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The assessment of major hazards: The road transport environment for conveyance of hazardous materials in Great Britain

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Abstract

The assessment of major transport hazards creates a requirement for a wide range of data on the transport environment. This environment is specific to the country concerned. The present paper gives an overview of the road transport environment in Great Britain. It gives information on the frequency of accidents involving heavy goods vehicles generally and heavy goods vehicles carrying hazardous materials in particular, on the circumstances surrounding certain types of accidents and on the probability of certain outcomes of accidents. Certain limited information is also given for comparative purposes on the road transport environment in other countries.

1. Introduction

The assessment of major hazards arising in the road transport of hazardous materials requires the use of a wide range of data on the road transport environment. As in hazard assessment generally, two situations can arise with respect to the estimation of the frequency of particular accident scenarios. Either it is possible to estimate the frequencies of these scenarios from historical data or it is necessary to synthesise the frequencies, by methods such as modelling or fault tree analysis.

Thus for scenarios such as release of materials which are transported in large quantities (e.g. gasoline and LPG) it may well be possible to obtain historical data. For other scenarios such as release of chlorine or explosion of explosives in transport it is much more difficult. Moreover, even where historical data exist, it may still be necessary to resort to modelling for reasons such as the

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need to adapt the data to the particular assessment or to explore the effect of possible mitigatory measures.

The present work was carried out in connection with a study of the risks from the road transport of explosives [1]. Explosions occurring in such transport are very rare.

An earlier review of the various transport environments has been given by Appleton [2]. The work refers particularly to the transport of radioactive materials, another example of a transport hazard for which historical data on scenarios are lacking.

As will become apparent from the data given below, a large proportion of incidents involving hazardous materials are not due to traffic accidents, but to other causes. The prime concern in this paper is with incidents which occur during transport rather than during loading and unloading or in temporary storage, but some of the data sets also cover the latter.

2. Hazardous goods

Hazardous goods are taken here to be goods defined as such under the United Nations classification and regulated by the Classification, Packaging and Labelling Regulations (CPL) 1984.

These hazardous materials are mainly flammable and/or toxic liquids and liquefied gases, reactive chemicals and explosives.

3. Some basic road transport statistics

3.1 Sources of information

The principal source of information on road transport and on road accident statistics is the Department of Transport (DoT). Other important sources are the Home Office and the Transport and Road Research Laboratory (TRRL), which is part of the Department of the Environment (DoE).

Unfortunately, as so often happens, there are difficulties in relating information from one source to that from another. For example, DoT statistics are for HGVs with unladen weights of not less than 1.5 tonne, whereas the principal TRRL study of HGV fatal accidents deals with HGVs with unladen weights not less than 3 tonne.

3.2 Road network

There are two classifications of roads used in Britain. Roads are generally classified as trunk, principal, secondary, etc., whilst in accident statistics roads are described as A class, B class, and ‘other’. Broadly speaking, trunk and principal roads are equivalent to A class roads, whilst secondary roads are equivalent to B class and ‘other’ roads [3]. Table 1 gives the length of the road network in Great Britain in 1973 [4].

TABLE 1

Road network in Great Britain 1973 (after Johnson [4])

Length of road (km)						
BUA[a]		Total	Non-BUA		Total	Motorways
Trunk/ principal	Class II and below[b]		Trunk/ principal	Class II and below[b]		
13,874	117,052	130,926	32,383	163,587	195,970	1,752

[a] BUA: built-up area.
[b] Of these totals Class II roads are 8,746 in BUAs and 19,643 in non-BUAs.

TABLE 2

Gross vehicle weight of all goods vehicles on British roads in 1985 (after JMP Consultants [6])

Gross vehicle weight (te)	Proportion of vehicles (%)
<20	70
20–22	3
22–24	3
24–26	2
26–28	2
28–30	4
30–32	6
32–34	4
34–36	2
36–38	3
>38	1

3.3 Heavy goods vehicles

The vast majority of hazardous materials are carried in heavy goods vehicles (HGVs). The most common HGV is the rigid two-axle vehicle. A total of 435,000 HGVs were registered in 1986 [5]. Table 2 gives the distribution of HGV weights for 1985 [6].

Figure 1 shows some principal heavy goods vehicles together with their classifications [7].

3.4 Distances travelled

The distances travelled by HGVs in 1986 are shown in Table 3 by axle configuration, body type and road type. HGVs travelled a total of

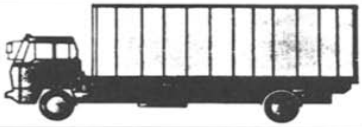
Recommended Description			Identifier	UK Maximum Gross Weight (tonnes)	Shape
LIGHT GOODS VEHICLES			2 axles	3.500	 no rear side windows
LORRIES	HEAVY GOODS VEHICLES (Vehicles over 7.5 tonnes gross require a Heavy Goods Vehicle Driver's Licence)	SMALLER 2-AXLE LORRIES	2 axles	Over 3.5 7.500	
		BIGGER 2-AXLE LORRIES	2 axles	Over 7.5 17.000	
		MULTI-AXLE LORRIES	3 axles rigid	24.390	
			3 axles artic.	24.390	
			4 axles rigid	30.490	
			4 axles artic.	32.520	
			Vehicle and draw-bar trailer	32.520	
			5 axles of more artic.	38.000	

Fig. 1. A simplified guide to lorry types and weights (after Department of Transport [7]).

TABLE 3

Distances travelled by heavy goods vehicles in 1986, by axle configuration, body type and road type (after Department of Transport [5])

HGV type	Distance ($\times 10^8$ km)		
	All speed limits	Non-BUR[b]	BUR[c]
Rigid			
2-axle	131	87	44
3-axle	11	8	3
4-axle	10	8	2
Articulated			
3-axle	6	5	1
4-axle	41	36	5
5-axle	18	17	1
All HGVs[a]	221	165	56

[a] Includes cases where the axle configuration was not reported.
[b] Non-BUR includes motorways.
[c] BUR: built-up road.

TABLE 4

Proportion of heavy goods vehicles in 1986 travelling on different road classes (after Davies [1])

Road class	Proportion of vehicles (%)	
	Non-BUR[a]	BUR
A	87.0	61.0
B	6.0	11.5
Other	7.0	27.5
Total	100	100

[a] Data exclude motorways.

221×10^8 km [5]. The average annual distance travelled per vehicle is thus 50,800 km ($221 \times 10^8/435{,}000$). Table 4 gives a breakdown of the HGV distances travelled by road class.

3.5 HGVs conveying hazardous materials

It has been estimated by Kletz [8] that in 1986 there were some 14,000 road tankers in operation. The authors have confirmed that this approximate figure is still valid. Kletz also gives the annual distance travelled per tanker as 60,000 miles (96,500 km).

Estimation of the total number of HGVs carrying hazardous materials (HGV/HMs) is deferred until later.

4. Accident statistics

4.1 Accident definitions

Accidents are commonly classified in the UK as personal injury (PI) accidents and damage-only (DO) accidents.

Road accident statistics derived from police records relate to personal injury accidents. The number of damage-only accidents generally has to be estimated from the number of injury accidents. For example, Dawson [9] in a study of the cost of accidents gives the number of personal injury accidents in 1968 as 264,200 and estimates the number of damage-only accidents as 1,583,000, giving a DO/PI accident ratio of 6. Appleton states that values of the ratio given in DoT and TRRL studies are in the range 6–12. He also states that a survey by the Safety and Reliability Directorate (SRD) of a small number of local authorities found a value of the DO/PI ratio of 2–3 but the reporting was not consistent. In any event, the problem of defining what constitutes an accident is more severe for damage-only than for personal injury accidents. Moreover, an accident severe enough to endanger the integrity of a load is likely to result in some personal injury. It is convenient, therefore, to work in terms of the personal injury accident criterion.

