounds) so that the resulting distribution of surface areas of fires was comparable to the limited accident data available on surface areas of fires. The procedure used to compare distributions is described shortly. The resulting distributions for leak area are:

Medium or heavy truck:

$$P_1(A_i) = 1 - e^{-\left(\frac{A_i - 0.1}{6}\right)^4}, \quad A_i \geq 0. \quad (9-28)$$

Light truck or auto:

$$P_2(A_i) = 1 - e^{-\left(\frac{A_i - 0.1}{5}\right)^4}, \quad A_i \geq 0. \quad (9-29)$$

²⁵Intuitively, the leak area depends on the collision severity, which in turns depends in part on the other vehicle involved. To maintain consistency with the distributions used to describe surface area for pool fires and the volume of fuel, A_i was also assumed to depend only on the other vehicle involved, although in fact it may be correlated with other measures of collision severity (such as peak contact velocity) as well.

Tanker:

$$P_3(A_i) = 1 - e^{-\left(\frac{A_i - 4}{10}\right)^4}, \quad A_i \geq 4 \quad (9-30)$$

No other vehicles:

$$P_4(A_i) = 1 - e^{-\left(\frac{A_i - 0.1}{5}\right)^4}, \quad A_i \geq 0. \quad (9-31)$$

Train:

$$P_5(A_i) = 1 - e^{-\left(\frac{A_i - 2}{8}\right)^4}, \quad A_i \geq 2 \quad (9-32)$$

In Eqns. 9-28 through 9-32, A_i is the leak area in in^2 and $P_i(A_i)$ is the probability that the leak area is less than or equal to A_i given that the other vehicle involved corresponds to that associated with index i .

Final distributions for surface area of fires are obtained from the combination of the pool and spill fire models as:

$$P_i(A) = w_p P_i(A_p = A) + w_s P_i(\overline{A}_s = A); \quad (9-33)$$

these distributions are dependent on the other vehicle involved as indicated by the index i . The pool and spill fire models are weighted by the factors w_p and w_s , respectively. These weights were adjusted (within reasonable bounds) so that the resulting distribution of surface areas of fires was comparable to the limited accident data available on surface areas of fires. The values adopted in this study are $w_p=0.8$ and $w_s=0.2$.

The distributions for the size of the fire resulting from a Monte Carlo simulation based on the approach outlined above are shown in Figure 9-8. In this figure, the size of the fire is expressed in terms of its diameter, which is equal to $\sqrt{4A/\pi}$. The distributions in Figure 9-8 are shown in terms of the MHE instead of the other vehicle involved. The relationship between the distributions in terms of the indicated MHE and the distribution in terms of the other vehicle involved are as follows:

1. The distributions for fire size when the MHE is (1) collision with a medium or heavy truck, (2) collision with a light truck or auto, (3) involvement with a tanker, (4) collision with any object, and (5) collision with a train are identical to those when the other vehicle involved is a (1) truck, (2) car, (3) tanker, (4) none, and (5) train, respectively.
2. The distributions for fire size when the MHE is rollover, fire or immersion were obtained by weighting the distributions for fire size when the MHE is truck, car, tanker, objects or train by the factors given in Table 9-5. The factors in Table 9-5 were obtained from consideration of the distribution of other vehicle involved by MHE given a fire occurrence,

which is shown in Table 9-6. The weighting factors for truck, cars, and tankers were determined using the data in Table 9-6 directly. It was assumed that if the other vehicle involved was coded as none, that either an object or train was involved and that the likelihood of an object or train involvement is in proportion to the frequency with which these events are coded as the MHE given a fire. Thus, the weighting factor for objects was computed as the product of the frequency that no other vehicle is involved (as determined from Table 9-6) and the ratio of fatal involvements in which the MHE was coded as collision with an object and those in which the MHE was coded as either collision with an object or collision with a train (from Table 8-18).

Table 9-5 Weighting Factors Used to Construct Distributions

	Truck	Cars	Tanker	Objects	Train
Rollover	6.41%	26.28%	0.64%	55.61%	11.06%
Fire	19.49%	32.96%	1.90%	38.07%	7.57%
Immersion	14.29%	57.14%	0.00%	23.83%	4.74%

Figure 9-8 Fire Size Distributions

Table 9-6 Distribution of Fatal Involvements by Other Vehicle Involved and MHE Given a Fire Occurrence

MHE	Other Vehicle Involved			
	None	Truck	Car	Tanker
Rollover	104	10	41	1
Fire	288	123	208	12
Immersion	2	1	4	0

The validity of these analytical simulations can be judged against accident data. Unfortunately, the number of accidents in the TIFA supplemental database for which the surface area of the fire is known is rather limited. Because of this limitation, distributions for fire size that depend on the other vehicle involved cannot be developed. Therefore, only the overall distributions for the surface area of fires can be compared. Distributions for both the lower bound and upper bound estimates of fire surface area as given in the TIFA supplemental data file are compared to a weighted distribution of fire surface areas based on the Monte Carlo simulation in Figure 9-9. The weighted distribution for the analytical model is obtained as:

$$P(A) = \sum_i K_i P_i(A) \quad (9-34)$$

where K_i are weighting factors that apply to the probability that the other vehicle involved corresponds to that associated with the index i . In order to provide a valid comparison, the K_i are based on the distribution of other vehicle involved for those accidents for which the surface area of the fire is not unknown. The K_i are 0.35, 0.47, 0.02, 0.14 and 0.02, for $i=1-5$ (truck, car, tanker, none, train), respectively. Comparison of the results in Figure 9-9 suggests that the choice of distributions for the leak areas associated with spill fires and the weighting factors applied to the pool and spill fire models are appropriate and valid. Additional support for this conclusion can be obtained by comparing the available accident data for fire duration with the analytical simulation, which is done in the next section. The sensitivity of the analytical simulation to the weighting factors applied to the pool and spill models and to the distributions for leak area associated with spill fires is described further in Appendix D. As mentioned previously, this sensitivity analysis can be used to develop distributions of the tuned parameters that can be used in an uncertainty assessment.

9.3.4 Fire Duration

The time necessary to completely burn all fuel, t_b , is:

$$t_b = \frac{V}{A\dot{y}} \quad (9-35)$$

where V is the volume of fuel, A is the surface area of the fire, and $\dot{y}$ is the fuel surface recession rate. The fuel surface recession rate is taken to be 0.16 in/min, just as it is in

Eqn 9-22. As described in the previous section, V and A are defined by distributions that depend on the other vehicle involved. Thus, distributions of t_b that also depend on the other vehicle involved, $P_i(t_b)$, can be determined from a Monte Carlo simulation. Although A is weakly dependent on V , this correlation was ignored in the Monte Carlo simulation used to develop distributions of t_b .

