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Technical Assessment of Petroleum Road Fuel Tankers

WP3: Accident Data and Regulatory Implications

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Executive Summary

Vehicles used to carry large quantities of dangerous goods, such as petroleum products and chemicals, must meet the requirements of the European Agreement on the Carriage of Dangerous Goods by Road (ADR). Following examination, certain petroleum road fuel tankers have been found not to be fully compliant with the provisions of Chapter 6.8 of ADR. Amongst other things, these tanks are seen to exhibit extensive 'lack of fusion' indications in the circumferential welds.

Following an initial technical assessment¹ of the circumferential welds, which showed that the welds might rupture under rollover and ADR load conditions, the Department for Transport (DfT) commissioned further research to assess the safety of these non-compliant tankers. The researchers were also tasked to explore any opportunities arising for better regulation which could improve both the safety and efficiency of all petroleum road fuel tankers. The research consisted of three work packages:

- WP1 – Full scale testing and associated modelling, led by the Health and Safety Laboratory (HSL).
- WP2 – Detailed Fracture and Fatigue Engineering Critical Assessment (ECA), led by TWI Ltd.
- WP3 – Accident data and regulatory implications, and production of an overall summary report of the research, led by TRL Ltd.

Specifically, the stated objectives of WP3 were:

- Task 1 – Determine representative rollover and collision loads, and
- Task 2 – Identify regulatory implications and potential amendments.

The aim of Task 1 was to provide background intelligence on fuel tanker accidents, e.g. the frequency of such events, their main characteristics and the prevalence and cause of fuel spillage and/or tank rupturing. Tank rupture was thought, at the outset of the project, likely to be rare, so the research net was cast wide and involved an international review of multiple sources:

- i. Published international research literature (from 1995 – 2014)
- ii. DfT statistics/records (including STATS19² data, ADR and RIDDOR reports)
- iii. Local news media articles
- iv. Detailed (in-depth) truck accident databases (RAIDS)³
- v. Stakeholder surveys (of tanker operators, repairers and international experts)

In total, 116 papers and articles were identified by the literature search. Various studies of relevance were identified internationally, in particular from the USA and Germany.

Although the absolute numbers are likely to underestimate the true picture, indications are that 'FL vehicles' (6-axle articulated tankers above 7.5 tonnes mgw licensed to carry flammable liquids) are involved in 1.58 injurious collisions per 100 similar vehicles per annum; almost 20% lower than the rate of all 6-axle artics. The annual rollover

¹ 'Short-term Fitness for Service Assessment of [non-compliant] Road Tankers, TWI (Draft) Report 23437/1/13, September 2013 and 'Project 23437 Contract Amendment: Additional FEA for assessment of [non-compliant] road tankers, TWI (Draft) Report 23437/2/13, October 2013.

² The database of police-reported road accidents in Great Britain

³ The Road Accidents In-Depth Studies database

involvement rate (in injury accidents) of these FL vehicles is 0.11 per 100 registered vehicles per annum; 43% lower than the rate of all 6-axle artics.

Taking into account damage-only accidents (based on estimates from German data and GB news reported incidents), it is estimated that there are around 81 to 108 collisions in GB each year involving 6-axle FL vehicles >7.5 tonnes mgw and severe enough to cause an injury or tow-away damage. Further, it is estimated that 5 to 7 of these collisions involve the FL vehicle rolling over.

There were approximately 220 of the non-compliant tankers originally operating on GB roads, out of a total FL vehicle fleet (6-axle artics > 7.5 tonnes mgw) of around 3,400 vehicles (on average, 2007 - 2012). Assuming these non-compliant tankers have similar involvement rates to all six-axle articulated FL tankers above 7.5 tonnes mgw, it can therefore be estimated that these non-compliant tankers were likely to be involved in up to 7 collisions per year, severe enough to cause an injury or tow-away damage. This would include one rollover collision occurring every 2.2 years, on average.

Based on German records on frequency of load spillage, it could be anticipated that there might be up to 5 spillage incidents involving 6-axle FL vehicles >7.5 tonnes mgw per annum in GB. If the likelihood of spillage in a collision was identical, a collision of a non-compliant tanker involving spillage could be expected to occur once every three years.

It is possible that factors such as the low centre of gravity of petroleum tankers (compared to other types of tanker), a greater focus on driving standards and driver safety within the industry, and greater investments in vehicle-based safety technologies amongst the major oil company fleets, all together lead to accident, rollover and spillage frequencies somewhat lower than those experienced by other types of FL-registered articulated vehicles. This hypothesis could not be fully tested during the research. The safety record of petroleum fuel tankers may well be better, on average, than these other tankers, but no amount of safety interventions can be certain to eliminate all risks.

As an absolute minimum, articulated petroleum road fuel tankers have been found to have overturned in 6 separate incidents in the UK over the last four years. If the UK fleet of such vehicles is as high as 1,500, as stakeholders and our own estimates suggest it might be, this implies a rollover frequency of no less than 0.1 per 100 registered vehicles per year (0.1%). This provides a lower bound estimate for the 220 non-compliant tankers of an overturn incident involving them likely once every 4.5 years on average.

An alternative way of expressing this risk of rollover is to consider the probabilities of one or more of the non-compliant tankers overturning in any given period of time. For the 120 non-compliant tankers thought (at the time of drafting this report) to still be in use on UK roads, there is estimated to be a 51% chance of at least one overturning in the next 6 years, and a 66% probability when a period of 9 years is considered.

Some stakeholders consulted during this research have suggested that the rollover risks for the non-compliant tankers might be even lower than the lower bound estimates made above, perhaps by a factor of two. No supporting evidence has been provided, but if the probability of an individual non-compliant tanker overturning in any one year were actually 0.05% (rather than 0.1%), then over a six year period, the probability of at least one rollover incident involving one of the 120 non-compliant tankers would be 30%, and over 9 years it would be 42%. So while the absolute rollover probabilities based on estimates provided by industry stakeholders may be somewhat lower than those indicated by the research, they are of the same order of magnitude.

In total, 15 officially reported incidents from the period 2005 to 2013 have been identified as being relevant to this study, i.e. involved a flammable liquid tanker. Eight of the 15 accidents (53%) involved a spilt load, of which 6 cases were major spills, i.e. >1,000 litres. These major spills were associated with overturning in 5 out of 6 cases and a side impact (impact with the jib of a mobile crane) in the other. Three of the 6 cases were with aluminium tanks, the other three were of unknown material. One case involved an overturn with a steel tank and did not lead to spillage.

The analysis of STATS19 data, RIDDOR reports and local news reports on tanker accidents involving spillage of flammable liquids indicates a high probability of quite significant under-reporting of ADR incidents to DfT. The best available estimate is that only around 10% of the incidents that should be reported (albeit based on a strict interpretation of the ADR requirements) are actually reported to DfT; of the 5 to 7 rollover incidents involving 6-axle articulated FL vehicles likely to be occurring each year in GB, only 0.6 are currently being reported, on average, as ADR Incidents to DfT. To improve the level of reporting, the following might be considered: Enhanced guidelines and training for operators; a dual reporting system; an ongoing periodic review of local news media articles; and a web-based central data repository. Future research would benefit from additional information on tank, vehicle, and damage in the incident reports.

A review of the RAIDS databases (Road Accident In-Depth Studies) has identified over 80 incidents involving articulated tankers (not restricted to ADR tankers). Rollovers and rear impacts are identified as the main collision mechanisms, but load spillage was rare.

Contacts in the fuel tanker industry, from operators and repair organisations, were identified and surveyed. Generally, respondents did not provide precise accident involvement statistics to a common definition. Rates provided varied from 1.5 – 5 per million vehicle kilometres, but these usually included mainly minor incidents (e.g. during low speed manoeuvring or cracked wing mirrors). Where figures were provided for more serious incidents such as overturns and spillages, frequencies were generally very low; typically historical rollover frequencies of 1 in every 150 – 400 vehicles per year and major spillage resulting from 20-25% of those. Several respondents mentioned limited spillage (up to 50 litres) from impacts affecting valves and pipework.

The international literature, statistics, in-depth databases and stakeholder survey responses all point to the importance of rollover as a contributory factor in major fuel spillage incidents. They also suggest that rear impacts with other heavy vehicles are often contributory to more minor spillages.

Rollovers appear to be rare, and recent historical trends suggest they have become rarer still, probably as a result of preventative technologies and safer driving interventions (e.g. stability systems and fleet telematics). Major spills from overturning have also reduced in frequency. Technologies and driver training cannot, however, prevent all rollovers; such incidents do still happen, even amongst major oil company fleets.

For an overturn to result in major spillage, the evidence gathered indicates that a combination of overturning and sliding is usually involved, with rupture of the tank arising from scraping or puncturing impacts with road-side objects and structures. A low speed overturn by 90 degrees onto a rigid flat surface without significant sliding or other secondary impacts, as used in Work Package 1 (WP1) to validate a mathematical model of the said tankers, appears unlikely to lead to significant fuel spillage.

No evidence has been found to indicate that failures of circumferential welds have played any significant role in real-world fuel spillage incidents, although none of the non-compliant tankers are known to have been involved in such incidents in the UK.

In overturning without sliding, previous testing reported in the international literature suggests roll rates of 100 to 150 deg/s (1.75 to 2.60 radians/s) are likely at the point of impact of the tank with the ground. For the testing and modelling carried out in WP1, a simple tilt and topple test achieving a roll rate at impact within this range would appear, therefore, to be a realistic representation of that scenario.