The main exception to the above is fires. Fire brigade records allow the derivation of fire statistics. Major studies of fires have been made in 1974 by North [10] and in 1981 by McLean [11].

The significance of the definition of an accident depends on the use to which it is to be put in the hazard assessment. Broadly speaking. the definition is important if historical data on releases are lacking, but this is less so if such statistical information is available. The reason is that in the latter case it is possible to work with a definition of an accident which is to a degree arbitrary and to work in terms of the probability of release given an accident so defined. If on the other hand data are not available and it is necessary to model the accident in order to determine the probability of release, the definition of what constitutes an accident becomes more significant, since it determines the accident frequency.

In the following the UK accidents considered are injury accidents, except for fires.

4.2 Injury accidents

For vehicles generally Johnson and Garwood [12] found that the proportion of fatal accidents in the total of serious injury and fatal accidents for the period

1959–1965 was in the range 5.1–9.2% for roads with speed restrictions of 30 or 40 m.p.h. and in the range 8.3–14.5% for other roads.

A study by the DoT [13] in 1987 obtained for the ratio of fatal accidents to all injury accidents values in the range 0.018 : 1 to 0.025 : 1.

Some data on casualties in HGV accidents are given in Table 5. A study of fatal accidents involving HGVs in 1976 has been given by Riley and Bates [14].

TABLE 5

Casualties in heavy goods vehicle accidents in 1986 (after Department of Transport [13])

A. No. of casualties

Other vehicle type	Fatalities	Casualties
HGV	24	672
LGV	–	137
Bus/coach	–	47
Car	4	622
Motorcycle	–	17
Pedal cycle	1	8
SVA (no pedestrian)	32	1045
SVA (pedestrian)	171	1184
Other	28	747
Total	260	4479

B. No of HGVs involved in injury accidents: rigid HGVs

Road type	No. of vehicles involved							
	Fatal accidents				All accidents			
	2-axle	3-axle	4-axle	All	2-axle	3-axle	4-axle	All
Non-BUR	239	41	50	330	3672	714	657	5082
BUR	164	32	25	221	3988	631	463	5043
All speed limits	403	73	75	551	7660	1345	1120	10125

C. No. of HGVs involved in injury accidents: articulated HGVs

Road type	No. of vehicles involved							
	Fatal accidents				All accidents			
	2-axle	3-axle	4-axle	All	2-axle	3-axle	4-axle	All
Non-BUR	35	127	83	245	447	1444	872	2763
BUR	15	39	15	69	283	674	316	1273
All speed limits	50	166	98	314	730	2118	1188	4036

TABLE 5 (*continued*)

D. No. of casualties by road type

Road type	Fatalities	All casualties
Non-BUR		
A roads	451	6452
B roads	34	838
Other roads	37	1095
All roads	522	8385
BUR		
A roads	205	4926
B roads	34	933
Other roads	74	2316
All roads	313	8175
All speed limits		
Motorways	73	1888
A roads	656	11,378
B roads	68	1771
Other roads	111	3411
All roads	908	18,448

E. Proportion of casualties by road type

Road type	Fatalities (%)	All casualties (%)
Non-BURs	57.5	45.5
BURs	34.5	44.3
Motorways	8.0	10.2

F. No. of occupant casualties

Occupants	Fatalities			Casualties		
	Non-BUR	BUR	All	Non-BUR	BUR	All
Drivers	53	8	61	1987	773	2760
Passengers	14	8	22	354	205	559
All occupants	67	16	83	2341	978	3319

Grattan and Hobbs [15] studied injuries to occupants of HGVs. In 1975 there were 3200 occupant casualties in HGVs, of which 800 were serious or fatal, the latter numbering 71. These casualties were usually the result of collision between two HGVs or between the HGV and a roadside obstacle. A 5% sample of the serious or fatal injuries was studied. All fatal injuries were associated with either massive intrusion of the cab structure or ejection of the occupant.

Hobbs et al. [16] have examined various classifications of injury, in a study which relates the injury classifications to the length of stay in hospital.

Kletz [8] quotes figures given by Hills [17] for the number of deaths from the road transport of hazardous chemicals in the UK in the period 1970–80 as 16 deaths overall, making an average of 1.23 deaths/y. From the context these are the deaths attributable to the load. Kletz also states that the average number of deaths per fatal accident is 1.5.

4.3 HGV accident frequency

In 1986 HGVs travelled 221×10^8 km and there were 13,429 accidents involving HGVs. A number of accidents involve more than one HGV. The number of HGVs involved in accidents is thus somewhat more than the number of accidents involving an HGV. The number of HGVs involved in accidents in 1986 was nearly 15,000.

Statistics on accidents involving HGVs are given in Tables 6–13. Table 6 gives the number of HGVs involved in accidents and Table 7 the number of accidents involving HGVs by axle configuration, body type and road type. Table 8 gives a breakdown of the road class on which the accidents occurred. Table 9 gives the number of HGV accidents in 1986 by combination of vehicles involved. Table 10 gives the frequency of HGV accidents by axle configuration, body type, road type and road class. Table 11 gives the frequency of HGV accidents in built-up areas by axle configuration, body type, road class and combination of vehicles involved. Table 12 gives the frequency of HGV

TABLE 6

Number of heavy goods vehicles involved in accidents in 1986 by axle configuration, body type and road type (after Department of Transport [5])

HGV type	Roads		
	All speed limits	Non-BUR[b]	BUR
Rigid			
2-axle	7660	3672	3988
3-axle	1345	714	631
4-axle	1120	657	463
Articulated			
3-axle	730	447	283
4-axle	2118	1444	674
5-axle	1188	872	316
All HGVs[a]	14,773	7958	6815

[a] Includes cases where the axle configuration was not reported.
[b] Non-BUR includes motorways.

TABLE 7

Number of accidents involving heavy goods vehicles in 1986 by axle configuration, body type and road type

HGV type	Roads		
	All speed limits	Non-BUR[b]	BUR
Rigid			
2-axle	7264	3482	3782
3-axle	1275	677	598
4-axle	1062	623	439
Articulated			
3-axle	692	424	268
4-axle	2009	1370	639
5-axle	1127	827	300
All HGVs[a]	13,429	7403	6026

[a] The only figure in this table given in the DoT statistics is that of 13,429 for the total number of accidents involving HGVs. The ratio of the number of accidents involving HGVs to the number of HGVs involved in accidents is thus 0.948 (13,429/14,773) and the other figures in the table have been obtained by applying this ratio to the figures in Table 2.
[b] Non-BUR includes motorways.

TABLE 8

Proportion of heavy goods vehicle accidents in 1986 occurring on different road classes (after Department of Transport [1])

Road class	Proportion of accidents (%)	
	Non-BUR	BUR
A	76	60
B	10	11
Other	14	29
Total	100	100

[a] Data exclude motorways.

single-vehicle accidents by axle configuration, body type and road class. Table 13 gives the proportion of HGV accidents by junction type and by impact position.