In this study, the time to completely burn all fuel, t_b , is used as an approximate measure of the fire duration. In previous studies, distributions of fire duration were developed based on the time to completely burn all fuel, but an adjustment was made to account for the effects of fire-fighting efforts [2-4]. The effects of fire-fighting were considered in this study. Models of fire-fighting based on Reference 4 were developed, but since the effect of including fire-fighting in the analytical model on the overall distribution for fire duration is not very significant, especially in comparison with the uncertainty in the accident data, the additional complexity associated with including the effects of fire-fighting in the analytical model was not warranted. Thus, the analytical simulation for fire duration in this study does not incorporate the effects of fire-fighting, which tends to give a conservative result.

Figures 9-10 through 9-14 show distributions for fire duration based on a Monte Carlo simulation for t_b for accidents in which the other vehicle involved is a truck, car, tanker, object, and tanker, respectively. Each figure includes a set of curves that represent distributions for specific values of fire diameter.

Figure 9-9 Comparison of Distributions for Fire Surface Area--Simulation vs. Accident Data

Figure 9-10 Fire Duration Distributions (Other Vehicle Involved is Truck)

Figure 9-11 Fire Duration Distributions (Other Vehicle Involved is Car)

Figure 9-13 Fire Duration Distributions (No Other Vehicle Involved)

Figure 9-12 Fire Duration Distributions (Other Vehicle Involved is Tanker)

Figure 9-14 Fire Duration Distributions (Other Vehicle Involved is Train)

The validity of these analytical simulations can be judged against accident data. Unfortunately, the number of accidents in the TIFA supplemental database for which the duration of the fire is known is very limited. Because of this limitation, distributions for fire duration that depend on the other vehicle involved cannot be developed based on the accident data. Therefore, only the overall distributions for the duration of fires can be compared. Distributions for both the lower bound and upper bound estimates of fire duration as given in the TIFA supplemental data file are compared to a weighted distribution of fire durations based on the Monte Carlo simulation in Figure 9-15. The weighted distribution for the analytical model is obtained as:

$$P(t) = \sum_i K_i P_i(t_b) \quad (9-36)$$

where K_i are weighting factors that apply to the probability that the other vehicle involved corresponds to that associated with the index i . In order to provide a valid comparison, the K_i are based on the distribution of other vehicle involved for those accidents for which the duration of the fire is not unknown. The K_i are 0.33, 0.31, 0, 0.30 and 0.06, for $i=1-5$ (truck, car, tanker, none, train), respectively. Comparison of the results in Figure 9-15 in conjunction with those in Figure 9-9 suggests that the choice of distributions for the leak areas associated with spill fires and the weighting factors applied to the pool and spill fire models are appropriate and valid.

Figure 9-15 Comparison of Distributions for Fire Duration--Simulation vs. Accident Data

As indicated in Figure 9-15, the maximum observed fire duration from TIFA cases between 1984 and 1988 was 240 minutes. Preliminary results from the on-going data collection described in Appendix C include an accident involving a fire that had a duration of 480 minutes. Based on Eqn. 9-35, the maximum theoretical fire duration is approximately thirty-three hours. The maximum theoretical duration results from an accident involving a tanker with 10000 gallons of fuel concentrated in a small pool (surface area of 50 ft²). This scenario is obviously very unlikely as it requires either a very slow spill or an unrealistic pool depth (over 25 ft).

10.0 Application of Accident Data in Risk Assessment

From the description and review of existing data sources in Chapter 4, it is clear that the TIFA file provides the best match with the risk assessment requirements. TIFA, since it includes the FARS accident level variables and extensive physical detail collected by telephone interviews, contains most of the variables and code levels necessary to support the a detailed description of accident types. In addition, police reports were available for 1984-1988 TIFA cases, which were used to obtain additional information on accident severity.

The primary drawback to TIFA is that it is limited to fatal accidents. This limitation does not affect the utility of the TIFA file or the TIFA supplemental data in terms of describing the distribution of accident types and accident severities. As shown in Chapter 8, the distribution of accident types based on fatal accidents from the TIFA file is generally comparable to that based on tow-away accidents based on the GES file. The discussion in Chapter 9 demonstrated that, in general, fatal accidents pose a greater threat to hazardous cargoes than non-fatal accidents. However, a risk assessment based only on fatal accidents may not be comprehensive; i.e., it may be possible for some accidents that do not involve a fatality to pose a threat to hazardous cargoes. While fatal accidents typically involve collisions at high speeds, and so are of primary interest in evaluating threats to the integrity of the AT/SST, an analysis limited to fatal accidents may not encompass all the accidents of interest.

By contrast, any accident that could pose a threat to the containment of hazardous cargoes is almost certain to involve a tow-away of at least one vehicle or a fatality. However, the data on types and severities of accidents involving a tow-away or fatality (hereafter referred to as tow-away accidents) is not as detailed or comprehensive as that for fatal accidents.

In DPTRA, these concerns were addressed by basing the overall accident rate on tow-away accidents and considering the fraction of tow-away accidents with severities comparable to fatals. The distribution of accident types and severities based on TIFA and TIFA supplemental data is appropriately used with the product of the overall tow-away accident rate and the fraction of tow-away accidents with severities comparable to fatals. This approach provides consideration of all accidents that could pose a threat to the containment of hazardous cargoes and a detailed characterization of accident types and severities.

The GES file provides information that can be used to estimate the percent of tow-away accidents that have severities comparable to fatal accidents. The estimates are approximate and subject to large uncertainties.

The number of heavy truck accident records in the GES file is somewhat limited but it does include accidents ranging from minor property damage to tow-away accidents to fatalities. The GES database includes fields that describe the maximum injury severity, the damage severity and whether or not a vehicle was towed. For tow-away accidents involving a tractor semi-trailer, the distribution of accidents by damage severity and injury severity based on GES data is shown in Table 10-1. Columns 2-5 list the percentages of all accidents that have a

maximum injury severity as indicated by the corresponding row in column 1 that also have the indicated damage severity. By contrast, column 6 lists the percentage of all tow-away accidents that have the indicated maximum injury severity. Comparison of rows 3 and 5 for columns 2-5 of Table 10-1 indicates that fatal accidents are more severe than tow-away accidents in general. This observation is also supported by comparisons of the severities of non-fatal accidents based on police reported accidents from the state of Michigan and fatal accidents based on TIFA, as discussed in Chapter 9. Unfortunately, the damage severity categories are somewhat ambiguous. In particular, the most severe category (disabling) may include anything from radiator damage to total demolition of the vehicle.