Possible regulatory enhancements include (tractor unit) fuel tank design/location, tank material specifications to better protect against damage as overturned tankers slide along the ground, and greater impact protection for tanker pipework.

There are important limitations, however, affecting the above analyses. Most important, fuel spillage incidents appear to be highly complex, involving various factors and secondary impacts. This means it is not possible to identify a single "average" accident configuration. This is compounded by the general paucity of detailed information on specific accidents, particularly exact tank failure mechanisms and/or damage patterns.

Extending the testing and modelling work to cover other relevant impact scenarios that do involve a significant risk of load loss, however, is likely to be much more complex. Three major mechanisms are indicated to interact in quite complex ways to induce such risks; rollover, sliding and tearing. It may well not be feasible to devise a single test that achieves all three, so a step-by-step approach may be appropriate.

A review of existing regulatory mechanisms identified two existing performance-based test procedures that may at least form starting points for the development of enhanced requirements for road fuel tankers, to further reduce the risks of major spillage in complex, but realistic, rollovers. These are the static rollover test in UN(ECE) Regulation No. 66 and the front pillar pendulum impactor test in UN(ECE) Regulation No. 29. The frontal impact pendulum test procedure within Regulation No. 29 was also assessed but was found not to be readily usable as a rear impact test for tankers.

A simpler approach may be feasible, however, if actually it is only the final (penetrating impact) phase that really involves a heightened risk of tank rupture, and this risk is not affected by any pre-existing roll and/or slide damage. In that scenario, a pendulum test may be all that is needed, though the size, shape and impact energy of the impactor, as well as the impact angle and location on the tank, would need to be carefully considered. However, this type of test may not be well suited to testing the integrity of circumferential weld seams.

US research suggests that rollovers can be severe enough to cause the tank to roll by more than ninety degrees before it hits the ground, so a vertical drop test of a tank onto its roof, perhaps from a height in the range 1 – 2 metres, could be considered representative of some real-world scenarios. In this context, a modified version of the static roof strength test in UN(ECE) Regulation No. 29 might also be relevant and would likely be simpler to implement and carry out than a dynamic drop test. The accident data evidence, however, suggests that full overturns by 180 degrees may be very rare in GB.

It should also be emphasised that much of the earlier research reviewed relates to tanks used in other countries, not necessarily complying with ADR, and often many years ago, so caution is needed when translating the results into UK tanks in use in 2014.

1 Introduction

1.1 Project Background

Vehicles used to carry dangerous goods, such as petroleum and chemicals, must meet the requirements of the European Agreement on the Carriage of Dangerous Goods by Road (ADR). Following examination, certain petroleum road fuel tankers have been found not to be fully compliant with the provisions of Chapter 6.8 of ADR. Amongst other things, these tanks are seen to exhibit extensive 'lack of fusion' indications in the circumferential welds.

Following an initial technical assessment⁴ of the circumferential welds, which showed that the welds might rupture under rollover and ADR load conditions, the Department for Transport (DfT) commissioned further research to assess the safety of these non-compliant tankers, in their original state and with modifications to improve their safety, relative to fully compliant tankers. The researchers were also tasked to explore any opportunities arising for better regulation which could improve both the safety and efficiency of all petroleum tankers.

The research consisted of three work packages:

- WP1 – Full scale testing and associated modelling, led by the Health and Safety Laboratory (HSL)
- WP2 – Detailed Fracture and Fatigue Engineering Critical Assessment (ECA), led by TWI Ltd (TWI, formerly known as The Welding Institute).
- WP3 – Accident data and regulatory implications, and production of an overall summary report of the research, led by TRL Ltd (TRL, the Transport Research Laboratory).

This report describes the findings from Work Package 3, which is primarily to provide real-world accident information to enable the test and modelling findings to be set in their proper, real-world risk context.

The objectives of the work package are described below and Chapter 2 describes the research methods used to meet those objectives. Chapter 3 sets out the results and key findings from literature and regulatory reviews. Chapter 4 details the accident data findings, while Chapter 5 discusses those from stakeholder surveys. Chapter 6 discusses the key findings and their implications for further testing and modelling work and potential regulatory enhancements. The conclusions are presented in Chapter 7.

1.2 Objectives

The DfT has commissioned this research to examine the risks associated with certain non-compliant petroleum tankers, identify reasonable mitigation strategies and explore any opportunities arising for better regulation.

Specifically, WP3's stated objectives are:

⁴ 'Short-term Fitness for Service Assessment of [non-compliant] Road Tankers, TWI (Draft) Report 23437/1/13, September 2013 and 'Project 23437 Contract Amendment: Additional FEA for assessment of [non-compliant] road tankers, TWI (Draft) Report 23437/2/13, October 2013.

- Task 1 - Determine representative rollover and collision loads; and
- Task 2 - Identify regulatory implications and potential amendments.

Further objectives regarding peer review activities and producing a summary of the findings and implications of all the Work Packages are not covered in this report.

2 Research method

WP3 was divided into two tasks. The aim of Task 1 was to provide background intelligence on fuel tanker accidents, e.g. their frequency and how often rollovers and rear impacts lead to fuel spillage and/or tank rupturing, and in what specific circumstances.

This will help define the overall risks and inform the test and modelling work (other WPs) to ensure simulated conditions are broadly realistic.

Tank rupture was thought, at the outset of the project, likely to be rare, so the research net was cast wide and involved an international review of multiple sources:

- i. Published international research literature (from 1995 – 2014)
- ii. DfT statistics/records (including STATS19⁵ data and ADR incident reports)
- iii. Local news media articles
- iv. Detailed (in-depth) truck accident databases (RAIDS)⁶
- v. Stakeholder surveys (of tanker operators, repairers and international experts)

Further details regarding the methodologies employed under each of these headings are given in the following Chapter.

The results were also used to inform Task 2, supplemented by a dedicated review of potentially relevant current legislation, also described more fully in the next Chapter.

⁵ The database of police-reported road accidents in Great Britain

⁶ The Road Accidents In-Depth Studies database

3 Research literature and regulatory reviews

This task involved a search using TRL's access to various international research literature databases and the internet. Research papers and articles were identified using the search terms "tanker", "tank trucks" or "liquid cargo handling" AND "road" AND "incident", "rollover", "roll over", "collision", "spillage", or "rupture". Date limits of 1995 – 2014 were used.

In total, 116 papers and articles were identified using these search terms (set out in full in Appendix A). No directly relevant UK published research was found. However, various studies of relevance were identified internationally, in particular from the USA and Germany but also Spain, Netherlands and China. The following sections describe the directly relevant literature in more detail.

To inform the identification of regulatory implications and the potential for amendments to current regulations, some existing regulations and international standards were also reviewed. The results are described in the final section of this Chapter.

3.1 German research literature

"Tanker trucks in the current accident scene and potentials for enhanced safety", Gwehenberger & Langweider, 2002

This analysis draws heavily on the earlier THESEUS project (discussed below). The main risk leading to hazardous material spillage was reported to be single vehicle accidents with rollover and rear/side impacts with other HGVs.

The report highlights the role of "local" (point) and "global" (distributed) loads – for local loads, material strength properties determine failure threshold, but for global loads "failure tends to occur where abrupt transitions in rigidity, for example in the bases, bracing rings or welded bracing bands, impede distortion."

The report's authors criticised the move to aluminium tanks; "a stainless steel tank with a wall thickness of 3 mm is almost twice as safe for transporting class 3 hazardous substances by road than a tank made of aluminium alloy of the conventional type" [5 mm wall thickness].

They recommended changing ADR to require medium-pressure tanks (4 bar test pressure), and effective collision-protection systems at the rear and sides of vehicles.

"THESEUS – Maximum possible tanker safety through experimental accident simulation", Rompe & Heuser, 1996.

Over the course of a nine year research programme, thirty six crash tests and twelve dynamic overturn tests were performed and the results are summarised in this report.

The test parameters used were devised from an analysis of 232 road accidents of tankers (including rigid tankers, articulated tankers and drawbar trailer tankers) involving the risk of spillage of dangerous goods.

Single vehicle accidents accounted for 44% of all the accidents studied, but 71% of the spillage cases – half on bends, half on straight sections of road. The average vehicle speed before overturn was 48 km/h, with 28% occurring above 70 km/h.

Rear and side impacts with other vehicles accounted for 32% and 28% respectively. The average rear impact speed was 20 km/h.

The overturn tests used an articulated tanker – driven at 50 km/h on a curve, rolling onto a smooth road surface. The report does not state exactly how these tests were carried out, but it is likely that the vehicles were driven by remote control.

Without any obstructions, the overturned tankers skidded for 25-35 m before coming to rest. Tank deformations of 35-80 mm were typical, but no failures/spillages were recorded. Both stainless steel and aluminium alloy tanks were tested – surface scratches were found to be deeper for the steel tanks (1.8 mm) than aluminium (0.6 mm).

Where vertical obstructions were placed in the vehicle's path, the subsequent impacts led to high local loads that caused severe spray from the caps of the tank openings, but still no structural failures.

Rear impacts with another HGV at 25-27 km/h led to spillage in 63% of the tests, from local intrusion of impacting parts.

German HGV accident statistics. Statistisches Bundesamt, 2013. Verkehrsunfaelle - Unfaelle von Gueterkraftfahrzeugen im Strassenverkehr.