The basic annual accident statistics for HGVs in 1986 are:

No. of accidents = 13,429/y

No. of vehicles involved in accidents = 15,000

Proportion of vehicles involved in accidents = 15,000/435,000 = 3.4%/y

Frequency of accidents = $13{,}429/(221 \times 10^8) = 0.62 \times 10^{-6}$/km

TABLE 9

Number of heavy goods vehicle accidents in 1986 by combination of vehicles involved (after Department of Transport [5])

A. All accidents

	Accidents	
	Number	Proportion (%)
Accidents involving		
Single vehicle	1994	14.8
Two vehicles	8452	63.0
Three or more vehicles	2983	22.2

B. Two vehicle and single vehicle accidents

	Accidents	
	Number	Proportion (%)
Accidents involving		
Single vehicle	890	8.5
Car	5271	50.4
Bus/coach	186	1.8
LGV	594	5.7
HGV	529	5.1
Motorcycle[a]	1012	9.7
Pedal cycle	723	6.9
Pedestrian	1104	10.6
Other	137	1.3
Total	10,446	100.0

C. Two vehicle accidents only

Accidents with	Proportion (%)
Car	62.4
Bus/coach	2.2
LGV	7.0
HGV	6.3
Motorcycle[a]	12.0
Pedal cycle	8.6
Other	1.5
Total	100.0

[a] Motorcycles include combinations.

TABLE 10

Frequency of heavy goods vehicle accidents in 1986

A. Accidents by axle configuration, body type and road type[a]

HGV type	Frequency (accidents/10^6 km)		
	All speed limits	Non-BUR[b]	BUR
Rigid			
2-axle	0.55	0.40	0.86
3-axle	1.16	0.85	2.00
4-axle	1.06	0.78	2.20
Articulated			
3-axle	1.15	0.85	2.68
4-axle	0.49	0.38	1.28
5-axle	0.63	0.49	3.00
All HGVs[a]	0.62	0.46	1.08

B. Accidents by road class (after Department of Transport [5])

Road class	Frequency (involvements/10^6 km)	
	Non-BUR	BUR
A class	0.57	1.19
B class	1.15	1.21
Other	1.30	1.28
All	0.48	1.22

C. Accidents by axle configuration, body type and road class

HGV type	Frequency (accidents/10^6 km)					
	Non-BUR			BUR		
	A	B	Other	A	B	Other
Rigid						
2-axle	0.35	0.70	0.80	0.84	0.68	0.90
3-axle	0.74	1.48	1.69	1.95	1.98	2.09
4-axle	0.67	1.35	1.55	2.14	2.19	2.30
Articulated						
3-axle	0.74	1.48	1.69	2.62	2.67	2.81
4-axle	0.33	0.66	0.76	1.25	1.28	1.34
5-axle	0.43	0.85	0.97	2.91	2.99	3.14
All HGVs	0.66	1.32	1.51	1.05	1.08	1.13

[a] Accident frequency data in Section A are derived from data given in Tables 3 and 7

[b] Non-BUR includes motorways.

TABLE 11

Frequency of heavy goods vehicle accidents on BURs in 1986 by axle configuration, body type, road class and combination of vehicles involved

A. Car, bus/coach and motorcycle

HGV type	Frequency (accidents/10^6 km)								
	Car			MC			Coach/bus		
	A	B	Other	A	B	Other	A	B	Other
Rigid									
2-axle	0.45	0.46	0.48	0.09	0.09	0.09	0.02	0.02	0.02
3-axle	1.04	1.05	1.11	0.20	0.20	0.21	0.04	0.04	0.04
4-axle	1.14	1.16	1.22	0.22	0.22	0.24	0.04	0.04	0.04
Articulated									
3-axle	1.39	1.42	1.49	0.27	0.27	0.29	0.05	0.05	0.05
4-axle	0.66	0.68	0.71	0.13	0.13	0.14	0.02	0.02	0.03
5-axle	1.55	1.59	1.67	0.30	0.31	0.32	0.05	0.06	0.06
All HGVs	0.56	0.57	0.60	0.11	0.11	0.12	0.02	0.02	0.02

B. LGV, HGV and pedal cycle

HGV type	Frequency (accidents/10^6 km)								
	LGV			HGV			Pedal cycle		
	A	B	Other	A	B	Other	A	B	Other
Rigid									
2-axle	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.07
3-axle	0.12	0.12	0.12	0.11	0.11	0.11	0.14	0.14	0.15
4-axle	0.13	0.13	0.14	0.11	0.12	0.12	0.16	0.16	0.17
Articulated									
3-axle	0.16	0.16	0.17	0.14	0.14	0.15	0.19	0.20	0.21
4-axle	0.07	0.08	0.08	0.07	0.07	0.07	0.09	0.09	0.10
5-axle	0.17	0.18	0.19	0.16	0.16	0.17	0.21	0.22	0.23
All HGVs	0.06	0.06	0.07	0.06	0.06	0.06	0.08	0.08	0.08

[a] Accident frequencies in this table have been derived from the data in Tables 9 and 10.

4.4 Impact accidents

A study of the impact speed of HGVs in accidents has been made by Davies and Lees [18] based on tachograph records. Table 14 gives the impact speeds obtained in this study. The accidents may be regarded as a biased sample in

TABLE 12

Frequency of heavy goods vehicle accidents involving only a single vehicle in 1986 by axle configuration, body type and road class

A. BUR

HGV type	Frequency (accidents/10^6 km)								
	SVA (no pedestrian)			SVA (pedestrian)			Total SVA		
	A	B	Other	A	B	Other	A	B	Other
Rigid									
2-axle	0.05	0.05	0.06	0.07	0.07	0.07	0.12	0.12	0.12
3-axle	0.12	0.12	0.13	0.15	0.15	0.16	0.27	0.27	0.29
4-axle	0.13	0.13	0.14	0.17	0.17	0.18	0.30	0.31	0.32
Articulated									
3-axle	0.16	0.17	0.18	0.20	0.21	0.22	0.36	0.38	0.40
4-axle	0.08	0.08	0.08	0.10	0.10	0.10	0.18	0.18	0.18
5-axle	0.18	0.19	0.20	0.23	0.23	0.24	0.41	0.42	0.44
All HGVs	0.07	0.07	0.07	0.08	0.08	0.09	0.15	0.15	0.16

B. Non-BUR

HGV type	Frequency (accidents/10^6 km)								
	SVA (no pedestrian)			SVA (pedestrian)			Total SVA		
	A	B	Other	A	B	Other	A	B	Other
Rigid									
2-axle	0.02	0.04	0.05	0.03	0.05	0.06	0.05	0.09	0.11
3-axle	0.05	0.09	0.11	0.06	0.11	0.13	0.11	0.20	0.24
4-axle	0.04	0.08	0.10	0.05	0.10	0.12	0.09	0.18	0.22
Articulated									
3-axle	0.05	0.09	0.11	0.06	0.11	0.12	0.11	0.20	0.24
4-axle	0.02	0.04	0.05	0.03	0.05	0.06	0.05	0.09	0.11
5-axle	0.03	0.05	0.06	0.03	0.07	0.08	0.06	0.12	0.14
All HGVs	0.04	0.08	0.09	0.05	0.10	0.12	0.09	0.18	0.21

[a] Accident frequencies in this table have been derived from the data in Tables 9 and 10.

TABLE 13

Road position and impact position for heavy goods vehicle accidents

A. Road position (after Department of Transport [5])

Junction type	Proportion of accidents (%)			
	Rigid		Articulated	
	Non-BUR	BUR	Non-BUR	BUR
Roundabout	3.4	5.5	5.0	8.9
T or staggered junction	13.7	36.0	10.0	32.9
Y junction	1.3	1.7	1.1	1.4
Crossroads	4.2	13.6	3.1	12.5
Multiple junction	0.5	1.7	0.5	2.7
Slip road	2.7	0.5	4.1	1.3
Private entrance	5.0	5.0	3.0	5.2
Other	1.0	1.6	1.0	2.1
Not at or within 20 m of junction	68.2	34.4	72.2	33.0
Total	100.0	100.0	100.0	100.0

B. Impact position (after Riley and Bates [14])

Impact position	Proportion of impacts (%)				
	Car	MC	LGV	HGV	All vehicles
Front	66	41	63	53	59.4
Side	16	31	9	15	18.6
Rear	14	26	28	24	18.1
Other	4	2	0	8	3.9
Total	100	100	100	100	100.0

that the accidents were sufficiently serious for the police to have an interest and may tend therefore to give an overestimate of impact speed in injury accidents generally.

