QUANTITATIVE CHARACTERIZATION OF THE
ENVIRONMENT EXPERIENCED BY CARGO
IN MOTOR CARRIER ACCIDENTS*

31 970
J. T. Foley
W. F. Hartman

D. W. Larson
R. K. Clarke

INTRODUCTION

This paper presents highlights and conclusions from a detailed study¹ which was performed to determine the severity of motor carrier accidents. The analysis is based upon accident rates reported for intercity shipments of property² by Class I and II Interstate Motor Carriers. The definition of terms used in this paper and the method of analysis are those described in the first paper of this set of four; the general presentation format will be similar to the aircraft accident report.

DATA SOURCES

As mentioned previously, accident rate statistics were obtained from Ref. 2, which in addition also provided frequency of occurrence of the various accident types (head-on with another truck, rear end into auto, ran off road, etc.). These statistics showed the average accident rate to be 2.5 accidents/10⁶ miles. The required velocity distributions for each of these types of accidents were obtained from reports of statewide motor vehicle traffic accidents in Texas and Alabama.^{3, 4} These velocity distributions are shown in Fig. 1.

*Work supported by United States Atomic Energy Commission.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
389

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Fig. 1. Cumulative Net Velocity Distributions for Various Categories of Collision or Overturn Accidents.

ENVIRONMENTS OF CONCERN

In the process of analysis of the truck environment, it becomes essential to choose a particular type of truck shipment. The system chosen for consideration was that involving the smaller (up to perhaps 2 tons) hardened containers in closed vehicles; the result and conclusions therefore are not directly applicable to large shipping casks or bulk material shipments. With this cargo definition, the three dominant accident environments (which will be experienced by cargo) are crush, puncture, and fire; impact and immersion are of lesser consequence. The secondary role of impact results from the absence of a true impact environment which meets the definition given in the opening paper of this group. This

definition stated that impact is the striking or being struck by an object with no sharp protrusion with the duration of the contact being on the order of a few milliseconds. The most common form of impact in truck accidents involves containers colliding with trailer walls or other cargo. In these collisions, an amount of energy which is insufficient to damage a hazardous materials container is absorbed by the container. Severe impact accidents such as a locomotive colliding with a trailer stalled at a grade crossing or a container dropping off of a high bridge and striking concrete can present a serious impact potential, but the probability of environments such as these occurring is much less (at least half an order of magnitude) than the probability of equally severe crush, puncture, or fire environments.

Crush Environment

The crush environment model was derived by subjecting a spring mass model of the motor carrier to the various types of accidents with the velocity distributions of Fig. 1. The parameter used to characterize crush potential was the relative acceleration between the cargo and the trailer; consideration of the mass of cargo whose inertial load must be borne by each container then produces a distribution of crush forces. The crushing load, therefore, is a function of the cargo composition and will vary as the load composition changes.

This model, when coupled with the accident frequency data, results in Fig. 2 which shows the prediction of the total force acting on a container for what was considered a composite representative load - 5% full loads of stiff containers and the other 95% with a 20-80 mix of stiff and soft packages. This curve indicates a very high probability of damage to soft containers. To achieve some estimate of container crush resistance,

two containers (an L-10 and an SP5795) were crushed statically at Sandia Laboratories and were found to withstand at least 60,000 pounds total force without major deformation. From Fig. 2, it is predicted that an environment more severe than this value will occur once in every 1.82×10^8 miles. Also note that the frequency falls off very rapidly at high values as it decreases by over an order of magnitude between 100,000 and 140,000 pounds.

Fig. 2. Probability per Mile of Experiencing a Total Crush Force Greater Than That Shown.

The possibility of the container being crushed statically under the wreckage was also considered, but inclusion of this factor did not materially alter the results shown in Fig. 2.

Puncture Environment

Analytically, the probability of a probe puncturing a container is, to a first order, governed by the parameter V/R where V is the velocity of the container relative to the probe and R is the radius of the probe. Therefore, the puncture environment is described by the velocity distribution determined from the spring-mass model analysis of the various accidents and estimates of the probability of the presence and creation of the different size probes which possess a puncturing potential. Fortunately, the implied dependence upon R is essentially cancelled by consideration of the acceptance angle for the collision over which puncture will occur and the probe will not bend. For small angles, this acceptance angle varies linearly with probe radius so that the product of the environment severity and the probability of this severity occurring (probe not bending) exhibits only a slight dependence on the probe radius.

The statistics to which this puncture model were applied were gathered from the accident information compiled by the DOT's Office of Hazardous Materials.⁵ From this information, the frequency of puncture of soft packages was inferred and the analytical method outlined above was used to predict what fraction of these packages would have been punctured had they been stiff containers. These data are shown in Fig. 3, with the 40 inch drop onto a 6 inch diameter probe being noted at $V/R = 58 \text{ sec}^{-1}$. As a matter of interest, it is noted that the Federal Specification criteria for puncture is predicted to be exceeded once in every 9.1×10^8 miles; from Fig. 2, a container would be expected to experience a crush force in excess of 110,000 pounds in this same distance.

Here, as for crush, ejected containers were considered but found to affect the results only slightly.

The puncture environment, as mentioned in the introductory paper, also depends somewhat upon the composition of the cargo load but probably to a lesser extent than it does for crush.

Fig. 3. Probability per Mile of a Hardened Container Experiencing Puncture Environment More Severe Than V/R (Based on Puncture Rate for 'Soft' Package of 3.4×10^{-8} per Mile).