Table 10-1 Distribution of Tow-Away Accidents by Injury Severity and Damage Severity

Maximum Injury Severity	Damage Severity				Any
	None	Minor	Functional	Disabling	
No Injury	12.63%	37.78%	23.41%	26.19%	46.13%
Injury	8.86%	36.86%	24.90%	29.39%	49.06%
Fatality	2.72%	17.51%	23.05%	56.72%	4.35%
Other	0.00%	58.28%	36.82%	4.90%	0.47%
Any	10.20%	36.47%	24.21%	29.12%	100.00%

Two approaches were considered for estimating the percentage of tow-away accidents that have severities comparable to fatalities. The first approach assumes that the severity of accidents that do not result in a fatality is substantially lower than the severity of fatal accidents and that non-fatal accidents do not pose a threat to the containment of hazardous cargoes. As can be seen from Table 10-1, 4.35% of tow-away accidents also involve a fatality. The second approach is based on excluding an appropriate percentage of tow-aways such that the distribution of damage severity for fatalities is replicated. This can be accomplished by screening out 86.35% of tow-aways involving no damage, 75.45% of those with minor damage, and 51.33% of those with functional damage (retaining all those that are disabling). The net result is that by retaining 51.25% of tow-aways, the distribution of damage severity for fatalities can be matched. The damage levels used in the GES file are somewhat ambiguous and disabling accidents for tow-away accidents may or may not be nearly as severe, in general, as those for fatal accidents. Thus, the two approaches described represent a lower and upper bound estimate, respectively, for the fraction of tow-aways with severities comparable to fatalities.

11.0 Summary

This report provides distributions of the types and severities of accidents involving tractor semi-trailers that can be used in risk assessments for transportation of hazardous cargoes. The primary data are based on traffic accidents involving at least one fatality. The information presented in this report was specifically developed to support a probabilistic assessment of the risk of transporting certain radioactive materials in the AT/SST for the DOE, but application to other carriers and other types of hazardous cargoes may be possible if appropriate adjustments are made in the data.

Distributions of accident types as defined by the types of vehicles and/or other objects involved, collision occurrence, angle of impact, location of principal impact, rollover occurrence and fire occurrence are described in Chapter 8. Distributions of peak contact velocity, skid distance, fire temperature, fire size, fire separation, and fire duration were developed to define the severity of the accident, as discussed in Chapter 9. The report also includes a discussion of the application of this data in risk assessments for transportation of hazardous cargoes in Chapter 10.

--This page left almost blank intentionally--

12.0 References

- [1] J. S. Phillips, D. B. Clauss and D. F. Blower, "Determination of Influence Factors and Accident Rates for the Armored Tractor/Safe Secure Trailer," SAND93-0111, Sandia National Laboratories, Albuquerque, New Mexico, June 1993, DRAFT.
- [2] L. E. Fischer et al., "Shipping Container Response to Severe Highway and Railway Accident Conditions," NUREG/CR-4829, UCID-20733, Lawrence Livermore National Laboratories, February 1987.
- [3] A. W. Dennis, J. T. Foley, W. F. Hartman and D. W. Larson, "Severities of Transportation Accidents Involving Large Packages," SAND77-0001, Sandia National Laboratories, Albuquerque, New Mexico, May 1978.
- [4] R. K. Clarke, J. T. Foley, W. F. Hartman and D. W. Larson, "Severities of Transportation Accidents," SLA-74-0001, Sandia Laboratories, Albuquerque, New Mexico, July 1976.
- [5] National Center for Statistics and Analysis, "National Accident Sampling System (NASS), Crashworthiness Data Subsystem, Analytical User's Manual," 1989.
- [6] "Office of Motor Carriers, 1987, Codebook," Transportation Data Center, University of Michigan Transportation Research Institute, Number 89-19, September, 1989.
- [7] K. P. Sullivan and D. L. Massie, "Trucks Involved In Fatal Accidents, 1990 Factbook," UMTRI-93-1, University of Michigan Transportation Research Institute, April 1993.
- [8] "Fatal Accident Reporting System, 1990, Codebook, Version 197," Transportation Data Center, University of Michigan Transportation Research Institute, Number 91-10, August 1991.
- [9] "General Estimates System 1989, A Review of Information on Police-Reported Traffic Crashes in the United States," DOT-HS-807-665, U.S. Department of Transportation, National Highway Traffic Safety Administration, December 1990.
- [10] "Michigan Codebook, 1990," Transportation Data Center, University of Michigan Transportation Research Institute, Number 91-6, June 1991.
- [11] L. B. Fricke, "Traffic Accident Reconstruction," Northwestern University Traffic Institute, 1990.
- [12] J. F. Marquardt, "Vehicle and Occupant Factors that Determine Occupant Injury," Society of Automotive Engineers, Automotive Engineering Congress, Detroit, MI, February 25-March 1, 1974.

- [13] J. D. McClure et al., "Relative Response of Type B Packagings to Regulatory and Other Impact Test Environments," Proceedings of the 6th International Conference on Packaging and Transportation of Radioactive Materials, pp 1247-1253, Berlin, Germany, November 10-14, 1980.
- [14] K. P. Sullivan, D. Blower, L. Pettis, "Trucks Involved In Fatal Accidents, Codebook 1989" UMTRI-92-10, University of Michigan Transportation Research Institute, February 1992.
- [15] "NASS General Estimate System 1989 Codebook - Version 120390," Transportation Data Center, University of Michigan Transportation Research Institute, Number 91-2, February 1991.
- [16] M. E. Larsen, "MELTER: A Model of the Thermal Response of Cargoes Transported in the Safe-Secure Trailer Subject to Fire Environments for Risk Assessment Applications," SAND93-0737, Sandia National Laboratories, September, 1993, DRAFT.
- [17] D. R. Stephens, "Fire Resistant Pits: Reducing the Probability of Accidental Plutonium Dispersal from Fuel Fires," UCRL-ID-110556, Lawrence Livermore National Laboratory, March 1992.
- [18] National Fire Protection Association, "The SFPE Handbook for Fire Protection Engineering," 1st edition, P. J. Dinunno, ed., SFPE 8-88.
- [19] K. S. Mudan, "Thermal Radiation Hazards from Hydrocarbon Pool Fires," Prog. Energy Combust. Sci., 10, pp. 59-80, 1984.
- [20] J. A. Mansfield and L. J. Linley, "Measurement and Statistical Analysis of Flame Temperatures from Large Fuel Spill Fires," Naval Weapons Center Technical Publication 7061, Naval Weapons Center, China Lake, CA, January 1991.

Appendix A: Supplemental Data for Rollover Accidents

Table A-1 lists data taken from approximately 100 police accident reports for accidents in which rollover was the MHE. YR denotes the calendar year in which the accident occurred; ST is a two-digit code for the state in which the accident occurred; CASE corresponds to the FARS case number; VEH denotes the FARS vehicle number; QT is the number of quarter-turns experienced by the *trailer*; SD/A is the actual skid distance measured by the investigating officer or taken off a police diagram determined to be to scale; SD/E is an estimated value of the skid distance determined from a diagram without an accurate scale; Comments notes any other event(s) that occurred during the accident. Finally, note that 99 indicates that a value is unknown.