4.5 Fire accidents

An investigation of fire in road vehicles was carried out by North [10]. Although reported in 1974, most of the data relate to 1971 and are therefore rather old. The study does, however, contain some information on certain special aspects of vehicle fires, which are given below after consideration of the main fire statistics.

TABLE 14

Impact speeds of heavy goods vehicles in accidents (after Davies and Lees [18])

A. Collisions involving other vehicles

Impact speed (m.p.h.)	Non-BUR	BUR	Motorways
0–9	1	3	0
10–19	2	4	0
20–29	1	10	2
30–39	5	12	1
40–49	9	5	2
50–60	2	2	2
>60	1	0	0
Total	21	36	7

B. Single vehicle accidents

Impact speed (m.p.h.)	Non-BUR	BUR	Motorways
0–9	1	0	0
10–19	3	4	0
20–29	2	11	0
30–39	2	5	1
40–49	1	6	1
50–60	0	0	2
>60	0	0	1
Total	9	26	5

TABLE 15

Causes of fires in road vehicle fires 1984 (after Department of Transport [19])

Cause	Number	Proportion (%)
Deliberate ignition	7434	22.0
Smokers' materials	1165	3.4
Wiring of vehicle	8980	26.6
Oil and petroleum in contact with hot components	8475	25.1
Crash, collision	881	2.6
Other	4042	12.0
Unknown	2793	8.3
Total	33,770	100.0

Information on the causes of fires in vehicles in 1985 has been given by the DoT [19]. In that year out of some 248,000 accidents there were some 33,000 fires. The causes of these fires are given in Table 15. It can be seen from the table that the vast majority of vehicle fires are non-crash fires.

Information has also been obtained from the Home Office [20] for goods vehicle fires specifically. In 1986 fire brigades attended 7,212 van and lorry fires. Not all of these were on the public highway.

Of the 2578 HGV fires, 2559 (99.3%) were non-crash fires and 19 (0.7%) were crash fires. No breakdown is available for non-crash fires by vehicle type, but for crash fires the breakdown is as shown in Table 16. The causes of the HGV non-crash fires are given in Table 17.

TABLE 16

Number and frequency of heavy goods vehicle crash fires in 1986 (after Nyman [20])

A. Number of crash fires

HGV type	Non-BUR	BUR	All speed limits
Rigid			
2-axle	5	5	10
3-axle	1	1	2
4-axle	1	1	1
Articulated			
3-axle	1	0	1
4-axle	2	1	3
5-axle	1	0	2
All HGVs	11	8	19

B. Frequency of crash fires[a]

HGV type	Frequency (fires/10^8 km)		
	Non-BUR	BUR	All speed limits
Rigid			
2-axle	0.06	0.12	0.08
3-axle	0.12	0.28	0.16
4-axle	0.11	0.31	0.15
Articulated			
3-axle	0.12	0.38	0.16
4-axle	0.05	0.18	0.07
5-axle	0.07	0.42	0.09
All HGVs	0.06	0.15	0.09

[a] Crash fire frequencies in Section B have been derived from the data in Table 10

TABLE 17

Causes of heavy goods vehicle non-crash fires (after Nyman [20])

Cause	Number	Proportion (%)
Deliberate	352	14
Smokers' materials	147	6
Electrical	720	28
Oil, petrol, other fuel	1044	41
Sparks	31	1
Overheating	24	1
Other/unknown	241	9
Total	2559	100

TABLE 18

Location of lorry and tanker fires (after North [10])

Location	Proportion of fires (%)	
	Lorries	Tankers
Road or verge	71.7	67.4
Motorway	10.5	15.2
Field, open land	6.4	4.9
Cark park, yard	10.1	9.7
Garage forecourt	0.7	0.5
Garden	0.1	0.5
Other (specified)	0.5	1.6
Total	100	100

The study by North gives some information on the location of vehicle fires. His data for lorries and tankers are given in Table 18. They show that for HGVs some 82% of fires occur on roads. About another 10% occur in car parks, yards and garage forecourts, probably for the most part in built-up areas.

North also gives information on the number of fatalities and on the damage caused in vehicle fires, which may help to determine the severity of such fires. In 1971 there were 241 vehicle fires of which 16 were in lorries and 10 in tankers and in two lorry fires there was one death in each fire and in two tanker fires one death in each. In 1972 there were 289 vehicle fires of which 19 were in lorries and 12 in tankers and in one tanker fire there were two deaths, there being no deaths in the lorry fires. Thus for lorries out of 35 fires two were fatal (6%) and for tankers out of 22 fires three were fatal (14%).

TABLE 19

Number and frequency of a certain type of load-threatening accident (after James [21]—see text)

Road type	No. of accidents	Distance travelled (miles)	Accident frequency[a]	
			(accidents/mile)	(accidents/km)
Motorway	310	3202×10^6	9.68×10^{-8}	6.0×10^{-8}
A class	740	3855	19.2	11.9
B class	47	172	27.0	10.4
Total	1097	7229	15.2	9.4

[a] Allsop et al. [22] give an accident frequency (accidents/10^8 km) as follows: motorways 11.5; A roads 36.5; B roads 114; other roads 83.1.

North gives information on the resultant damage in a sample of car fires in 1971. Out of 200 fires 73 caused minor damage, 44 damaged the original compartment, 24 damaged or severely destroyed the original compartment, 15 damaged more than one compartment, 2 damaged the exterior, 40 (20%) damaged or destroyed the whole car, and 2 had no recorded result.

From the above the following annual estimates can be made for HGV fires.

No. of crash fires = 19

Crash fires as a proportion of accidents = 19/13,429 = 0.14%

No. of non-crash fires = 2559

Non-crash fires as a proportion of accidents = 2559/13,429 = 19%

4.6 Load-threatening accidents

Investigations of accidents which might threaten the load of a large HGV transporting radioactive waste have been made by James [21) and by Allsop et al. [22]. The study by James is concerned with articulated, five-axled HGVs. For the determination of accident frequency he assumes that only serious accidents, involving death or serious injury, have the potential to threaten the load. Thus James considers only accidents where the subject vehicle was an articulated HGV of gross vehicle weight (GVW) of more than 1.5 tonnes, where death or serious injury was involved, and where the accident either was a single vehicle accident or involved another HGV of GVW greater than 1.5 tonnes. Table 19 shows his data for the number and frequency of such accidents.

Also shown in the table are the results obtained by Allsop et al. They considered all injury accidents involving either four-axle or five-axle HGVs in overturning or side damage. The accident frequencies obtained by these workers are appreciably higher. For motorways and A roads their results are higher than those of James by a factor of 2–3. The factor is greater for B roads and other roads, but James' data shows relatively little distance travelled by these large HGVs on the lower class roads.

4.7 Chemical accidents

An account of the chemical accidents attended by the UK public fire service in 1980 has been given by Maclean [11]. There were 983 special service calls in which dangerous chemicals were involved and 968 actual incidents. The incidents occurred at both fixed installations and in transport.

Table 20 gives the nature and number of these incidents. The principal chemicals involved, together with the number of incidents, were: hydrochloric acid (66), ammonia (65), LPG (42), sulphuric acid (34) and sodium hydroxide (30). There were 14 incidents involving petroleum and 10 involving ammonium nitrate. Of these incidents 132 were fires in which the presence of the chemical affected the fire fighting to a significant degree, 18 were fires in which dangerous chemicals behaved in an abnormal manner and 25 were fires at which dangerous chemicals were present and gave rise to casualties.