The German Federal Statistical Office publishes an annual report on road accidents of HGVs. The accident numbers of tankers transporting dangerous goods since 1999 are summarized in the following Table. These relate to all reported accidents severe enough to have either caused at least one casualty or enough damage to mean at least one vehicle involved had to be towed away.

The statistics are broken down by accident severity, but only as far as injury accidents and damage-only incidents. Generally speaking, injury accidents account for about two-thirds of the cases, and a similar proportion of the spillage cases. No other data is contained in the report on types of accidents or the volume of spilt goods, but these data are useful for basic incident frequency and risk analyses.

Table 1. German accident statistics

	1999-2003 (average)	2004-2008 (average)	2009	2010	2011	2012
All accidents with flammable liquid tankers (injury and damage-only combined)	186	143	88	126	89	87
of which: involved spillage of dangerous goods	26	15	1	6	0	2
Likelihood of spillage when involved in severe accident	14%	10%	1%	5%	0%	2%

3.2 Other European research literature

"A survey of accidents occurring during the transport of hazardous substances by road and rail", Oggero et al, 2005 (Spain).

This report describes an analysis of the Major Hazard Incidents Data Service (MHIDAS) data; 9,000 incidents relating to the transport, processing and storage of hazardous

materials between the early years of the 20th Century⁷ and 2004 from over 95 countries (note, this database is no longer maintained).

1,932 incidents involving land transport analysed – 37% on rail, 63% on road.

This is a fairly high-level review, so details are limited, but the report states that the data agrees with some Dutch research suggesting overturning followed by hazardous material (hazmat) release was the most significant transport accident type.

74% of the incidents were some form of vehicle-vehicle or single vehicle collision.

“Rollover stability of tank trucks, test and calculation requirements based on ECE 111 regulation”, Martin et al, 2010 (Spain).

This report starts by reviewing Spanish accident statistics (from ADR incident reports) and then describes two new approaches to improving the accuracy of the static roll stability calculation required by ECE Regulation No. 111⁸.

The Spanish incident report data has 43 spillage cases and 45 without. The most frequent accident types involving spillage are rollover and running off road (60%), followed by collisions with other vehicles (15%).

The authors identified issues with Regulation No. 111 including the height of the side supports used in tilt testing, the tank filling level and the accuracy of the calculation method.

“Tank lorry fires involving dangerous goods”, Dutch Safety Board, 2006 (Netherlands).

This report describes the reporting system in the Netherlands and finds that it is not properly fulfilled nor enforced. Official accident statistics are also reported to be deficient in that they cannot adequately record accidents involving dangerous goods.

The report then focuses on fires involving tank vehicles carrying dangerous goods, describing six such incidents in the Netherlands between 1999 and 2005. Specific risk factors identified include the size, construction and placement of vehicle fuel tanks.

The report suggests that measures to shield and strengthen fuel tanks, as well as reducing their capacity or compartmentalizing them, would help reduce the risks of post-impact leaks and consequent fires.

⁷ The database was started in the early 1980s, but reference is made to incidents from the early years of the 20th Century.

⁸ UNIFORM PROVISIONS CONCERNING THE APPROVAL OF TANK VEHICLES OF CATEGORIES N AND O WITH REGARD TO ROLLOVER STABILITY - applies to the rollover stability of tank vehicles of category N2, N3, O3 and O4 intended for the carriage of dangerous goods as defined in the ADR agreements.

3.3 Research literature from the USA and China

“The dynamics of tank-vehicle rollover and the implications for rollover-protection devices”, UMTRI, 1998 (USA) & “Cargo tank rollover force verification”, FMCSA, 2006 (USA).

These reports describe track tests and computer simulations of tanker rollover accidents (the 2006 report covers track tests carried out to validate the simulations reported by UMTRI in 1998).

A wide range of roll inducing manoeuvres were simulated (126 each for five different tractor-semitrailer combinations). The simulation runs went up to the moment the tank contacted the ground. Three basic scenarios were defined; mild, 90 degree roll with slide and 180 degree rollover.

In a mild rollover, simulated roll rates at impact ranged from 100 – 150 deg/s.

Where a vehicle landed on its side and then slid, impacts with vertical objects (e.g. guardrails, retaining walls or embankments) were simulated to occur at velocities (perpendicular to the road) of 20-40% of the initial forward speed of the vehicle. Yaw angles of +/- 20 degrees were predicted.

In the more dramatic simulated events, the vehicle could become airborne and roll rapidly enough so that the impact with the ground was with the roof of the tank. Downward velocities ranging from 1.8 – 9 m/s were simulated, with pitch angles +/- 5 degrees.

The 1998 report recommends designing tanks to withstand impacts normal to the roof of at least 3.6 m/s, with 7.2 m/s identified as desirable (equivalent to drop testing from 0.7 m and 2.7 m respectively). Angular (pitch) misalignment at impact “could increase the effective severity of impact by about ten-fold”.

The 2006 tests showed generally good correlation with the 1998 simulations, except for vertical velocity at impact where the test values were found to be about half those simulated.

“Hazardous materials serious crash analysis: phase 2”, FMCSA, 2005 (USA).

For this study, 1,629 crashes were analysed (from 2002). 914 involved class 3.0 products (flammable liquid hazardous materials), and 20% of those resulted in a spillage.

Rollover was found to significantly increase the probability of a spill, and the more load carried, the greater the likelihood of a rollover.

Rollover, loss of control and run off-road were closely associated with Class 3.0 spills.

“Cargo Tank Roll Stability Study”, FMCSA, 2007 (USA).

Crash statistics (all tanker accidents not just hazmat) were used to evaluate four complementary mitigation strategies; driver training, electronic stability aids, new vehicle designs and highway design.

The authors found an average of 1,265 cargo tank rollovers per annum (in 2002). Run-off road with a tripped rollover was the most common scenario (47%) identified, with un-tripped rollovers accounting for a further 14%.

An evasive manoeuvre by the driver was a factor in 5-10% of rollovers. Driver error was a factor in 75%. Only 7% occurred on entrance/exit ramps.

"Simulation of Nonlinear Dynamics of Liquid Filled Fuel Tanker Shell Structure subjected to Rollover Collision with Validation", Park, Gilmore & Singer, 1998 (USA).

This report is mainly concerned with the modelling of a tank structure, but does describe some earlier (1983) accident data and highlights that "puncture of tank shell is a major source of spillage both in crash and in rollover accidents".

The report goes on to describe the design of a pendulum impact test used to plastically deform the tank being tested. The pendulum consisted of a 91 kg steel beam, and was impacted end-on at speeds of 2.4 and 4.2 m/s.

The report describes good correlation between the tested and simulated tank deformations, and goes on to report use of the model to simulate a ninety degree rollover impact onto rigid, level ground, but does not present any analysis to link the testing and simulations to real-world accident data.

"A survey on hazardous materials accidents during road transport in China from 2000 to 2008", Yang et al, 2010 (China).

This report describes an analysis of 322 on-road hazmat accidents in China. Driver errors leading to collisions with other vehicles or improper emergency responses accounted for 60% of the cases examined. 85% of the cases involved release of hazardous material, usually (64%) without subsequent fire/explosion or gas cloud. Fires occurred in 10% of cases, and explosions in 3%.

3.4 Current regulations and standards

In preparation for possible future regulatory amendment proposals, the main goal of this task was to establish whether certain aspects of the existing regulatory environment (relevant to heavy goods vehicles and/or the carriage of dangerous goods by road) could be of potential use in enhancing the regulations affecting petroleum road fuel tankers. If these existing regulatory mechanisms already represent realistic heavy vehicle impact and rollover scenarios, adapting them for ADR might offer an easier implementation path than developing an entirely bespoke set of procedures, for example.

3.4.1 Current ADR requirements

ADR⁹ section 6.8 contains "requirements for the construction, equipment, type approval, inspections and tests, and marking of fixed tanks (tank-vehicles), demountable tanks and tank-containers and tank swap bodies, with shells made of metallic materials, and battery-vehicles and multiple element gas containers (MEGCs)". It therefore provides the main technical requirements concerning the design, construction and testing of the petroleum road fuel tankers of interest to this study.

These requirements include some non-mandatory provisions for "protection of the tank against damage through lateral impact or overturning", but they are purely design-based, rather than requiring any performance-based testing. The design requirements are provided in section 6.8.2.1.20¹⁰. For shells with a circular or elliptical cross-section

⁹ European Agreement Concerning the International Carriage of Dangerous Goods by Road, applicable as from 1 January 2013.

¹⁰ Note that these requirements are mandatory for tanks with a capacity of 1,000 litres or more.

having a maximum radius of curvature of 2 m (as would be the case for the tank vehicles of interest), there is "protection against damage" when:

"the shell is equipped with strengthening members comprising partitions, surge-plates or external or internal rings, so placed that at least one of the following conditions is met:

- *Distance between two adjacent strengthening elements of not more than 1.75 m.*
- *Volume contained between two partitions or surge-plates of not more than 7 500 l.*

The vertical cross-section of a ring, with the associated coupling, shall have a section modulus of at least 10 cm³.

External rings shall not have projecting edges with a radius of less than 2.5 mm.

Partitions and surge-plates shall be dished, with a depth of dish of not less than 10 cm, or shall be corrugated, profiled or otherwise reinforced to give equivalent strength. The area of the surge-plate shall be at least 70% of the cross-sectional area of the tank in which the surge-plate is fitted.