Table A-1 Rollover Accident Data

YR	ST	Case	Veh	QT	SD/A	SD/E	Comments
84	6	248	1	2	122		none
84	6	369	1	4	0		none
84	6	388	1	1	0		slid along guardrail, went thru, fell 40' onto concrete
84	6	750	1	1		20-40	none
84	6	1207	2	1		40-60	collision w/auto caused overturn
84	6	1951	1	2	75		hit guardrail and turned on side
84	6	2652	1	1	6		hit tree and turned on side
84	6	2784	1	2	110		slid down 30° incline
84	6	2925	1	1	0		blown tire, ran off road, tipped over after stopping
84	6	3600	1	1		10-25	hit road sign, ran off road
85	6	197	1	2	293		trailer slid 75' on one side, then 218' on its top
85	6	535	1	1	58		trailer slid on its side into guardrail
85	6	1685	1	2		50-100	damaged guardrail
85	6	1884	1	4+	450		went thru guardrail and rolled down embankment
85	6	1956	1	2		50-75	slid on top
85	6	2799	1	1		10-20	hit large boulder
85	6	2864	1	1		50-150	hit bull/cow in road, ran off road
85	6	3182	1	2		10-25	hit parked auto at 55 mph
85	6	3348	1	1	25		hit guardrail, sign, and divider
85	6	3519	1	1		10-25	slight glance off another truck, then thru guardrail
85	6	3810	1	1		10-25	trailer just spun around in a circle and fell over
85	6	3851	1	2		10-25	side swiped parked truck
85	6	3948	2	1	50		fell off bridge 50 feet onto side
85	6	4098	1	1		150-175	hit auto, overturned onto it, then slid off road
87	6	1537	1	2	181		hit concrete support
87	6	2038	1	1		100	none
87	6	2185		1		100-150	rear-ended auto, rear-ended truck, rolled over on car
87	6	2185	4	1		50-100	trailer burned
87	6	2292	1	2		55	hit wooden power pole and barbed-wire fence
87	6	2424	2	1	114		minor impact with auto
87	6	2573	1	1		250-300	hit guardrail and slid to stop
87	6	2848	1	1		0-20	none (slid in soft sand)

Table A-1 (continued)

YR	ST	Case	Veh	QT	SD/A	SD/E	Comments
87	6	3371	1	2		50	rear-ended auto
87	6	4132	1	1		0-50	bounced off rock embankment and overturned
87	6	4403	1	1		10-15	fell over while rounding curve
87	6	4452	1	1	100		trailer hit wood and steel guardrail and flipped
87	9	248	1	1	100		tractor hit guardrail causing rollover
87	12	13	1	1		10-20	ran off road and overturned
87	12	409	2	1		25-50	hit auto
87	12	603	1	3		10-50	ran off road
87	12	1281	1	1		10-20	turned over while exiting freeway
87	12	1322	2	2		10-15	rear-ended auto, hit fence, and overturned
87	12	1413	1	1	235		ran off road
87	22	201	1	1		150-200	drove over trailer in road; hit trees
87	22	319	1	1		9999	head-on side-swipe with heavy truck
87	22	406	1	1		100	hit fence
87	22	442	1	1		0-50	rear-ended car, then hit heavy truck at 45°
87	22	633	1	2	45		none
87	24	289	1	1		50-100	hit embankment, signpost, guardrail
87	24	348	1	1		0-50	none
87	24	373	1	1		0-50	glanced off side of auto, hit guardrail, and turned
87	48	1979	1	1		0-50	guardrail stopped vehicle
87	48	2550	1	1		0-20	stopped after collision with concrete canal
87	48	2829	1	1		50-100	slid into car while on its side
88	6	163	1	1		75-100	none
88	6	554	1	1	220		none
88	6	1529	1	2		50	none
88	6	1742	1	1	151		struck auto head-on
88	6	1900	1	99	80		hit guardrail and slid down embankment
88	6	2294	1	2	40		40' plunge (45° slide) down ravine
88	6	3679	2	1	186		glancing blow with auto
88	12	207	1	1		25-50	glancing blow with rear end of auto
88	12	251	2	1		50-100	glancing blow with auto
88	12	296	2	1		50-100	glancing blow with auto
88	12	525	1	2	415		none
88	12	2458	2	1	205		impact with auto
88	12	2699	1	1		10-50	none
88	18	75	1	2		50-100	hit ditch causing rollover
88	18	532	1	2	213		hit signs and flipped
88	18	538	1	2		0-5	ran off road, hit signs, lost control
88	18	610	1	2		100-200	truck rear-ended a U-haul
88	18	725	1	2	157		ran off road and rolled over
88	18	756	1	1	64		rolled over trying to make turn
88	24	498	1	1		0-50	none
88	24	541	2	1		100-200	hit auto and guardrail
88	32	20	1	1	76		hit several signs and overturned
88	32	215	1	1	114		hit horse
88	47	252	1	2	240		hit embankment and overturned
88	47	281	1	1		0-50	hit trees

Table A-1 (continued)

YR	ST	Case	Veh	QT	SD/A	SD/E	Comments
88	47	347	1	1	20		hit trees
88	47	398	1	1	76		hit guardrail, rolled once, slid 74' and rolled again
88	47	414	1	1		50-100	hit guardrail
88	47	467	1	1	34		none
88	48	505	1	3		0-50	none
88	48	1053	1	1	100		broke through guardrail and fell 20 ft onto concrete
88	48	1125	1	3		25-50	none
88	48	1191	1	1-5	50		none
88	48	1458	1	2		50-75	ran off road and turned over
88	48	1572	1	1		50-100	none
88	48	1714	1	2	20		none
88	48	2579	1	3		100-150	none
88	51	255	1	2		50+	struck trees
88	51	364	1	1		50-100	struck and slid along guardrail
88	54	8	1	99	150+		crashed thru guardrail, hit rock outcrop
88	54	57	1	2	140		none
88	54	100	1	2	325		none
88	54	345	1	99		100-150	glanced off auto, hit guardrail, hit embankment

--This page left almost blank intentionally--

Appendix B: Supplemental Data for Immersion Events

Tables B-1 through B-3 list data from the survey of 30 accidents in which immersion was the MHE. These accidents occurred during the 5-year period 1984-1988, and represent those for which police reports were available at the time this study was conducted. The states (and their state codes) in which these accidents occurred include: Arizona (4), Arkansas (5), California (6), Florida (12), Georgia (13), Idaho (16), Illinois (17), Indiana (18), Kentucky (21), Louisiana (22), Maine (23), Michigan (26), North Carolina (37), Ohio (29), Oregon (41), Pennsylvania (42), South Carolina (45), Tennessee (47), and Virginia (51). The first entry in the table is an accident code; the first two digits are the year in which the accident occurred, the next two digits are the state code, the next four digits are the FARS case number, and the last digit is the FARS vehicle number. QT denotes the number of quarter-turns that occurred during the accident. VA and VE are the actual or estimated speeds at the time of the accident (in mph).