For all transport incidents, both road and rail, there were 419 incidents, excluding cases in which chemicals were washed ashore. Of these 105 (25%) occurred in rural areas, 187 (45%) in urban industrial areas, 113 (27%) in urban residential areas and the remaining 14 (3%) in unrecorded locations.

As far as concerns the road transport incidents, there were 335 incidents of which 21 (6%) were on motorways, 120 (36%) on A class roads, 56 (17%) on B class roads, 29 (9%) on unclassified roads, 96 (29%) occurred in a parking area off the public roads and the remaining 14 (3%) in unrecorded locations.

TABLE 20

Nature of chemical incidents attended by UK public fire services in 1980 (after Maclean [11])

Nature of incident	Number of incidents	Proportion of incidents (%)
Chemical overheated	9	1
Spillage	419	43
Leakage	211	22
Vapour, gas escape	80	8
Potential spillage	11	1
Fire	173	18
Explosion	10	1
Chemical found	19	2
Other	20	2
Unknown	16	2
Total	968	100

In 243 (73%) of the incidents the vehicle was attended. Therefore the number of incidents in which it was unattended was up to 92 (27%).

In only 36 (11%) of the cases was an accident reported as the primary cause of the incident.

4.8 Background on accidents

A discussion of the UK accident statistics is given by Johnson and Garwood [12], McBean [23] attempts to assess the influence of road features on accident frequency and Scott [3] that of traffic density, whilst Storie [24] considers the effect of driver characteristics.

A study of HGV accidents was made in 1979 by Neilson et al. [25], but the data given above are more up-to-date.

5. Collision analysis

The attempt to estimate the frequency of a particular type of event arising from an HGV collision will depend both on the probability of the event given a collision with a particular effective impact velocity, and on the frequency of a collision of sufficient severity with this impact velocity.

The effective impact velocity will depend on the closing, or impact, speed. For a single vehicle accident all that is required is the impact speed of a single HGV. Data from which may be constructed a probability density function for HGV closing speeds in accidents were given in Table 14. For an accident involving two vehicles it is necessary to combine the probability density functions of the two vehicles. In such cases the probability density function for HGV impact speed may be used for both vehicles. The determination of the probability of a given combined impact speed in head-on collision of two HGVs is described in the Appendix.

Some form of collision analysis can then be used to determine the effect on the vulnerable vehicle for collisions of particular severities. Hence the probability of the event of interest given collision can be estimated.

An early example of such an approach was the investigation by Westbrook [26] of the comparative risks of chlorine transport by road, rail and pipeline. The study included a road tanker collision analysis to determine the probability of puncture given a crash.

A series of collision analysis studies for HGVs for US conditions is available in Gardner and Moffatt [27].

6. HSE transport risk studies

The Advisory Committee on Major Hazards in its Third Report [28] recommended that although its terms of reference were restricted to fixed installations, the major hazard potential from the transport of hazardous materials should also receive attention. In pursuance of this recommendation, the Health and Safety Executive (HSE) have carried out a number of studies on transport risks. Some of these are concerned with rail transport and with consequence modelling, which are not of concern here, but others bear on the frequency of road transport incidents and the probability of hazardous events.

Canadine and Purdy [29] give a hazard assessment of the rail and road transport of chlorine. The principal producer of chlorine in the UK is ICI. The company has some 19 road tankers with payloads 15–21 tonne. Over a 60-year period there have been three leaks. Two were due to incompletely closed valves and were quickly rectified and the third was minor.

The frequency with which these tankers are involved in accidents is significantly lower than for commercial transport generally. The vehicles are fitted with various arrangements to reduce the accident rate such as high quality suspension, anti-skid devices, anti-jack-knife systems, fuel cut-off devices, additional fire protection, regular and fog lights, etc. The tankers have their liquid and vapour valves protected in a recessed valve chest at the front of the vehicle. They have excess flow valves and the two latest vehicles also have remotely operated shutoff valves.

Since 1976 the company has taken additional measures to reduce the consequences of any collision. Additional rear and side protection has been fitted to resist penetration, absorb energy and spread the load in case of collision. The value of these measures was illustrated in 1985 when the most serious accident recorded to date occurred. A chlorine tanker was hit by a 38 tonne articulated lorry travelling at an estimated 60 m.p.h. down a hill near Baslow in Derbyshire. The vehicle veered diagonally across the road and hit the chlorine tanker on its front offside, stopping it dead and driving it sideways across the road. The side protection on the tanker absorbed most of the collision energy and spread the load as it was designed to do; there was no leak.

7. Exposed population

7.1 Population density and other characteristics

A study of the density and other characteristics of the population which might be exposed to hazardous materials has been given by Petts et al. [30]. The information given includes data for the UK on population densities, both by day and by night, on the proportions of person indoors and outdoors, and on the proportion of the population which may be considered particularly vulnerable.

There have also been specialist studies of the population density along routes taken in the transport of hazardous materials. These include the TRIP program referred to in the second Canvey Report [31] and the study by Canadine and Purdy [29] already mentioned.

7.2 High density targets

Of particular interest is the probability that any incident will occur at a location where large numbers of people are exposed. An estimate of this probability for built-up areas may be made from V-2 rocket incidents. The distribution of the rockets which fell on London was effectively random. Analysis of the 517 V-2 incidents in London gives 8.9% which caused ≥ 10 deaths and 1.4% which caused ≥ 33 deaths.

7.3 Emergency services

In addition to the population who are normally in the area, personnel of the emergency services who attend the accident are also at risk. It is not uncommon in an incident involving the road transport of hazardous materials that a significant proportion of the casualties include such personnel.

A typical road accident involving injury and fire would probably be attended by one police patrol car (2 persons), one fire tender (4–5 persons) and one ambulance (2–3 persons). If the incident is considered serious and time permits, additional fire tenders may attend [32, 33].

8. Emergency services

8.1 Attendance times

In assessing the consequences of an incident, the time for the fire services to attend may be important. In accordance with Home Office guidance, fire brigades classify areas into different categories of risk. For each category there is a specified minimum number of pumps (i.e. fire engines) which are required to attend the scene and a maximum time for their arrival. Information from the London Fire Brigade [32] indicates that a vehicle fire is normally attended by one fire engine and that for the type of area through which road transport of explosives takes place, for example, the maximum attendance time is 20 minutes. The mean attendance time is between 10 and 15 minutes.

9. Some studies in other countries

There have been a number of studies in North America on the transport of hazardous materials. Several of the more recent studies are considered here.

A review of accidents involving, and releases from, vehicles carrying hazardous materials has been given by Glickman [34]. The data are based on the reporting system of the Department of Transportation, Office of Hazardous Materials Transportation. The basic data consist of the distance travelled by trucks carrying hazardous materials and the number of accidents involving a spillage.

The reporting system requires the recording of any unintentional release occurring during loading/unloading, transportation, or temporary storage. The author equates such releases to spillages. Spillages are treated as significant if they involve more than 5 US gallons or 40 lb of material. From these reporting requirements, from the data given by Maclean above and from the other data given below, it would seem that most of these spillages do not in fact occur due to road traffic accidents on the public highway.

Some data from the study are shown in Table 21. The frequency of spillages is obtained by simply dividing the number of spillages by the distance travelled by the vehicles.

There are several points of interest in these data. One is the rather high ratio of distance travelled by vehicles other than tank trucks to that travelled by tank trucks. Another is the rather lower ratio of the number of significant spillages for vehicles other than tank trucks to the number for tank trucks. Another is the striking difference in the frequencies of spillage between private trucks and trucks for hire.