The thickness of the partitions and surge-plates shall in no case be less than that of the shell."

There are separate requirements for thicknesses of shell material, but if the above damage protection requirements are met, a reduced shell thickness is permitted. Mild steel shells with a diameter exceeding 1.80 m, for example, need only be at least 4 mm thick if they meet the damage protection requirements, whereas in the absence of such protective measures they must be at least 6 mm thick. Equivalent thicknesses apply to all other materials, e.g. stainless steel or aluminium alloy.

There are also some requirements (6.8.2.1.28) for the protection against damage caused by overturning of fittings mounted on the upper part of the tank. Again, these are purely design-based, however:

"This protection may take the form of strengthening rings, protective canopies or transverse or longitudinal members so shaped that effective protection is given." No guidance is provided on what constitutes "effective" in this context.

ADR Section 6.5 concerns requirements for the construction and testing of intermediate bulk containers (IBCs). Unlike section 6.8, these requirements do contain provisions for performance-based testing, including a "topple test". A closer examination of these requirements, however, found that this topple test only applies to flexible IBCs (see photo for an example). The test itself (section 6.5.6.11) simply involves the flexible IBC being "caused to topple" onto any part of its top onto a rigid, non-resilient, smooth, flat and horizontal surface from a height varying from 0.8 to 1.8 m, depending on the packing group to which it belongs. Pass criteria is simply that there must be no loss of contents, except for a "slight discharge, e.g. from closures or stitch holes, upon impact shall not be considered to be a failure of the IBC provided that no further leakage occurs". Such a test might be relevant to poor stacking of such containers or mishaps in craning them, but appear to be of little or no relevance to carriage by road, and certainly of no relevance to the carriage of flammable liquids in metal tanks.



Figure 1. A flexible intermediate bulk container (IBC)

3.4.2 Current UN(ECE) requirements

UN(ECE) Regulation No. 29 concerns the protection of the occupants of the cab of a commercial vehicle. It contains performance-based test requirements for the strength of the cab in various simulated impact and rollover conditions. N₃ vehicles and N₂ vehicles > 7.5t must pass three separate tests:

- Test A – frontal impact
- Test B – frontal pillar impact
- Test C – roof strength

Test A (Figure 2) involves a large (1,500 kg) flat, rectangular metal pendulum (2.5 m wide and 0.8 m high) being swung into the front of the cab, impacting 50 – 55 mm below the level of the R point of the driver's seat. The impact energy is 55 kJ (for vehicles > 7.5 t). The vehicle passes the test if, after it, a sufficient survival space for the occupants remains. The cab doors must not open during the tests, but do not have to be open-able after the tests.

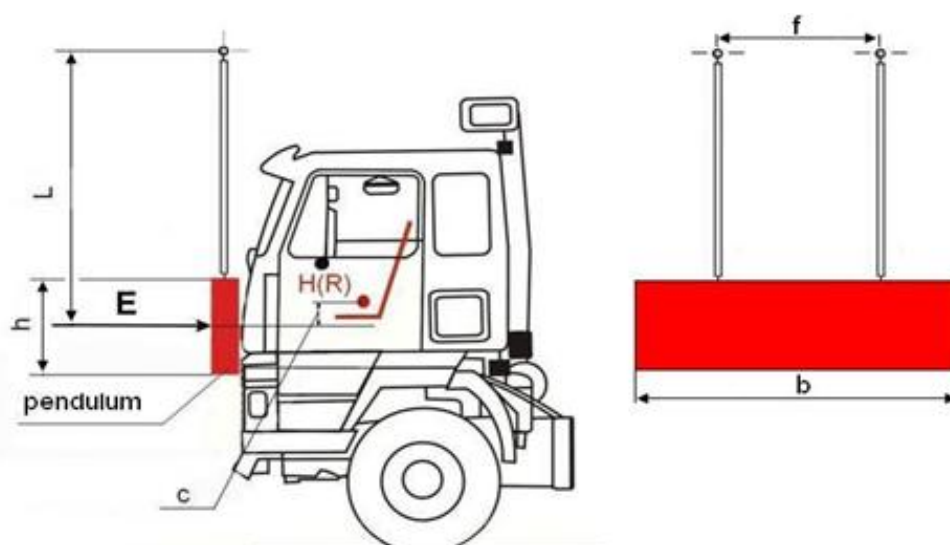


Figure 2. Frontal impact test (Test A, Regulation 29)

These conditions are intended to represent an HGV colliding with the rear of another heavy vehicle, striking the main structural parts of that vehicle within the chassis and/or load platform. The impact energy is broadly equivalent to an impact at around 6 km/h for a 40 t vehicle, so it is not particularly severe but it does help to ensure that the driver (with seat belt) is able to remain in the cab and not be hit by intruding structural components in such an impact.

For such a test to be useful as a performance-based regulatory mechanism for fuel tankers, it would need to represent a rear impact in to the back of the tank (from a following heavy goods vehicle). However, in such a scenario, the main structural components of the impacting vehicle would normally be somewhat lower than the structure of the tank trailer. Only the relatively 'soft' upper frontal structure (in the windscreen area) would tend to interact with the tank itself. A large rigid and heavy metal pendulum would not properly represent such an impact. That said, such a pendulum impact might be relevant to assess the integrity of the area at the rear of the tanker below the tank (at a height designed to be similar to the chassis members of the impacting vehicle), where pipework and other components potentially carrying fuel might be located.

Test B (Figure 3) is a relatively recent introduction to Regulation 29 and is a modified version of the A-pillar test required in Sweden for many years (VVFS 2003:29). It involves a cylindrical pendulum weighing at least 1,000 kg, with a diameter of 550 – 650 mm and length of at least 2.5 m. It is impacted horizontally, parallel to the median longitudinal plane of the vehicle such that its centre of gravity at impact is midway between the lower and upper windscreen frame. The impact energy is 29.4 kJ. This test is intended to replicate an overturned vehicle sliding on its side into a secondary (frontal) impact with a tree. The weight of the pendulum and energy involved is broadly equivalent to an impact at 7.7 ms^{-1} (28 km/h). As with Test A, an occupant survival space needs to be maintained for the test to be passed.

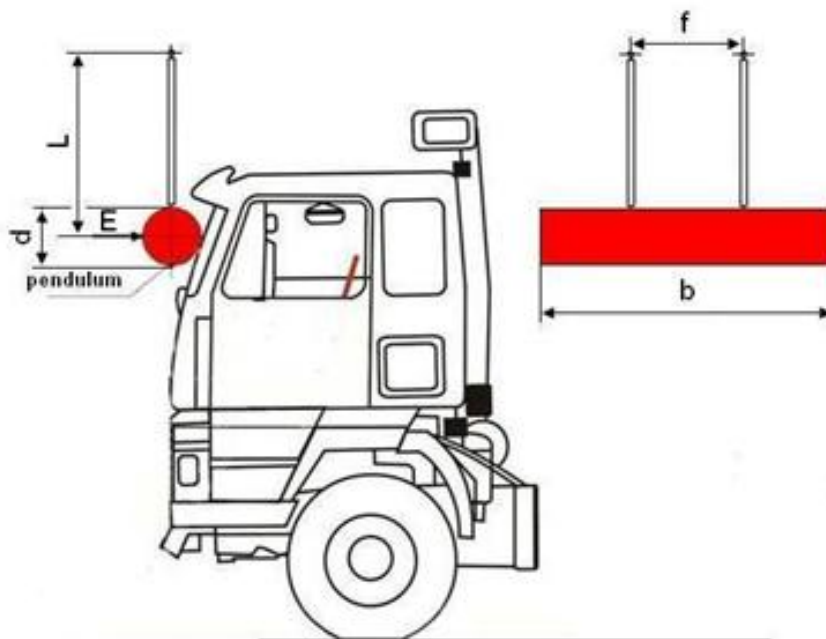


Figure 3. Front pillar test (Test B, Regulation 29)

While such a frontal impact would be unlikely to be relevant to the tank of a road fuel tanker in the event of an overturn (by ninety degrees), dropping a similarly sized “pendulum” onto the roof of a tank could potentially simulate a tanker overturning and sliding out of the curve into a tree. The Regulation 29 impact energy of 29.4 kJ could be achieved by dropping the 1,000 kg pendulum/cylinder from a height of 3 m above the roof of the tank.

Test C (Figure 4) combines a dynamic impact to the upper side of the cab with a static roof strength test.