Table B-1 Immersion Event; Trailer Submerged, Vehicle Fell Into Water

Accident Code	QT	Object Struck	VA	VE	Description
84-23-0204-1	0	GR	?	55	Broke thru GR; fell 25' onto ice; landed in 8 feet of water
84-41-0516-1	1	GR	?	55	Drove 284' thru median; 93' across road; thru 3' fence; went completely airborne; (down 65' embankment) head first into 15' deep Columbia River
84-47-0151-1	?	GR	?	55	Went over GR; hit bridge; fell into water (Carney Fork near Buffalo Valley); bridge height above water est. 10-20 feet.
85-51-0616-1	0	GR	<35	55	Load shift caused slide against GR and then over it into East River; falling 10-50 feet
86-45-0038-1	0	GR/embankment	?	?	Swerved to avoid dog; broke thru GR; fell 40' hitting river bank
87-22-0236-1	2	auto	56	55	V1 (56 mph) rear ended auto (0 mph); went over 3' 1" GR; fell 10-25' into Lake Ponchartrain (10-15' deep)
88-42-0565-1	0	GR	?	?	Swerved to avoid deer; thru GR; 65'; went airborne off 20' bank into 30' of water

Table B-2 Immersion Event; Trailer Submerged, Vehicle Drove Into Water

Accident Code	QT	Object Struck	VA	VE	Description
84-12-2268-1	2	none	25	55	Ran off road; 2QT; into canal
84-41-0451-1	1	guard rail (GR)	?	55	Slid 193' along GR; broke thru; 1QT; went into canal (mud bottom covered by 4.5 feet of water)
85-05-0203-1	0	GR	?	?	Left road; went 294'; hit GR; power unit caught fire; trailer went 205', 50' down embankment into river; submersion put out fire; rear end of trailer out of water
85-06-0922-2	?	auto	55	55	V2 (55 mph) hits auto (55 mph) head on; V2 went off road into 15 foot deep lagoon
85-12-0814-1	0	fence	55	35	Went through fence into canal
85-13-0220-1	0	none	55	55	Left road (driver asleep) went 528 feet and submerged in creek
85-16-0169-1	>4	GR	<55	55	Broke thru GR; went over embankment; turned several QTs; came to rest in river
85-21-0614-1	0	GR	?	55	Broke thru GR; down 25 ft embankment; into 13-15' deep creek
85-22-0056-1	1	none	10	55	Went down 9' embankment; 1 QT; majority of trailer submerged
85-47-0170-1	1	GR	<50	50	Ran off road; jackknifed; did 1QT; slid on side (50-150') into Tennessee River
86-37-0805-1	1	pole	50	55	V1 went down embankment; 340'; did 1QT; hit pole; slid on side; came to rest in creek
87-21-0285-1	1	none	?	5	V1 missed turn and drove down boat ramp into water
87-22-0393-2	0	auto	50	55	V2 (50 mph) hit auto (45 mph) head on; then drove into water; partially submerged
87-39-0017-1	2	van	40	45	V1 (40 mph) hit van (<45 mph) head on; went off road; over embankment; overturned in creek; partially submerged
88-21-0284-1	0	bridge rail	53	55	V1 (fell asleep); drove off road 784 feet; hit bridge rail; went 186' and then into river
88-26-1393-1	0	GR	?	?	Hit GR; went into Bay Creek
88-39-0955-1	2	GR	55	55	Hit GR; went into river upside down

Table B-3 Immersion Events; Trailer Not Submerged

Accident Code	QT	Object Struck	VA	VE	Description
84-04-0291-2	0	Auto	35	35	V1(auto) hits V2 head-on; V2 drives over V1; 1 QT; trailer immersed; power unit fire
85-18-0215-1	0	Bridge Wall		55	V1 hit wall twice driver ejected into river
87-16-0129-1	1	Guard Rail (GR)	?	50	V1 (tanker) ran off road; hit GR; 1 QT; V1 not submerged; tanker burned
87-39-1667-1	0	Auto	50	55	auto ran stop sign; V1 hit auto in side (50 mph) and then ran into river; only tractor was submerged
88-17-0078-1	1	Auto	?	?	V1 rear-ends auto; drove off road into ditch; went 800 feet; jackknifed; 1QT; power unit fire
88-42-0001-1	0	Wall	?	55	V1 hit wall and GR; cab fell 100 feet into river; trailer stayed on bridge

Appendix C: On-going Accident Severity Data Collection

The TIFA supplemental described in the body of this report covers years 1984-1988. This period was used because at the time the original study was conducted, 1988 was the last year for which the TIFA file was complete and because police reports were readily available as far back as 1984. Several limitations have been recognized in the accident data that was developed in this study. Therefore, a new contract was initiated with UMTRI to collect additional supplemental data on accident severities. In this on-going study, supplemental data for the TIFA file are collected at the same time the TIFA file itself is completed based on police reports and phone interviews of response personnel and other witnesses to the accident. In a manner similar to the effort described in Chapter 6, information on both collision severity and fire severity are being collected. However, by collecting the supplemental data in a more timely fashion and making use of phone interviews, we expect to greatly improve the number of cases for which variables such as fire size and fire duration are known or can be estimated. Furthermore, since better information is generally available, a single estimate is used for each variable of interest as opposed to the previous effort, for which upper bound, lower bound, and average estimates were used to describe many variables. In addition, refinements have been made in the types of information collected and the processes used to collect the information.

C.1 Collision Severity

Supplemental data for collision severity are collected based on information from police reports and phone interviews. The data are entered into a spreadsheet, which is then used to compute measures of collision severity. Table C-1 shows the format of the spreadsheet used to enter these data. Numbers in italicized text must be input; numbers in plain text are calculated. Rows 3 and 8 of the spreadsheet contain information on the case vehicle; rows 4 and 9 contain information on the other vehicle or object involved in the collision. For each case vehicle, only one event is coded.

The year (Yr), state code (St), case number (Case) and vehicle number (Veh#) are input so that the supplemental data can be combined with data in the TIFA file. The travel speed (Trav Spd, mph), skid distance (Skid Dist., ft) and coefficient of friction (Coef. Fric.) are used to calculate the speed at impact (Impct Spd, mph), using the spreadsheet formulas indicated in Table C-2.²⁶ The derivation of the formula used for impact speed is described in Reference 11. The impact angle (Angl, degrees), which is the angle subtended by the velocity vectors of the case vehicle and the other vehicle or object, is used to calculate the relative velocity (Rel Veloc., mph) between the case vehicle and the other vehicle or object. The weights of the case vehicle and the other vehicle or object are specified in lbs and are used in the calculation of

²⁶The spreadsheet and formulas were developed using Quattro Pro, Version 4.0, Borland International, 1800 Greens Hill Road, P.O. Box 660001, Scotts Valley, CA 95067-0001.

peak contact velocity (PCV). The derivation of the formulas used for relative velocity and the peak contact velocity can be found in Reference 12.