The overall frequency of significant spillages is:

$$\text{Frequency of significant spillages} = 1667/(16{,}220 \times 10^6)$$

$$= 0.1 \times 10^{-6} \text{ spillages/vehicle mile}$$

$$= 0.062 \times 10^{-6} \text{ spillages/vehicle km}$$

Harwood et al. [35] have collated information on hazardous material (HAZMAT) accidents. This information was obtained from the Department of Transportation's Research and Special Programs Administration (RSPA) Hazardous Materials Incident Reporting System (HMIR) data base. The system is based solely on self-reporting by carriers. No minimum release quantity or damage level is specified and technically any release, however, small is reportable. The requirements apply, however, only to interstate transport and carriers engaged solely in intrastate transport are not required to report HAZMAT incidents under this scheme.

Data were analysed for the period 1981–1985. During this time there were 28,433 HAZMAT incidents reported. Some data on these incidents are given in Table 22.

As the table shows, the proportion of HAZMAT incidents due to traffic was 11%. However, the proportion of severe incidents due to traffic lay between 35% and 68%, depending on the definition of severity. The authors give one definition of a severe incident as one involving injury or death, a fire or explosion or more than $50,000 dollars worth of damage.

The authors also give information from another data base, the Motor Carrier Accident Report maintained by the FHWA Bureau of Motor Carrier Safety (BMCS), now renamed the Office of Motor Carriers. This data base gives information on trucks involved in accidents, including whether the truck was carrying hazardous materials and whether a release occurred. The reporting

TABLE 21

Distance travelled and number and frequency of spillages for US trucks carrying hazardous materials in 1982 (after Glickman [34])

A. Distance travelled

Type of vehicle	Distance travelled (10^6 vehicle miles)
Trucks	
Private	6416
For hire	9804
Total	16,220
of which	
Tank trucks	
Private	4121
For hire	307
Total	4228

B. Number of spillages

Type of vehicle	No. of spillages	
	Total	Significant
Trucks		
Private	357	233
For hire	5314	1434
Total	5671	1667
of which		
Tank trucks		
Private	248	178
For hire	936	692
Total	1184	870

C. Frequency of spillages

Type of vehicle	Frequency of spillages (spillages/10^6 vehicle miles)	
	Total	Significant
Trucks		
Private	0.0556	0.0363
For hire	0.542	0.146
of which		
Tank trucks		
Private	0.0602	0.0432
For hire	3.049	2.254

TABLE 22

HAZMAT incident data from the Department of Transportation RPSA data base for 1981–85 (after Harwood et al. [35])

A. Location of incidents

Location	Proportion (%)	Number
On public highway	48	13,547
Off public highway	39	ca. 11,089
Unknown	13	ca. 3,797
Total	100	28,433

B. Failure involved in incidents on public highway

Failure type	Number	Proportion (%)
Traffic accident	1427	10.8
Body or tank failure	2741	20.2
Valve or fitting failure	3289	24.3
Cargo shifting	4945	36.5
Fumes or venting	15	0.1
Other	1100	8.1
Total	13,547	100.0

C. Hazardous materials involved in incidents on public highway

Material	All incidents (%)	Traffic incidents (%)
Flammable liquids	46	71
Toxic liquids	5	
Corrosive liquids	40	13

D. Consequences of incidents on public highway

Count	Number of incidents		
	Traffic incidents	Other incidents	All incidents
No. of incidents	1457	12,090	13,547
No. of deaths	50	4	54
No. of injuries	115	358	473

system applies, however, only to interstate carriers. Data from this source are given in Table 23.

An analysis of accident rates in three states (California, Illinois and Michigan) and of release probabilities overall in the USA has been given in a study by Harwood et al. [36], which follows on from the authors' earlier work

TABLE 23

Data on HAZMAT trucks involved in accidents from the Department of Transportation BMCS data base for 1984–85 (after Harwood et al. [35])

A. Truck accidents

Truck	Number
Non-HAZMAT trucks	71,164
HAZMAT trucks	3,703
of which	
No release	3,183
Release	530

B. Cargoes of HAZMAT trucks in accidents

Cargo	Number of accidents		
	No release	Release	Total
General freight	680	61	741
Gases in bulk	238	21	259
Solids in bulk	28	12	40
Liquids in bulk	1486	345	1831
Explosives	63	7	70
Empty	210	10	220
Other	467	62	529

C. Consequences of HAZMAT truck accidents

Count	Number of accidents		
	No release	Release	Total
No. of incidents	3183	520	3703
No. of deaths	273	53	326
No. of injuries	2514	441	2955

[35, 37]. The data were obtained from the accident reporting systems of these states. Table 24 gives data on accident frequencies and modes and Table 25 data on release frequencies and probabilities.

The accident frequencies differ appreciably between the different classes of highway. They also apparently differ appreciably between states. The probabilities of release given an accident, however, are relatively similar for rural highways as a group and for urban highways as a group.

TABLE 24

Truck accidents in three states in the USA (after Harwood et al. [36])

A. Number and frequency of accidents

Road type	California			Three states
	No. of accident involvements[a]	Distance travelled (10^6 miles)	Accident frequency[b] (accidents/ 10^6 miles)	Accident frequency[b] (accidents/ 10^6 miles)
Rural				
Two-lane	6577	3784.97	1.73	2.19
Multilane (undivided)	1070	196.58	5.44	4.49
Multilane (divided)	1801	1463.45	1.23	2.15
Freeway	5759	10850.90	0.53	0.64
Total	15207	16295.60	0.93	
Urban				
Two-lane	1778	420.69	4.23	8.66
Multilane (undivided)	2251	172.84	13.02	13.92
Multilane (divided)	4996	1427.47	3.50	12.47
One-way street	223	33.81	6.60	9.70
Freeway	28860	18107.00	1.59	2.18
Total	38108	20161.81	1.81	
Grand total	53315	39781.10	1.34	

B. Single vehicle accidents (California only)[c,d]

Road type	Proportion of accidents (%)						
	Non-collision accidents			Collisions with			
	Run off road	Overturn	Other	Fixed object	Parked vehicle	Non-motorist	Other
Rural							
Two-lane	4.5	6.6	4.4	7.0	2.4	0.6	5.7
Multilane (undivided)	3.6	7.5	3.9	7.5	4.3	0.4	5.7
Multilane (divided)	3.6	4.0	3.8	6.4	3.9	0.2	4.7
Freeway	3.5	3.3	3.8	7.4	3.8	0.4	5.0
Total	3.9	5.1	4.1	7.1	3.2	0.5	5.3
Urban							
Two-lane	1.5	2.6	3.4	5.1	3.6	0.3	3.9
Multilane (undivided)	0.2	0.6	2.6	5.1	8.5	0.8	4.0
Multilane (divided)	0.8	1.3	2.4	5.7	7.0	0.6	3.8
One-way street	0	2.2	0.9	6.3	9.4	1.3	2.2
Freeway	0.6	1.0	1.3	3.2	1.9	0.2	1.7
Total	0.6	1.1	1.6	3.8	3.1	0.3	2.2
Grand total	1.6	2.3	2.3	4.7	3.1	0.4	3.1

TABLE 24 (*continued*)

C. Multiple vehicle collision accidents[c]

Road type	Proportion of accidents (%) collisions with		
	Car	Truck	Other vehicle
Rural			
Two-lane	29.8	26.6	12.4
Multilane (undivided)	27.4	26.1	13.7
Multilane (divided)	33.4	26.4	13.8
Freeway	31.3	22.3	19.4
Total	30.6	24.9	15.3
Urban			
Two-lane	39.6	30.7	9.3
Multilane (undivided)	41.3	30.1	6.9
Multilane (divided)	43.7	28.1	6.6
One-way street	45.7	27.4	4.5
Freeway	50.6	25.6	13.9
Total	48.6	26.4	12.3
Grand total	43.4	26.0	13.1

[a] Accidents involving two or more trucks counted as two or more involvements.
[b] Average weighted according to vehicle-miles.
[c] Proportion of accidents in Sections B and C combined.
[d] There were no cases of collision with a train.