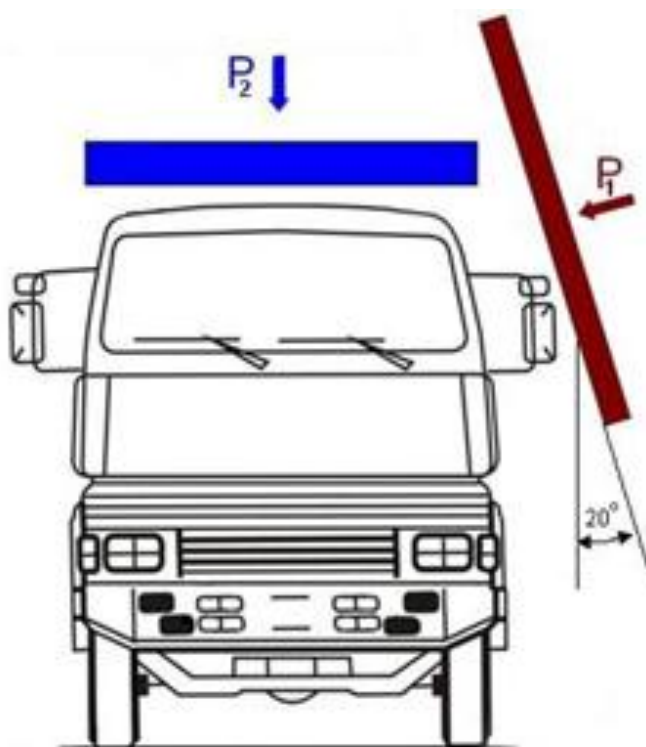


Figure 4. Roof strength (Test C, Regulation 29)

The dynamic impact preloads the structure via a 1,500 kg rigid, flat, rectangular impactor striking with an energy value of 17.6 kJ. The static load then simulates much of the weight of the cab itself acting on the (fully overturned) roof. The static load is 98 kN (equivalent to 10 tonnes) or less and corresponds to the maximum authorised mass of the front axle or axles of the vehicle. As with Tests A and B, an occupant survival space needs to be maintained for the test to be passed. The load is applied via a rectangular and flat device larger than the roof of the cab (i.e. the load is distributed over the whole of the roof area).

For a road fuel tanker, an equivalent test would need to impose the load over the whole of the uppermost part of the tank and be around 235 kN to simulate the combined maximum weight of the tank semitrailer (24 tonnes for a tri-axle).

UN(ECE) Regulation No. 66 concerns the strength of the superstructure of large passenger carrying vehicles (single deck buses and coaches). The requirements involve ensuring a survival space is provided in the event of a partial overturn. The exact rollover condition is shown in the figure, and involves a simple topple but into a rigid ditch set 800 mm below the level of the road surface.

The Regulation contains various alternative (equivalent) approval test methods, including a rollover test on body sections which are representative of the complete vehicle, quasi-static loading tests, quasi-static calculations based on the results of component tests and computer simulation via dynamic calculations.

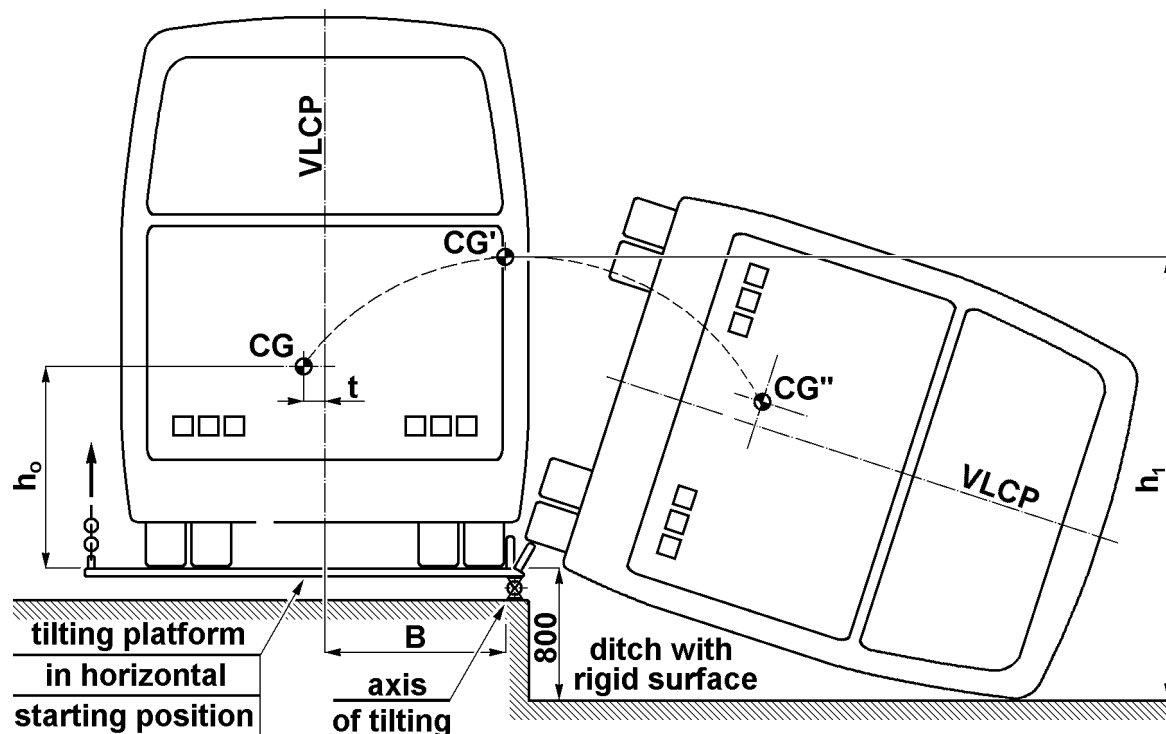


Figure 5. Rollover test specification, Regulation 66

Although the survival space criteria would obviously not be relevant to the tank of a road fuel tanker, the basic test method may well represent a rollover situation, and of somewhat greater severity than a simple topple onto a level road surface. The test does not, however, involve any forward or sideways motion of the overturned vehicle so does not replicate any post rollover sliding along the ground or subsequent impacts.

3.4.3 International standards

EN 13094:2008 provides design and construction requirements for metallic tanks for the transport of dangerous goods with a working pressure not exceeding 0.5 bar. Many of its provisions regarding tank shells are identical to those of ADR section 6.8, and indeed compliance with EN 13094:2008 is accepted with ADR as being equivalent. Unlike ADR, however, this standard also covers the concept of “global resilience”, and has provisions for a performance-based test of this resilience (section 6.9.2.2).

Global resilience is defined as the “ability of a shell with multiple divisions or surge plates to withstand a sideways impact with a beam”. The test involves applying a static load to a beam 4 m long and 430 mm wide such as to achieve a “penetration test distance” of 250 mm. The load is applied on one side of the shell section, near the centre line and in the radial direction (perpendicular to the direction of motion). The test is passed if the outer shell is not ruptured.

However, the test procedure only applies if manufacturers wish to use global resilience values higher than some standard figures provided or wish to use other types of reinforcement members (other than partitions or surge plates). It also only applies to shells of forms other than those with circular or elliptical cross-section having a maximum radius of curvature of 2 m. In reality, therefore, most fuel tankers, which are of circular or elliptical cross-section and are equipped with partitions and surge plates, would not need to be tested for global resilience.

It is unclear from the standard as to why a beam 4m long and 430 mm wide is used. It seems unlikely that such a narrow beam could be said to represent the loading imposed by the ground when a tank overturns onto its side, though it may be thought of as a reasonable proxy for a tank overturning onto a raised kerb of some kind.

As with some of the other regulations analysed, this standard does not attempt to allow for any post rollover sliding along the ground or secondary impacts arising.

4 Analysis of accident data and incident reports

Data was obtained from several different sources to aid the analysis. This included STATS19 data, BBC news reports, ADR incident reports and RIDDOR¹¹ reports, as well as two in-depth databses (TCIS and HVCIS). STATS19 provides data from all police reported road accidents involving personal injury in Great Britain. Using data held by the Driver & Vehicle Standards Agency (DVSA), it was possible to identify injury accidents involving tankers licensed to carry flammable liquids, and discover the circumstances of each accident.

BBC news articles from between 2009 and 2014 were also reviewed to gain an approximation of the frequency of rollover and spillage accidents of tankers in injury and non-injury accidents. However, data collected from this source was treated carefully due to the tendency of the media to mostly report particularly exceptional accidents such as events involving fatalities, spillages or road closures creating severe delays. The data was compared with ADR reports provided by DfT in order to establish any levels of underreporting by operators of accidents involving dangerous goods vehicles.

ADR incident reports must be produced by operators and supplied to DfT whenever a vehicle carrying dangerous goods is involved in a serious accident where the load is released or has a high probability of being released or causes injury. In addition to the ADR report, RIDDOR requires employers to report (to the Health and Safety Executive, HSE) and keep records of certain 'dangerous occurrences'. Incidents of interest to this study involving FL-registered tankers (defined in the following sections) needed to be reported under RIDDOR up until October 2013. Since then, HSE advise that amended requirements mean only ADR reports are required, unless there is an unintentional spillage of 500 kg or more. It was expected that BBC news reports would exist for many of the officially reported incidents as they are serious enough to be considered newsworthy. Incidents involving personal injury will also be recorded in STATS19. The relationship between these data sources can be seen in Figure 6.

The following section describes a review and analysis of collision and incident data with the objective of identifying representative rollover and collision loads for petroleum road fuel tankers.

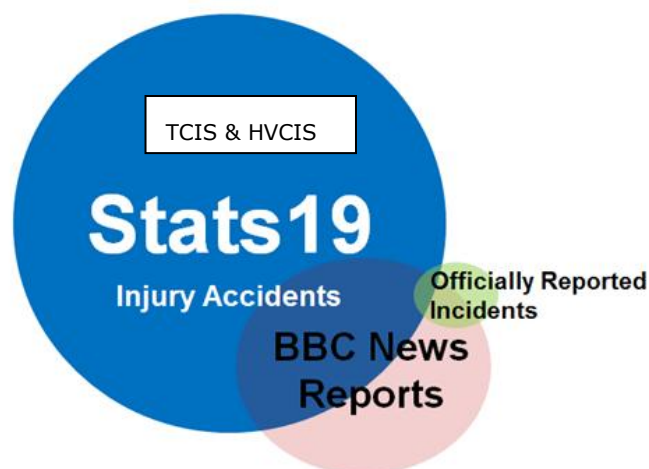


Figure 6. Sources of information analysed

¹¹ Reporting of Injuries, Diseases and Dangerous Occurrences Regulations

4.1 Preliminary STATS19 data

In Great Britain (GB), information relating to road accidents reported to the police is stored within the STATS19 database system. These data provide statistics about the circumstances of personal injury road accidents, including the types of vehicles involved and the consequent casualties. Only very basic vehicle information is recorded by the police, but vehicle registration numbers are also recorded, allowing STATS19 to be linked to more detailed vehicle data held by the Driver & Vehicle Standards Agency (DVSA).