Table C-1 Spreadsheet for Supplemental Collision Severity Data--On-going Study

	A	B	C	D	E	F	G	H	I	J	K	L
1	ESTIMATES				Trav	Skid	Coef.	Impct		Rel.		
2	Yr	St	Case	Veh#	Spd	Dist.	Fric.	Spd	Angl	Veloc.	Weight	PCV
3	0	0	0	0	-1	0	0	-1.0	0	0.0	0	-1.000
4	0	0	0	0	0	0	0	-1.0			0	-1.000
5												
6							road	mass	area	area	object	
7							surface	elements	tractor	trailer	struck	
8					veh	0	0	0	0	0	n/a	
9					veh	0		0	0	0	n/a	
10								comments:	none			

Table C-2 Cell Formulas used in Spreadsheet for Collision Severity Data--On-going Study

H3=IF(E3=-1,-1,SQRT(E3^2-(30*F3*G3)))
J3=SQRT((H3-H4*COS(I3*PI()/180))^2+(H4*SIN(I3*PI()/180))^2)
L3=IF(E3=-1,-1,J3/(1+K3/K4))
A4=A3
B4=B3
C4=C3
H4=IF(E3=-1,-1,SQRT(E4^2-(30*F4*G4)))
L4=IF(E3=-1,-1,J3/(1+K4/K3))
F8=D3
F9=D4

Accidents in which there was no single collision that caused a sudden, large change in velocity are considered sideswipes. Sideswipes are characterized by glancing impacts and a decrease in velocity over an extended time and distance. These types of collisions do not constitute a threat to the integrity of the trailer or the cargo restraint systems. Travel speed is coded as -1 for the case vehicle if the accident is considered to be a sideswipe, which effectively classifies the collision event as non-threatening. For accidents classified as sideswipes, the skid distances, coefficient of friction, impact angle and weights are not used.

If the case vehicle was involved in more than one collision, the collision producing the greatest change in velocity is coded. If there is no collision event, the travel speed is coded as -2. If there is a non-sideswipe collision event and the travel speed is unknown, it is coded as -9. Skid distance is entered only if explicitly known (skid distance may correspond to tire marks or sliding of the vehicle on its side). If impact speed is explicitly specified in the police report,

the skid distance and/or travel speed are adjusted such that the formula for impact speed gives the value indicated in the police report. In the case of impacts with fixed objects such as a wall or cliff, impact speed is the component of the truck's velocity that is perpendicular with the cliff. For these cases, travel speed is input to the spread sheet as travel speed times the sine of the angle between the vehicles direction of travel and a vector perpendicular to the surface of the object.

The coefficient of friction is based on the road surface, as indicated in Table C-3. The code values for road surface are also indicated in this table.

Table C-3 Code Values for Road Surface and Corresponding Range for Coefficient of Friction

Road surface	Code value	Coefficient of Friction
Dry	1	0.4 - 0.5
Loose gravel	2	0.3 - 0.4
Wet	3	0.3 - 0.4
Snowy/Icy	4	0.2 - 0.3
Unknown	9	

The weight of the vehicle or object used in the spreadsheet is the effective weight from the standpoint of momentum transfer. The process for estimating effective mass has been simplified. For vehicles, estimates are incremented only by the weight of an entire unit of the combination. That is, in the case of a tractor-semi-trailer, the effective mass is either the weight of the tractor, the trailer, or their sum, all of which are available in the TIFA file. In the case of a straight truck, the effective mass is the weight of the vehicle. The code values used to represent these mass elements are listed in Table C-4. For fixed and non-fixed objects, the mass element is coded as 4 for not applicable. Also, if travel speed is "-2" (no collision), the mass elements are coded as 4.

Table C-4 Code Values For Mass Elements

Mass Element	Code Value
Entire vehicle	1
Tractor only	2
Trailer only	3
Not applicable	4
Unknown	9

The following guidelines are used to evaluate the effective weight of vehicles other than medium or heavy trucks, objects, and trains:

1. The weight of large cars and pickups is assumed to be between 3500 and 4500 lb. depending on the model.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 2

2. The weight of mid-size cars is assumed to be between 3000 and 4000 lb. depending on the model.
3. The weight of small cars is assumed to be between 2000 and 3500 lb. depending on the model.
4. The weight of motorcycles is assumed to be less than 1500 lb.
5. For fixed objects, the weight is set to an arbitrarily large number (1×10^{12} lb.) if the object remained in place to reflect the fact that the velocity of the fixed object does not change in the collision. If the object did not remain in place (e.g., a telephone pole could be snapped off at its base), the weight is estimated at ten times the estimated actual weight of the object. Typical estimates for the weights of fixed objects that do not necessarily remain fixed are given in Table C-5.
6. For non-fixed objects, the effective weight is generally taken to be less than 1500 lb.
7. For trains, the effective weight is based on the number of locomotives and cars participating in the momentum exchange. In collisions in which the case vehicle was struck by the train; the effective weight is assumed to equal the total weight of all locomotives and cars in the train. In collisions in which the case vehicle struck the train, the effective weight is set equal to the combined weight of the locomotive or car struck and the locomotive(s) or car(s) immediately in front of and in back of the one struck (if present). Locomotives are assumed to weigh 350,000-400,000 lb., empty box cars 60,000 lb., loaded box cars 180,000-200,000 lb., and passenger cars 100,000 lb. If a car is not identified, it is assumed to be a boxcar.

Table C-5 Estimated Weights of Selected Fixed Objects

Object	Actual Weight, lbs.	Effective Weight, lbs
Tree	500-2000 per tree	5000-20,000 per tree
Guardrail	500-1000	5000-10,000
Telephone pole	1000	10,000
Light pole	1500	15,000

The cells labeled "area tractor" and "area trailer" are used to define the contact area for the major impact. Figure C-1 indicates the codes to be used for the power unit and trailer. For example, an opposite-direction sideswipe might be coded 1. A rear-end might be 7. An impact on the saddle-tanks of the tractor, just behind the cab, might be coded 6. For tractors or trailers that are not directly impacted and for objects, code 98 is used. If the travel speed is coded "-2" (non-collision), code 98 is entered. If the impact location is unknown, code 99 is used.

Tractor			Trailer		
3	5	8	3	5	8
2		7	2	9 (top) 10 (bot)	7
1	4	6	1	4	6

9 (top)
10 (bot)

Figure C-1 Codes for Contact Area on Tractor and Trailer

The cells labeled "object struck" are used to enter an alpha description of the object struck. The description is limited to 255 characters. One of the purposes of this field is to enable us to revisit cases as we learn more and are able to make better decisions about the effective masses of fixed objects. By entering a fairly complete description, we will be able to search for cases and ensure consistency. The description includes details that pertain to the effective mass. An additional cell is also available for general comments on collision severity.