An analysis of incidents in Canada in which there were releases of gasoline or LPG has been made by Stewart and van Aerde [38]. The incidents were those reported under the regulatory system as dangerous occurrences in the period 1986 to August 1987 (1.7 years). Thus not all accidents were reported and the data are therefore not comparable with those reported under the US HAZMAT scheme.

There were 41 incidents involving gasoline. A proportion of these may not have been transport incidents. The proportion known to be transport incidents was 81%, leaving between 0% and 19% which may not have been. Table 26 gives the number of incidents by type of release.

The three major types of incident were collision, collision/overturn and overturn. The proportion of lading released in these cases was 30–40%. For fires, the release was large (98%) except in one case where it was very small (3%). Of these three types of incident, overturns caused most container damage. The authors suggest that in collision accidents a large proportion of the energy is dissipated in other parts of the vehicle.

There were four evacuations of the public in the 41 incidents.

A similar analysis is given for the LPG incidents, but there were only nine of these.

TABLE 25

Probability and frequency of release of material in truck accidents in USA (after Harwood et al. [36])

A. Probability of release by accident type: single vehicle accidents

Accident type	Probability of release
Non-collision accidents	
Run off road	0.331
Overturn	0.375
Other	0.169
Collisions with	
Fixed object	0.012
Parked vehicle	0.031
Train	0.455
Nonmotorist	0.015
Other object	0.059

B. Probability of release by accident type: multiple vehicle accidents

Accident type	Probability of release
Collision with	
Passenger car	0.035
Truck	0.094
Other vehicle	0.037

C. Probability and frequency of release by road type

Road type	Probability of release	Frequency of release (release/10^6 vehicle-miles)
Rural		
Two-lane	0.086	0.19
Multilane (undivided)	0.081	0.36
Multilane (divided)	0.082	0.18
Freeway	0.090	0.06
Urban		
Two-lane	0.069	0.60
Multilane (undivided)	0.055	0.77
Multilane (divided)	0.062	0.77
One-way street	0.056	0.54
Freeway	0.062	0.14

TABLE 26

Tanker accidents involving release of gasoline in Canada (after Stewart and van Aerde [38])

Accident type	No. of releases						Proportion (%)
	Spill	Leak	Spill/fire	Fire	Other	Total	
Collision	2			1		3	7
Collision/overturn	5		1			6	15
Overturn	19	1			1[a]	21	51
Brake failure	2					2	5
Puncture	2	1				3	7
Fitting/hose failure		1		1		2	5
Fire				2[b]		2	5
Military exercise	1					1	2
Bridge collapse	1					1	2
Total	32	3	1	4	1	41	

[a] Environmental contamination.
[b] One of these is classified as spill/fire.

Further more general data are given in the review of transportation of hazardous materials in Ontario by Gorys [39].

Griffiths and Linklater [40] have reported a study performed in 1980 of some 42 accidents involving road tankers transporting flammable materials in New South Wales (NSW). In 1979 in NSW there were some 3000 road tankers carrying flammable loads and some 100 pressurised tankers. The annual crash rate was 2.5%, which was the same as for all vehicles.

There were 42 accidents investigated, 11 involving non-articulated vehicles and 31 involving articulated vehicles. There were 18 rollovers, 5 for the non-articulated vehicles and 13 for the articulated vehicles.

In 24 cases there was no leakage of the bulk load but in three of these there was leakage of the prime mover fuel tanks. In 10 of the rollover cases there was substantial leakage. In two of the non-rollover cases the tank was punctured and burned out. Of the other non-rollover cases, one involved loss of "a lot" of product from a fractured pipe fitting, one loss from a discharge pipe and two loss from vents.

The authors state that fire occurred in 5% of cases. This would seem to cover the two cases of burnout just mentioned and to imply that none of the other cases involved a fire.

The authors obtained data on the various factors which influenced the accident under the headings: mechanical, environmental, behavioural and general.

Factors causing rollover included high centre of gravity, 'soft' roll stiffness and sloshing of the liquid. None of the tankers appeared to have side baffles.

From these data the following estimates may be made for crash fires:

No. of crash fires = 2

Crash fires as proportion of accidents is then 2/42 or 4.8%

10. Some estimates for HGVs conveying hazardous materials

Some estimates are now made for HGVs conveying hazardous materials (HGV/HMs) in Great Britain.

10.1 No of HGV/HMs

The number of road tanker HGV/HMs was given above as 14,000. There are in addition HGVs other than tankers carrying hazardous materials. The number of such vehicles which at some time transport hazardous materials may be quite large, but what matters in the present context is the number of equivalent 'full-time' vehicles. There appears to be no reliable source of information for this figure. An estimate has therefore been made. The data for hazardous cargoes in the USA given in Section B of Table 23 indicate that the ratio of non-tank truck to tank truck HGV/HMs is about 0.6. Those given in Section B of Table 21 for significant spillages indicate that the ratio of non-tank truck to tank truck HGV/HM spillages is about 0.9. The former figure is regarded as a better guide. A roadside survey conducted by the authors is consistent with this estimate. The ratio of 0.6 is used for Great Britain also, which yields:

No. of tanker HGV/HMs = 14,000

No. of non-tanker HGV/HMs = $0.6 \times 14{,}000 = 8400$

No. of HGV/HMs = $14{,}000 + 8400 = 22{,}400$

10.2 Distance travelled by HGV/HMs

Then for the distance travelled by HGV/HMs

Distance travelled by individual vehicle = 60,000 miles = 96,500 km

Distance travelled by fleet = $22{,}400 \times 60{,}000 = 13.4 \times 10^8$ miles = 21.6×10^8 km

10.3 Accident frequency for HGV/HMs

HGVs carrying hazardous materials have a higher standard of design and operation, although the extent of this is variable. It may therefore be expected that the accident rate would be less. Information obtained by the authors for munitions vehicles indicates a reduction factor of about 0.1–0.33. For HGV/HMs it seems doubtful whether such a large reduction is appropriate. Accordingly, the estimate used here is 0.8.

Griffiths and Linklater [40] found that the proportion of HGV/HMs suffering an accident was the same as for HGVs generally. Although a lower accident rate per unit distance travelled is assumed here for HGV/HMs, these vehicles travel a greater distance per year, and the net effect is to give them an annual accident rate comparable with or rather greater than that of other vehicles.

Taking the estimate

Ratio of HGV/HM to HGV accident rates = 0.8

then for HGV/HM accidents:

Frequency of accidents = $0.8 \times 0.62 \times 10^{-6}$/km = 0.50×10^{-6}/km
No. of accidents = $0.50 \times 10^{-6} \times 21.6 \times 10^{8}$ = 1080 accidents/y
No. of vehicles involved in accidents = (15,000/13,429) × 1080 = 1206
Proportion of vehicles involved in accidents = 1206/22,400 = 5.4%/y

For MoD munitions vehicles (MVs) taking the estimate

Ratio of MV to HGV accident rates = 0.2
Frequency of accidents = 0.12×10^{-6}/km

10.4 Release frequency and probability for HGV/HMs

An estimate of the frequency and probability of release given an accident can be made from the data given by Maclean. From his data:

No. of releases due to traffic accidents = 36

Then

Frequency of release = 36/(21.6×10^{8}) = 0.017×10^{-6} releases/km
= 0.027×10^{-6} releases/mile
Probability of release given traffic accident = 36/1080 = 0.033 = 3.3%

These estimates are based on attendance by a fire brigade and should be regarded as lower limits.