A preliminary analysis has been undertaken by the DfT Statistic Department using data from reported injury accidents in GB that occurred between 1994 and 2012 inclusive. However, for articulated vehicles, the link between the STATS19 and DVSA databases is limited by the fact that vehicle registration mark is associated with the tractor unit rather than the trailer which is being towed. Most tractor units (which, unlike the semitrailers, have registration numbers) are coded by DVSA as simply "tractor units", so it is not possible to identify those used to pull tanker semi-trailers. However, some vehicles that are identified as articulated do have the body type coded as "tankers". This discrepancy in body type codes does cast some doubt over the robustness of this analysis method, but it provided the best initial estimate of the numbers for this type of vehicle. The analysis has also been restricted to 6-axle articulated tankers, because these are the most likely axle configuration used to transport petroleum products.

The numbers of licensed 6-axle articulated tankers as identified in this data set, their involvement in injury accidents, and the numbers of those that overturned in an accident, by year, are shown in the Table 2 below.

Although the absolute numbers are likely to underestimate the true picture, indications are that 6-axle articulated tankers currently have approximately a 1 in 45 probability of being involved in an injury accident per year (2.2 involvements per 100 registered vehicles) and a 1 in 625 chance of overturning¹² during involvement in an injury accident in any one year (0.16 overturns per 100 registered vehicles).

The data shows that the involvement rate of tankers in injury accidents has reduced over time. The involvement rate of these tankers in rollover collisions has been variable, but has shown a clear reduction since 2006.

¹² Overturning recorded in STATS19 can be pre- or post-impact.

Table 2. STATS19 and DVSA¹³ data combined, 1994 – 2012.

Year	Six axle artic tankers licensed	Number of vehicles involved in injury accidents	Involvement rate (per 100 registered vehicles per annum) 5 year rolling average	Number of vehicles overturning ¹² in injury accidents	Overturning rate (per 100 registered vehicles per annum) 5 year rolling average
1994	200	8	-	0	-
1995	210	15	-	2	-
1996	245	10	-	0	-
1997	257	9	-	0	-
1998	283	8	4.2	1	0.25
1999	607	24	4.1	1	0.25
2000	655	14	3.2	0	0.10
2001	913	34	3.3	0	0.07
2002	979	24	3.0	2	0.12
2003	915	29	3.1	3	0.15
2004	906	35	3.1	6	0.25
2005	807	11	2.9	2	0.29
2006	703	23	2.8	0	0.30
2007	664	10	2.7	0	0.28
2008	570	20	2.7	2	0.27
2009	501	12	2.3	1	0.15
2010	498	10	2.6	1	0.14
2011	452	5	2.1	0	0.15
2012	438	6	2.2	0	0.16

¹³ Registered vehicles identified as goods vehicle by body type, not by taxation class.

4.2 Detailed STATS19 data from accidents involving FL-registered vehicles

4.2.1 Number of registered vehicles

The analysis was limited to articulated vehicles with a 3+3 wheel plan above 7.5 tonnes mgw (in the following referred to simply as '6-axle artics') because this is the most commonly used type to transport petroleum. A sub-group of these 6-axle artics are certified under ADR Regulations to carry flammable liquids (FL), i.e. are registered as 'FL vehicles'. Analysis of vehicle certification data by DVSA provided the vehicle stock numbers for both groups as detailed in Table 3 (more recent data could not be obtained). Note that FL certification under ADR Regulations needs to be obtained for both the tractor unit and the trailer, but only the number of tractor units could be obtained from DVSA data. Because an FL trailer must be towed by an FL tractor unit, a ratio of one tractor unit to one trailer was assumed for the following analysis.

Table 3. Number of registered vehicles (years 2007-2012)

Year	6-axle artic vehicle stock	Of which, FL vehicle stock
2007	77,489	2,363
2008	76,622	3,037
2009	74,359	3,270
2010	76,201	3,626
2011	78,481	3,924
2012	80,389	4,236
Average	77,256.8	3,409.3

4.2.2 Number of recorded collisions

During the study, a technique was developed whereby it was possible to identify FL trailers involved in collisions by linking the STATS19 data¹⁴ to the DVSA data through the vehicle registration mark of the FL tractor unit. These were identified by the DfT for the years 2007 to 2013. For this seven year period, 438 FL vehicles were identified in the collision data (see Table 4) and these 438 vehicles were involved in 437 collisions¹⁵.

¹⁴ Data are Crown Copyright and are reproduced with permission of the Department for Transport.

¹⁵ "Collisions" means accidents or incidents rather than individual collisions within a single accident or incident

Table 4. Breakdown of STATS19-recorded FL vehicles involved in collisions by vehicle type (years 2007-2013)

Wheel plan	FL vehicles 3.5 t – 7.5 t mgw	FL vehicles >7.5 t mgw	Unknown	Total FL vehicles
2-axle + artic	0	6	0	6
3-axle + artic	2	23	1	26
2+2 artic	0	3	0	3
2+3 artic	0	2	0	2
3+2 artic	0	2	0	2
3+3 artic	24	370	2	396
Unknown	0	3	0	3
Total FL vehicles	26	409	3	438

As can be seen from Table 4, the vast majority of FL vehicles (370 of 438, 84.5%) were articulated vehicles with a 3+3 artic wheel plan above 7.5 tonnes mgw, which is in line with the expectations. The classification of the other vehicles might not be as reliable; for example, it seems unlikely that a considerable number of 6-axle articulated vehicles below 7.5 tonnes mgw exist. As mentioned above the analysis was limited to vehicles with a 3+3 wheel plan above 7.5 tonnes mgw (6-axle artics). This allows a fair comparison of the sample group of FL vehicles with a comparator group of all 6-axle articulated vehicles above 7.5 tonnes mgw (including the FL registered sub-group). The 370 such FL vehicles were involved in 369 collisions. The following sections provide an overview of the collision involvement rate to provide an estimate of the frequency of potential spillage incidents involving non-compliant FL tankers, and a comparison of the collision typology of both groups in order to reveal potential indications of higher risk collisions of FL vehicles.

4.2.3 Collision involvement rate

Of particular interest for this study is the collision involvement rate of FL vehicles compared to all 6-axle artics. The numbers provided in Table 5 are annual averages for the years 2007 to 2012 (vehicle fleet data for 2013 was not available). It can be seen that the annual involvement rate of FL registered vehicles in injury collisions is almost 20% lower than the rate of all 6-axle artics. This trend is even more marked for rollovers where the involvement rate is 43% lower. The reasons for the lower involvement rate cannot be derived from this analysis; however, it can be assumed that better driver education, fleet telematics devices and commonplace fitment with Electronic Stability Control (ESC) contribute to the reduced rates. ESC is particularly effective in preventing some rollover collisions.

Table 5. Average annual collisions and collision involvement rate (average numbers for 2007-2012)

	FL vehicles of interest		6-axle artics	
	Annual collisions	Annual collisions per 100 registered vehicles	Annual collisions	Annual collisions per 100 registered vehicles
All injury collisions (STATS 19)	54.0	1.58	1,519.5	1.97
of which:				
Rollover collisions	3.7	0.11	145.2	0.19
Non-rollover collisions	50.3	1.48	1,374.3	1.78

An analysis of the rollover collisions on a yearly basis (see Table 6) indicates that the rollover involvement rate for all 6-axle artics reduced by half between 2007 and 2012 and appears to show a downward trend over time. The involvement rate of the FL vehicles of interest, however, does not show a marked downward (or upward) trend over the years. The fluctuations between years are naturally higher due to the low absolute case numbers, which is why average numbers from the period 2007-2012 will be used as best estimates for the subsequent calculations related to these FL vehicles.

Table 6. Rollover collisions and rollover collision involvement rate per year (2007-2013)

Year	FL vehicles of interest		6-axle artics	
	Rollover collisions	Rollover collisions per 100 registered vehicles	Rollover collisions	Rollover collisions per 100 registered vehicles
2007	2	0.08	189	0.24
2008	7	0.23	175	0.23
2009	5	0.15	131	0.18
2010	2	0.06	148	0.19
2011	0	0.00	132	0.17
2012	6	0.14	96	0.12
2013	3	n/a ¹⁶	114	n/a

In addition to these recorded injury collisions, an unknown number of damage-only collisions occurred. Official data from Germany (described in the literature review) indicates that for every two injury collisions involving an FL tanker there was another one involving damage only (severe enough for a vehicle being towed away from the scene). Based on an analysis of news reported collisions (described later in this Chapter), a

¹⁶ The number of registered vehicles is unknown for 2013.

higher ratio of one severe damage-only collision for each injury collision is possible. Using these ratios as a guide, a full estimate for GB would thus be that there are around 81 to 108 FL vehicle collisions each year severe enough to cause an injury or tow-away damage (around 2.38 to 3.17 per 100 registered FL vehicles) of which 5 to 7 involve the FL vehicle rolling over (around 0.16 to 0.22 per 100 registered FL vehicles of interest).