C.2 Fire Severity Data

Figure C-2 shows the new supplemental data form used for collecting fire severity data. This information is extracted directly from police accident reports and phone interviews, independently reviewed and checked for accuracy, and then key-punched into the existing data file. The data fields include the year, state number, case number and vehicle number so that the data can be combined later with data in the TIFA file.

Each fire in the accident is assigned a unique number (Fire No.). The number of fires coded for a specific case vehicle takes into consideration how the nature of the fires might have differed if the case vehicle had been an AT/SST. Thus, if the cargo of the case vehicle was lumber and the lumber caught on fire, the lumber fire is disregarded. On the other hand, fires involving the tractor, fuel system, brakes or any other element of the tractor or trailer (excluding cargo) of the case vehicle are coded. In addition, all fires associated with other vehicles, objects or material not part of or carried by the case vehicle are coded. A data form is filled out for each case vehicle and each applicable fire; all other information on the form is coded in relation to that specific case vehicle and fire source.

For example, consider an accident involving a collision between two tractor semi-trailers (vehicles 1 and 2). Both of their fuel tanks rupture and catch fire. The fire spreads from the fuel tank of vehicle 1 to the cargo in the trailer of vehicle 1. The trailer and cargo of vehicle 2 are not involved in the fire. For vehicle 2, three fires are coded: the fuel tank fire of vehicle 2, the fuel tank fire of vehicle 1, and the trailer/cargo fire of vehicle 1. For vehicle 1, only two fires are coded: the fuel tank fire of vehicle 2 and the fuel tank fire of vehicle 1. The fire in the trailer/cargo of vehicle 1 is disregarded in considering the fire affecting vehicle 1 since the SST will not burn in this manner.

If the only fire in the accident involved the cargo of the case vehicle, the fire source number is assigned the number 98, meaning that the fire is not applicable. If a fire could not be identified from the police report, this field is coded 99, meaning that the number of fires and all other information with respect to the fire environment is unknown.

Most of the remaining information required on the form is self-explanatory. If an entry is unknown, all nines are entered. For example, if the fire duration is unknown, the code 9999 is entered. The fire duration is intended to represent the time period during which an energetic open flame existed (excluding any time that the combustibles were smoldering). A brief description of the type of fire can be entered under the heading "Description". The shortest distance from the fire to the trailer of the case vehicle is based on the shortest distance from the outside surface of the trailer to the outside surface of the fire. The length and width of the fire are used to define the surface area of the fire, which represents the ground area covered by open flame. If information on the surface area of the fire is not explicitly provided but it is known that a vehicle was engulfed in fire (as stated in police reports or phone interviews), the surface area of the fire is taken to be approximately equal to the footprint of that vehicle. The walls of the trailer of the case vehicle with a direct line of sight to the fire are used to define which walls are directly heated by the fire.

C.3 Summary

At this time, the TIFA file and the supplemental data files for 1992 are complete. The intent of this on-going study is to collect three to five years of supplemental data.

1992 AT/SST Fire Supplemental Information Form

Accident Year:
 1 2

State: Case No.: FARS Vehicle No.:
 3 4 5 6 7 8 9 10

Fire No.:
 11 12

Estimated fire duration: min How was this fire extinguished?
 13 14 15 16
Burned out ☐ 1
Extinguished with hand equipment ☐ 2
Extinguished with other equipment ☐ 3
Unknown ☐ 9

Item burning:

Fuel System ☐ 1
Cargo ☐ 2
Vehicle components ☐ 3
Object (building, structure, etc.) ☐ 4
Other ☐ 5
Unknown ☐ 9

Type of fire:

Combustible gas ☐ 1
Combustible liquid ☐ 2
Combustible solid ☐ 3
Object ☐ 4
Other ☐ 7
Unknown ☐ 9

Description:
 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34

Mass of combustible cargo/fuel: lbs
 35 36 37 38 39

Shortest distance from fire to trailer of case vehicle: ft
 40 41 42

Length of fire: ft
 43 44 45

Width of fire: ft
 46 47 48

Walls of trailer of case vehicle
with direct line of sight to fire:

Front:	Rear:	Bottom:	Top:	Left:	Right:
Yes ☐ 1	Yes ☐ 1	Yes ☐ 1	Yes ☐ 1	Yes ☐ 1	Yes ☐ 1
No ☐ 2	No ☐ 2	No ☐ 2	No ☐ 2	No ☐ 2	No ☐ 2
Unk ☐ 9	Unk ☐ 9	Unk ☐ 9	Unk ☐ 9	Unk ☐ 9	Unk ☐ 9
49	50	51	52	53	54

Orientation of this fire relative
to closest point on trailer of
case vehicle: o'clock
 55 56

Figure C-2 Supplemental Data Form for Fire Severity--On-going Study

--This page left almost blank intentionally--

Appendix D: Sensitivity of Analytical Simulation for Fire Surface Area and Duration to Weighting Factors and Leak Area Distributions

Sections 9.3.3 and 9.3.4 describe a Monte Carlo simulation used to develop distributions for the surface area and duration of fires. In this simulation, the weighting factors applied to pool and spill fire models, w_p and w_s , respectively, and the parameters of leak area distributions were selected based on comparisons with accident data. The sensitivity of the overall distributions to these factors and parameters is described in this Appendix.

The leak area distributions depend on the other vehicle involved and are of the form:

$$P_i(A_i) = 1 - e^{-\left(\frac{A_i - a_i}{c_i}\right)^{b_i}} \quad (D-1)$$

where $P_i(A_i)$ is the cumulative probability that the leak area is less than A_i and a_i , b_i , and c_i are the adjustable parameters of the distribution.

Table D-1 shows the values of the weighting factors and distribution parameters considered and indicates the Figures in which the corresponding results are displayed. There is a clear trade-off between the comparisons for surface area and those for duration. Decreasing the weighting factor for the spill models or decreasing the likelihood of large leak areas by adjusting the distribution parameters tends to decrease the likelihood of large surface areas and increase the likelihood of long fire durations. The values of the weighting factors and distribution parameters selected as the baseline appear to provide a very good balance for the trade-off between the accuracy of the overall distributions for surface area and duration of fires.