These results may be compared with the US figures. From the data given in Table 23, the probability of release given a traffic accident lies in the range 0.055–0.090. The estimate for the UK is somewhat low relative to these figures, but not unduly so.

For the frequency of release, the US figures are in the range 0.06–0.77 releases/10^6 miles, the higher figures being for the less common road categories. For the three dominant road categories the figures are 0.06, 0.14 and 0.19 releases/10^6 miles. The estimate for the UK is much less than these figures. This appears to be due partly to a lower probability of release given an accident and partly to a lower accident rate.

10.5 Fatal accidents for HGV/HMs

Ratio of fatal accidents to injury accidents = 0.022

No. of fatal accidents = 0.022 × 1206 = 26.5/y
No. of fatalities per fatal accident = 1.5
No. of fatalities from accidents = 1.5 × 26.5 = 39.8 (say 40)

About one death per year is attributable to the load and the rest are due to traffic accidents.

11. Individuality of incidents

It is easy in a preoccupation with incident statistics to lose sight of the individuality of some of the accidents which have occurred involving the road transport of hazardous materials. Mention has already been made of the chlorine tanker crash with a lorry travelling down hill at 60 m.p.h. Other incidents with rather unusual features include the San Carlos campsite disaster [41], which was not initiated by either crash or fire and which involved a vulnerable target, and the explosion of an explosives lorry at Peterborough [42], which involved a fire rather than a crash and occurred off the road in a company yard.

12. Discussion

The information given above is intended to provide a basic set of data which may be of assistance in the assessment of the hazards of road transport in Great Britain.

The information provided includes some data which may be used to make generic estimates based on historical event data. However, some hazards are realised so rarely that data are sparse or non-existent. In such cases it is possible to proceed using estimates of event frequency based on the statistics of a small number of events or even zero events.

Alternatively, an attempt may be made to model the event, in which case a different set of data is required. The information given includes some data of this kind also.

Moreover, enough has been said to indicate that even where historical data do exist, they may or may not be directly applicable. A case in point is the provision of side protection on tankers. This is provided on the ICI chlorine vehicles but not on the Australian road tankers described. In such cases it may be appropriate to modify any historical data to take account of the difference between the conditions to which those data apply and the conditions of the problem in hand. Again this may involve modelling and the use of data appropriate to that.

The principal aim of the paper has been to provide data relevant to events arising from traffic accidents. These events are not synonymous with hazardous material incidents involving vehicles and in fact may constitute only a small proportion of the latter. Care is needed, therefore, in interpreting data on hazardous material incidents.

Two of the principal events which may cause an incident are collision and fire. However, other events should not be neglected. For road tankers other causes of release may be leaks from valves and from overfilling.

With regard to fire, for HGVs generally non-crash fires are much more frequent than crash fires. The Australian work indicates, not surprisingly, that

TABLE 27

Summary of principal data given in this paper

A. Great Britain

Road network	Sec. 3.2
Length	Sec. 3.2; Table 1
HGVs	
Types	Figure 1
Number	Sec. 3.3
Weight distribution	Sec. 3.3; Table 2
Distance travelled	
Overall	Sec. 3.4; Table 3
Road classes	Sec. 3.4; Table 4
HGV accidents	Sec. 4.2
Number	
Overall	Sec. 4.3; Tables 6, 7
Vehicle type and road class	Sec. 4.3; Tables 5–9
Frequency	
Overall	Sec. 4.3
Vehicle type and road class	Sec. 4.3; Tables 10–12
Junction type and impact position	Sec. 4.3; Table 13
Impact speeds	Sec. 4.4; Table 14
HGV fire accidents	Sec. 4.5
Number, frequency	Sec. 4.5
Causes	Sec. 4.5; Table 15
Crash fires	
Number	Sec. 4.5; Table 16
Non-crash fires	
Number	Sec. 4.5
Causes	Sec. 4.5; Table 17
Location	Sec. 4.5; Table 18
HGV load-threatening accidents	Sec. 4.6
Number	Sec. 4.6; Table 19
HGV chemical accidents	Sec. 4.7
Number	Sec. 4.7; Table 20
HGV/HMs	
Number	Sec. 3.5; 10.1
Distance travelled	Sec. 3.5; 10.2
HGV/HM accidents	
Number, frequency	
Overall	Sec. 10.3
Release accidents	Sec. 10.4
Fatal accidents	Sec. 10.5
MV accidents	
Frequency	Sec. 10.3
Exposed population	
Population density	Sec. 7.1
High density targets	Sec. 7.2
Emergency services	
Attendance times	Sec. 8.1

TABLE 27 Continued

B. North America

HGV/HMs	
Distance travelled	Sec. 9; Table 21
HGV/HM accidents and releases	
Number, frequency	Sec. 9; Tables 21, 23–25
Vehicle type	Sec. 9; Table 21
Road class	Sec. 9; Tables 21, 22, 24, 25
Failure type	Sec. 9; Tables 22, 26
Materials involved	Sec. 9; Tables 22, 23
Consequences	Sec. 9; Tables 22, 23
Injuries	Sec. 9; Tables 22, 23

this is less so for road tankers carrying flammable materials. Nevertheless, the figures suggest that even for such tankers non-crash fires may be more significant.

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Appendix

Probability of a given combined impact speed in head-on collision of two HGVs

One problem which arises in assessing the hazards of road transport is the estimation of the probability of a head-on collision of two HGVs. Given that there is available a distribution of HGV impact speeds such as that shown in Table 14, the distribution of the impact speeds of an HGV–HGV head-on collision and the probability that the speed lies within a certain range may be obtained as follows. Consider a normal distribution of HGV impact speeds $f(x)$ on built-up roads, where x is the impact speed, with a mean $\bar{x}$ and standard deviation σ. Then for the distribution $f(x_c)$ of the combined (i.e. summed) impact speeds

$$\bar{x}_c = 2\bar{x} \tag{A.1}$$

$$\sigma_c^2 = 2\sigma^2 \tag{A.2}$$

$$\sigma_c = \sqrt{2}\sigma \tag{A.3}$$

The probability P that the combined impact speed x_c lies between x_{c1} and x_{c2} is then

$$P[x_{c1} < x_c < x_{c2}] = P[((x_{c1} - \bar{x}_c)/\sigma_c) < z_c < ((x_{c2} - \bar{x}_c)/\sigma_c)] \quad (A.4)$$

$$= P[a < z_c < b] \quad (A.5)$$

$$= I(b) - I(a) \quad (A.6)$$

$$= P \quad (A.7)$$

Values of $I(a)$ and $I(b)$ can be obtained from standard tables of the normal distribution.

As an illustration consider the following example:

$\bar{x} = 30.6$ m.p.h., $\sigma = 12.2$ m.p.h. $\bar{x}_c = 2 \times 30.6 = 61.2$, and

$\sigma_c = \sqrt{2} \times 12.2 = 17.3$ m.p.h.

The probability that the collision speed is between 110 m.p.h. and 130 m.p.h. is then:

$$P[((110 - 61.2)/17.3) < z_c < ((130 - 61.2)/17.3)]$$

$$= P[2.28 < z_c < 3.98] = I(3.98) - I(2.82)$$

$$= 0.9999 - 0.9976 = 2.3 \times 10^{-3}$$

This method provides a simple and rapid estimate of the probability of the combined collision speed, given a collision. The results are, however, only as good as the quality of fit of the distribution used. Specifically, the method relates to the tail of the distribution. The fitting and use of tails is a common problem in the use of distributions. In some cases it may be preferable to use alternative methods which give a more accurate treatment of the tail.