As reported earlier, over recent years in Germany, between 0% and 5% of severe collisions have involved spillage of load (see Table 1). It could, therefore, be anticipated that there might be up to 5 spillage incidents involving 6-axle FL vehicles >7.5 tonnes mgw per annum in GB, if the situation in GB is similar to that in Germany.

4.2.4 Collision typology

Rollovers can be expected to exert high loads on the tank welds and therefore involve a particular risk of load spillage due to faulty welds. In the seven year period from 2007 to 2013, a total of 25 rollover collisions involving FL vehicles of interest were recorded in STATS19. From Table 7 it can be seen that the share of such FL vehicles that roll over in collisions is at a lower level than in the comparator group (Note: Rollovers recorded in STATS19 can occur pre- or post-impact). Due to the smaller case numbers the figures for FL vehicles are subject to greater uncertainty. The differences should therefore not be overrated, but it can be clearly seen that there is no indication of a higher rollover rate per collision of the FL vehicles.

Table 7. Distribution of collision types

Collision type	Coll. involving FL vehicle		Coll. involving 6-axle artic	
	Count	Percentage	Count	Percentage
Rollover	25	6.8%	985	9.3%
No rollover	344	93.2%	9,554	90.6%
Total collisions	369	100.0%	10,539	100.0%

The distribution of accident severity in rollover and non-rollover cases is given in Table 8. The percentages indicate a similar distribution in rollover and non-rollover cases in both the FL vehicle group and the comparator group. Note that the accident severity is determined based on the most severely injured casualty in the collisions (KSI: at least one killed or seriously injured casualty; Slight: at least one slightly injured casualty and no more severely injured casualties). The most severely injured casualty is not necessarily an occupant of the lorry, hence not all KSI collisions can be assumed to pose a risk to the integrity of the tank, as these include, for example, pedestrian impacts that led to fatally or seriously injured vulnerable road users, or frontal impacts into the rear of passenger cars.

Table 8. Distribution of accident severities

Accident severity	Coll. involving FL vehicle				Coll. involving 6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
KSI	5	20.0%	73	21.2%	284	28.8%	2,043	21.4%
Slight	20	80.0%	271	78.8%	701	71.2%	7,511	78.6%
Total collisions	25	100.0%	344	100.0%	985	100.0%	9,554	100.0%

Table 9 provides an overview of the average number of casualties and vehicles per collision in both groups. The average number of casualties is lower in rollover cases than non-rollover cases, which is in-line with expectations because rollover incidents are more likely to be single vehicle incidents. This holds true for both groups of vehicles. The more marked trend for FL vehicles might be attributed to fluctuations due to low case numbers.

Table 9. Average casualties and vehicles per collision

	Coll. involving FL vehicle		Coll. involving 6-axle artic	
	Rollover	No rollover	Rollover	No rollover
Average casualties per collision	1.04	1.50	1.24	1.45
Average vehicles per collision	1.48	2.51	1.35	2.37

Table 10 details the breakdown of the road classes where recorded collisions occurred. The trends observed are similar across FL vehicles and the comparator group: Most of the collisions (well over half) occur on A-roads, followed by motorways and B-roads. Rollovers occur by far most frequently on A-roads. No marked differences can be observed between FL vehicles and comparator group. Note that these figures do not take into account the relative traffic flow on the different road classes, i.e. the higher numbers of collisions on A-roads are likely to be due to these vehicles using A-roads more than the other road types. However, the relative difference between rollover collisions and collisions which don't involve the vehicle of interest rolling over should still be meaningful (as long as the number of collisions is not small).

Table 10. Road class of collision locations

Road class ¹⁷	Coll. involving FL vehicle				Coll. involving 6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
Motorway	3	12.0%	106	30.8%	170	17.3%	2,716	28.4%
A-roads	19	76.0%	194	56.4%	695	70.6%	5,592	58.5%
B-roads	3	12.0%	20	5.8%	66	6.7%	462	4.8%
C-roads	0	0.0%	6	1.7%	20	2.0%	231	2.4%
Unclassified	0	0.0%	18	5.2%	34	3.5%	553	5.8%
Total collisions	25	100.0%	344	100.0%	985	100.0%	9,554	100.0%

There were 229 FL vehicles and 6,471 6-axle artics involved in two-vehicle collisions. These collided with the types of vehicles as shown in Table 11. The relative proportions appear to be similar between FL vehicles and the comparator group. Collisions involving hitting or being hit by another heavy vehicle can be assumed to present a higher risk of damage to the tank. The vast majority of two-vehicle collisions are non-rollover cases. For FL vehicles it can be seen that only 19.1% of these involve collisions with potentially

¹⁷ Definitions of A, B and C roads are available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/315783/road-classification-guidance.pdf (section 1.13).

heavy vehicles ('goods vehicles'), whereas the rest are impacts with lighter vehicles. Although the latter presumably involve a smaller risk of damaging the tank, load spillage will occur in a proportion of these cases, e.g. if the impact of the light vehicle occurs at a high speed.

Table 11. Other vehicles hit in two-vehicle collisions

Other vehicle hit (two-vehicle collisions only)	FL vehicle				6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
Pedal cycles	0	0.0%	11	4.9%	0	0.0%	222	3.5%
Powered two wheelers	0	0.0%	10	4.4%	1	0.7%	251	4.0%
Cars, taxis and minibuses	3	75.0%	159	70.7%	104	73.2%	4,710	74.4%
Goods vehicles	1	25.0%	43	19.1%	35	24.6%	990	15.6%
Other and unknown	0	0.0%	2	0.9%	2	1.4%	156	2.5%
Total vehicles	4	100.0%	225	100.0%	142	100.0%	6,329	100.0%

There were 548 casualties involved in the 369 FL vehicle collisions, 99 of which were killed or seriously injured (KSI). The distribution of these casualties is shown in Table 12 (these include the occupants of the articulated vehicles). The majority of casualties were occupants of cars or goods vehicles. This is because cars make up the vast majority of vehicles on the road network and because these collisions all include at least one goods vehicle by definition.

Table 12. Breakdown of casualties by casualty group and injury severity

Casualty group	FL vehicle collisions				6-axle artic collisions			
	KSI		Slight		KSI		Slight	
Pedestrians	3	3.0%	6	1.3%	288	9.8%	187	1.5%
Pedal cyclists	5	5.1%	6	1.3%	102	3.5%	130	1.0%
Powered two wheeler users	5	5.1%	7	1.6%	204	6.9%	202	1.6%
Car, taxi and minibus users	51	51.5%	310	69.0%	1,388	47.2%	8,318	65.0%
Goods vehicle occupants	35	35.4%	110	24.5%	904	30.8%	3,519	27.5%
Other and unknown	0	0.0%	10	2.2%	53	1.8%	436	3.4%
Total casualties (all vehicles)	99	100.0%	449	100.0%	2,939	100.0%	12,792	100.0%

Table 13 provides an overview of the types of objects hit by FL vehicles and the comparator group in collisions. Objects hit off-carriageway present a risk of rupturing the tank, thus increase the risk of load spillage. 60% of the FL vehicle rollover collisions

involved hitting an object off-carriageway, i.e. a total 15 cases in the 7-year period analysed. The proportion is similar to the one observed in the comparator group.

Table 13. Objects hit off carriageway by articulated vehicles in collisions

Object hit off carriageway	FL vehicle				6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
No off carriageway object hit	10	40.0%	332	96.2%	437	43.5%	9,409	95.0%
Sign / post / pole / tree	4	16.0%	5	1.4%	172	17.1%	129	1.3%
Crash barrier / wall or fence	6	24.0%	4	1.2%	221	22.0%	204	2.1%
Entered ditch	4	16.0%	2	0.6%	64	6.4%	48	0.5%
Other permanent object	1	4.0%	2	0.6%	110	11.0%	110	1.1%
Total vehicles	25	100.0%	345	100.0%	1,004	100.0%	9,900	100.0%

Table 14 and

Table 15 provide a breakdown of collisions by time of day and weather conditions respectively. This does not indicate any marked differences between FL vehicles and comparator group. The vast majority of collisions in both groups happen during daytime hours (6am-6pm) under fine weather conditions. Note that this analysis focuses on potential outcomes of collisions, not collision causation. The figures are not suitable to draw conclusions about collision causation factors because they are not put in relation to any exposure data (such as mileage driven under each of the conditions).

Table 14. Breakdown by time of day

Time of day	Coll. involving FL vehicle				Coll. involving 6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
0-6	2	8.0%	33	9.6%	161	16.3%	900	9.4%
6-12	6	24.0%	139	40.4%	349	35.4%	3,691	38.6%
12-18	12	48.0%	117	34.0%	343	34.8%	3,682	38.5%
18-0	5	20.0%	55	16.0%	132	13.4%	1,281	13.4%
Total collisions	25	100.0%	344	100.0%	985	100.0%	9,554	100.0%

Table 15. Breakdown by weather conditions

Weather	Coll. involving FL vehicle				Coll. involving 6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
Fine	22	88.0%	287	83.4%	839	85.2%	7,862	82.3%
Raining / Snowing	3	12.0%	49	14.2%	115	11.7%	1,314	13.8%
Hazardous fog or mist	0	0.0%	2	0.6%	9	0.9%	110	1.2%
Other / unknown	0	0.0%	6	1.7%	22	2.2%	268	2.8%
Total collisions	25	100.0%	344	100.0%	985	100.0%	9,554	100.0%

The breakdown by road type and junction detail, provided in Table 16 and Table 17 respectively, indicates differences between rollover and non-rollover cases. As expected, the proportion of collisions happening at roundabouts is markedly higher for rollover than non-rollover cases. This holds true for both FL vehicles and the comparator group. The proportion of rollovers on single carriageways is higher among FL vehicles; although, the absolute numbers are very small, making a random fluctuation appear likely in this case.