Table D-1 Sensitivity Study for Simulation of Surface Areas and Durations of Fires

Name	Weighting Factors		Other Vehicle Involved	Distribution Parameters			Results Appear In:
	w_p	w_s		a_i	b_i	c_i	
Baseline	0.2	0.8	Truck	6	4	0.1	Figures 9-9 and 9-15
			Car	5	4	0.1	
			Tanker	10	4	4	
			None	5	4	0.1	
			Train	8	4	2	
Case 1	0.1	0.9	Truck	6	4	0.1	Figures D-1 and D-2
			Car	5	4	0.1	
			Tanker	10	4	4	
			None	5	4	0.1	
			Train	8	4	2	
Case 2	0.3	0.7	Truck	6	4	0.1	Figures D-3 and D-4
			Car	5	4	0.1	
			Tanker	10	4	4	
			None	5	4	0.1	
			Train	8	4	2	
Case 3	0.2	0.8	Truck	3	4	0.05	Figures D-5 and D-6
			Car	2.5	4	0.05	
			Tanker	5	4	2	
			None	2.5	4	0.05	
			Train	4	4	1	
Case 4	0.2	0.8	Truck	12	4	0.2	Figures D-7 and D-8
			Car	10	4	0.2	
			Tanker	20	4	8	
			None	10	4	0.2	
			Train	16	4	4

Figure D-1 Overall Distribution of Fire Surface Area: Case 1

Figure D-2 Overall Distribution of Fire Duration: Case 1

Figure D-3 Overall Distribution of Fire Surface Area: Case 2

Figure D-4 Overall Distribution of Fire Duration: Case 2

Figure D-5 Overall Distribution of Fire Surface Area: Case 3

Figure D-6 Overall Distribution of Fire Duration: Case 3

Figure D-7 Overall Distribution of Fire Surface Area: Case 4

Figure D-8 Overall Distribution of Fire Duration: Case 4

Acronyms

AT-armored tractor

DOE-U.S. Department of Energy

DOT-U.S. Department of Transportation

DPTRA-Defense Programs Transportation Risk Assessment

FARS-Fatal Accident Reporting System

FHWA-Federal Highway Administration

GCW-gross combination weight

GES-General Estimates System

GR-guardrail

GVWR-gross vehicle weight rating

LBE-lower bound estimate

MHE-most harmful event

NASS-National Accident Sample Survey

NHTSA-National Highway Traffic Safety Administration

OMC-Office of Motor Carriers

PSU-Probability Sampling Unit

SST-safe secure trailer

TIFA-Trucks Involved in Fatal Accidents

UBE-upper bound estimate

UMTRI-University of Michigan Transportation Research Institute

VIN-vehicle identification number

--This page left almost blank intentionally--

Nomenclature

A	surface area of a fire
A_t	cross-sectional area of the fuel tank
A_l	leak area (cross-sectional area of opening)
A_p	surface area of a pool fire
$\overline{A_s}$	time-averaged surface area of a spill fire
d	diameter of the fire
D	skid distance after a rollover
E	collision energy absorbed by the AT/SST
E_a	total energy absorbed in a collision
E_f	emissive power of the fire
E_m	emissive power of the luminous spots
E_s	emissive power of the smoke
g	acceleration due to gravity
h	height of the free surface of the fuel above the opening
h_0	initial fuel height
K_i	distribution weighting factors
M	effective mass of the case vehicle
m	effective mass of the other vehicle or object involved
P	cumulative probability function
PCV	peak contact velocity of the case vehicle
pcv	peak contact velocity of the other vehicle or object involved
Q	fuel spill rate
$\overline{Q}$	time-averaged spill rate
R	diameter of a fire
S	empirical coefficient used in evaluation of emissive power of the fire
t	time
t_b	time required to completely burn the fuel
t_d	collision duration
T	fire temperature
V	volume of fuel
V_r	relative velocity or closing velocity

v	velocity of fuel through an opening
w_p	weighting factor for pool fire model
w_s	weighting factor for spill fire model
$\dot{y}$	fuel surface recession rate
σ	Stefan-Boltzman constant

Distribution

- 6 U.S. Department of Energy
Attn.: E. G. Grewis, DP-20.1
D. R. Olson, DP-21
C. G. Halsted, DP-22
J. D. Rodgers, DP-22
J. R. Maisonet, DP-22
T. J. Goodwin, DP-22
19901 Germantown Rd.
Germantown, MD 20874
- 1 U.S. Department of Energy
Attn.: M. J. Conroy, EM-261
1000 Independence Ave., SW
Washington, D. C. 20585-0002
- 6 U.S. Department of Energy
Albuquerque Operations Office
Attn.: G. E. Runkle, HPD
G. V. Binns, NESD
R. O. Inlow, OSS
R. E. Sabre, TSD
R. H. Richey, TSD
D. B. Umshler, WPD
P.O. Box 5400
Albuquerque, NM 87185-5400
- 1 Argonne National Laboratory
Attn.: S. Y. Chen, EID-900
9700 S. Cass Avenue
Argonne, IL 60439-4832
- 2 Los Alamos National Laboratory
Attn.: A. A. Guthrie, ESA-11, MS C931
D. A. O'Brien, TSA-9, MS F684
P.O. Box 1663
Los Alamos, NM 87545
- 4 Lawrence Livermore National Laboratory
Attn.: G. L. Dittman, L-125
P.O. Box 808
Livermore, CA 94550

Distribution (continued)

- 1 Logicon R&D Associates
Attn: S. F. Woodford
6940 S. Kings Highway, Suite 202
Alexandria, VA 22310

- 10 University of Michigan Transportation Research Institute
Attn: K. Campbell (5)
D. Blower (5)
2901 Baxter Rd
Ann Arbor, MI 48109-2150

- 1 R. H. Odegaarden
6048 E. Star Valley Street
Mesa, AZ 85215-9609

- 1 J. S. Phillips
925 E. Navajo
Farmington, NM 87401

- 1 J. T. Risse
28 Riverside Rd.
Peralta, NM 87042

- 1 MS0405 D. D. Carlson, 6411
- 1 MS0491 R. E. Smith, 12333
- 1 MS0492 G. A. Sanders, 12332
- 1 MS0492 C. G. Shirley, 12332
- 1 MS0560 D. F. McVey, 5408
- 5 MS0567 R. K. Wilson, 9241
- 1 MS0631 R. W. Schwoebel, 12300
- 1 MS0718 J. W. Cashwell, 6641
- 1 MS0718 J. D. Whitlow, 6641
- 1 MS0763 W. F. Hartman, 9614
- 20 MS0763 D. B. Clauss, 9614
- 1 MS0763 R. D. Klett, 9614
- 1 MS0763 M. E. Larsen, 9614
- 1 MS0763 J. W. Moyer, 9614
- 1 MS0766 J. R. Kelsey, 9600
- 1 MS0767 E. R. Hoover, 9603
- 1 MS0767 S. C. Roehrig, 9604
- 1 MS0790 H. J. Abeyta, 9612
- 1 MS0790 B. D. Boughton, 9612

Distribution (continued)

1	MS0790	G. W. Crowder, 9612
1	MS0790	J. J. Roesch, 9613
1	MS0790	J. K. Deuel, 9613
1	MS9018	Central Technical Files, 8523-2
5	MS0899	Technical Library, 7141
1	MS0619	Technical Publications, 7151
10	MS0100	Document Processing for DOE/OSTI, 7613-2

**DATE
FILMED**

8 / 12 / 94

END