Fire Environment

While the frequency of occurrence of fires in truck accidents is low (16 in every 1000 accidents), the severity is great as attested to by their accounting for 10% of the incurred damage. Although statistical information on fire length and temperature is nonexistent, it is possible to

arrive at a prediction of these quantities through use of a Monte Carlo (probabilistic) description of fire-related events. This technique permits the optimum use to be made of available statistics, engineering judgments, and the theoretical predictions of the consequences of the several possible sequences of events. The assumptions invoked are too great in number to list here, but they are detailed in Ref. 1, and the data used as a basis for the analysis came primarily from Ref. 2, 5 and 6.

The results of this approach are shown in Fig. 4. The temperature-time product is chosen as the parameter to characterize the fire; this is probably valid between the temperature limits of about 1400°F to 2250°F. This curve can be used to select a fire duration test criterion based on the point of diminishing return rationale. It will be noted that the Federal Specifications fall within this region of cost effectiveness. Also note that the probable number of miles traveled in which a fire of greater severity than that of the Federal Specifications can be expected is about 3.6×10^8 miles. To increase this interval to the 9.1×10^8 mile figure which has been arbitrarily considered before would require a fire with a 1475°F effective radiating temperature to last for about one hour.

SEVERITY LEVELS

Figure 5 defines arbitrary accident severity levels for truck accidents. Here, for convenience, the fire temperature was chosen to be 1850°F so that this environment can be characterized by duration alone. Minor accidents include crush forces less than 20,000 lb, V/R values up to 20/sec, and 1850°F fires of less than 10 minutes duration. If any one of these levels is exceeded, the accident is not minor. The upper limits for moderate accidents are, therefore, 50,000 lb, 60/sec, and 20 min, and the upper limits on the other severity categories can be similarly defined.

Fig. 4. Probability of Exposing Cargo to Thermal Environment Exceeding Temperature-Time Product per Truck Mile.

NOTE: t , the fire duration, is for an 1850°F blackbody temperature.

Fig. 5. Accident Severity Categories

JOINT PROBABILITY

An appropriate measure of the performance of a hazardous materials container in truck accidents is the probability, given an accident, that the container's integrity is not breached by any of the environments. Since this study did not attempt to analyze container response, the combinations of environments defined above under severity levels were chosen to determine the frequency with which these levels were exceeded, i.e., if one had a container which would always survive these levels but always fail at any level in excess of these, this calculation would predict the failure rate. Table 1 shows the results of this analysis which predicts the most likely number of times a container will experience an accident more severe than the category indicated as a function of truck mileage. Note that the accident environments of concern for truck cargo are not the same as those of importance in air transportation. This difference alone precludes any comparison of these modes based on the arbitrary severity categories from being valid.

Table 1. Expected Number of Times a Container Will Experience an Accident More Severe Than Category Indicated

Severity Category	Number of Truck Miles		
	10^8	5×10^8	10^9
Minor	5	28	-
Moderate	1	6	12
Severe	0	2	4
Extra Severe	0	0	0
Extreme*	0	0	0

*As extreme accidents are unbounded at the upper end, there can be no accidents which exceed this category.

It is possible to use joint probability methods of combining the data in Figs. 2, 3, and 4 to determine which of the several environments is controlling the "failure" probability. Figures 6, 7, and 8 are part of a series of iso-probability curves; any point on one of these figures will cover the same percentage of accidents as any other point on that figure. This type of analysis, therefore, enables the effects of varying a container's capabilities to be assessed. Figure 6 shows the values of parameters which will cover 99.5% of the truck accidents, and the values in Figs. 7 and 8 will include 99.8 and 99.9%, respectively. Looking at Fig. 8 as an example of the use of these figures shows that a crush force of 146,000 lb, a puncture of 360/sec, and a temperature-time product of 60,000 will cover the same number of accidents (999 out of 1000) as will a crush force of 133,000 lb, a V/R of 100, and a Tt value of slightly less than 140,000 °F-min.

REFERENCES

1. R. K. Clarke, J. T. Foley, W. F. Hartman, and D. W. Larson, Severities of Motor Carrier Accidents, SLA-74-0002, Sandia Laboratories, Albuquerque, New Mexico (to be published).
2. Accidents of Large Motor Carriers of Property, Bureau of Motor Carrier Safety, Federal Highway Administration, U.S. Dept. of Transportation, published annually.
3. Summary of Rural and Statewide Motor Vehicle Traffic Accidents in the State of Texas, Calendar Year 1969 Statistics Services, Texas Dept. of Public Safety, April 22, 1970.
4. Summary of Rural Motor Vehicle Accidents in the State of Alabama, 1970, 1971.
5. Computer Listing, OIIM Hazardous Material Incidents Reports, July 1973.
6. Analysis of Accident Reports Involving Fire, Bureau of Motor Carrier Safety, FHA, Dept. of Transportation, published annually.

Fig. 6. Iso-Probability Plot $P = 0.995$ That Parameters of Fire, Crush, or Puncture Will Not Be Exceeded.

Fig. 7. Iso-Probability Plot $P = 0.998$ That Parameters of Cargo, Puncture, or Fire Will Not Be Exceeded.

Fig. 8. Iso-Probability Plot $P = 0.999$ That Parameters of Crush, Puncture, or Fire Will Not Be Exceeded.