Table 16. Breakdown by road type

Road type	Coll. involving FL vehicle				Coll. involving 6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
Roundabout	6	24.0%	25	7.3%	310	31.5%	730	7.6%
Dual carriageway	5	20.0%	177	51.5%	261	26.5%	4,856	50.8%
Single carriageway	12	48.0%	133	38.7%	363	36.9%	3,689	38.6%
Slip road / one way street	2	8.0%	9	2.6%	50	5.1%	256	2.7%
Unknown	0	0.0%	0	0.0%	1	0.1%	23	0.2%
Total collisions	25	100.0%	344	100.0%	985	100.0%	9,554	100.0%

Table 17. Breakdown by detail on junction situation

Junction detail	Coll. involving FL vehicle				Coll. involving 6-axle artic			
	Rollover		No rollover		Rollover		No rollover	
Roundabout / mini roundabout	9	36.0%	31	9.0%	361	36.6%	985	10.3%
Slip road	2	8.0%	21	6.1%	44	4.5%	511	5.3%
Private drive or entrance	0	0.0%	12	3.5%	3	0.3%	293	3.1%
Other junction	1	4.0%	62	18.0%	79	8.0%	1,777	18.6%
Not at or within 20m of a junction	13	52.0%	218	63.4%	498	50.6%	5,988	62.7%
Total collisions	25	100.0%	344	100.0%	985	100.0%	9,554	100.0%

4.3 Officially reported incidents (ADR and RIDDOR) and traffic logs

RIDDOR reports classed under 'tanker incident' or 'release, escape of substances' from the years 2011 to 2013 were provided by the HSE. Further information on ADR tanker incidents was provided by DfT from traffic logs and ADR incident reports from 2005 to 2013. The traffic logs record all incidents on the major road network where a traffic incident involved a dangerous goods vehicle. The ADR incident reports are (or at least should be) submitted to DfT by vehicle operators whenever their vehicles are involved in a serious accident or collision.

Under the terms of ADR section 1.8.5, a report has to be filed by the loader, filler, carrier or consignee

"if a serious accident or incident takes place during loading, filling, carriage or unloading of dangerous goods on the territory of a Contracting Party (...)".

A 'serious' accident in this context is further defined as being:

"if dangerous goods were released or if there was an imminent risk of loss of product, if personal injury, material or environmental damage occurred, or if the authorities were involved and one or more of the following criteria has/have been met:

Personal injury means an occurrence in which death or injury directly relating to the dangerous goods carried has occurred, and where the injury

(a) Requires intensive medical treatment;

(b) Requires a stay in hospital of at least one day; or

(c) Results in the inability to work for at least three consecutive days.

Loss of product of Class 3.0 flammable liquids means the release of dangerous goods in quantities of 1,000 kg / 1,000 litres or more".

Incidents, even rollovers, quite rarely lead to loss of load in these quantities or lead to injuries of the threshold severity levels and relating to the dangerous good carried (i.e. injuries sustained from the traffic accident alone are not considered in this instance). Crucially, the ADR regulation goes on to state:

"The loss of product criterion also applies if there was an imminent risk of loss of product in the above-mentioned quantities. As a rule, this has to be assumed if, owing to structural damage, the means of containment is no longer suitable for further carriage or if, for any other reason, a sufficient level of safety is no longer ensured (e.g. owing to distortion of tanks or containers, overturning of a tank or fire in the immediate vicinity)."

This implies that any incident of overturning warrants a completion of an ADR incident report, even more so if the tank structure has become distorted.

In total, 15 officially reported incidents from the period 2005 – 2013 have been identified as being relevant to this study, i.e. involved a flammable liquid tanker. The reports are summarised in Table 18. The name of the tank manufacturer is not provided in ADR or RIDDOR incident reports. To focus the analysis on articulated vehicles, rigid tankers were excluded where the vehicle type could be identified from the reports. Generally speaking, the ADR and RIDDOR reports relate to more severe incidents than those described in the traffic logs. The records of casualties are considered by TRL as unreliable: The ADR incident report form only requires information on casualties "*directly relating to the dangerous goods carried*" (i.e. injuries sustained from the traffic accident alone are not considered). This might be disregarded in some cases by operators filing reports.

Eight of the 15 accidents (53%) involved a spilt load, of which 6 cases were major spills, i.e. >1,000 litres, 1 case was a minor spill and 1 case unknown. The major spills were associated with overturning in 5 out of 6 cases and a side impact (impact with the jib of a mobile crane) in 1 out of 6 cases. 3 of the 6 cases were with aluminium tanks, the other three were of unknown material. The prevalence of aluminium tanks in the FL vehicle fleet is not known.

Seven of the 15 accidents (47%) did *not* involve spilt load, although 1 of these accidents led to minor loss of fuel from the tanker vehicle's running fuel tank, but no fire or explosion was reported. 2 out of 7 non-spill cases involved overturning. The remaining non-spill cases involved a mixture of rear, side and frontal impacts and vehicles catching fire (but without subsequent loss of product or explosion).

In total, 9 accidents involved overturning of which 7 led to load spillage (5 of which were major spills >1,000 litres, 1 minor spill, and 1 unknown). 2 of these 5 cases were with aluminium tanks (rest unknown). One case involving an overturn but not leading to spillage was with a steel tank (1 unknown).

Table 18. Officially reported incidents involving a flammable liquid tanker. Sources: ADR reports from 2005-2013, RIDDOR reports from 2011-2013, traffic logs from 2013

Year	Source	Summary	Load (UN number, class, packing group)	Loss of product	Collision	Overturn	Road type	Casualties	Ref
2005	ADR	No loss of product, but imminent risk of loss.	Flammable liquid (no details given)	None	Yes	No	Non-built-up – not motorway	None	1
2005	ADR	Tanker vehicle with tank trailer rolled into banking at side of the road. All load lost from tank trailer.	Diesel (UN 1202, 3, III)	Major (13,000 litres)	No	Yes	Non-built-up – not motorway	One injured	2
2005	ADR	Tanker tipped to the side after evading oncoming traffic. No loss of product from steel tank, but imminent risk of loss.	Diesel and kerosene (UN 1202, 3, III and UN 1223, 3, III)	None	No	Yes	Non-built-up – not motorway	None	3
2007	ADR	Tanker side-impacted by small vehicle at cross road.	Petrol and kerosene (UN 1203, 3, II and UN 1223, 3, III)	None	Yes	No	Non-built-up – not motorway	Two injured	4
2007	ADR	Tanker lost control while negotiating roundabout (icy road), hit kerb and tipped. Loss of product from aluminium tank.	Diesel (UN 1202, 3, III)	Major (15,000 litres)	No	Yes	Non-built-up – not motorway	None	5
2007	ADR	Collision with another vehicle.	Kerosene (UN 1223, 3, III)	None (minor fuel spillage from running tank)	Yes	No	Non-built-up – not motorway	One injured	6
2009	ADR	Empty tank vehicle collided with another vehicle.	None; empty petrol tanker (UN 1203, 3, II)	None	Yes	No	Non-built-up – not motorway	Not reported	7

Year	Source	Summary	Load (UN number, class, packing group)	Loss of product	Collision	Overturn	Road type	Casualties	Ref
2012	ADR & RIDDOR	Loss of control, tanker left the road, collided with objects and tipped to the side. Tree stump ruptured front compartment of aluminium tank.	Kerosene (UN 1223, 3, III)	Major (19,000 litres)	Yes	Yes	Non-built-up – not motorway	One fatality, one injured	8
2012	RIDDOR	Tractor unit and chassis carrying tank overturned on roundabout.	Dicyclopentadiene (UN 2048, 3)	None	No	Yes	Unknown	Not reported	9
2012	RIDDOR	Tanker collided with other heavy vehicle. Driver trapped in vehicle and suffered minor injuries.	Diesel (UN 1202, 3, II)	None	Yes	No	Unknown	One injured	10
2012	RIDDOR	Driver lost control and tanker overturned.	Gas oil and kerosene (UN 1202, 3, II and UN 1223, 3, III)	Minor (900 litres)	No	Yes	Unknown	Not reported	11
2012	RIDDOR	Articulated tanker was being towed by recovery vehicle and detached from the recovery vehicle. Trailer overturned.	Diesel and Petrol (UN 1202, 3, II and UN 1203, 3, II)	Major (4,000 litres)	No	Yes	Non-built-up – not motorway	None	12
2012	RIDDOR	Tanker mounted kerb and overturned.	Aviation fuel (UN 1863, 3, III)	Yes (quantity unknown)	No	Yes	Unknown	Not reported	13
2013	ADR & RIDDOR	Driver lost control and vehicle overturned.	Ethanol (UN 1170, 3, II)	Major (2,206 litres)	No	Yes	Non-built-up – not motorway	One injured	14
2013	ADR & TL	Mobile crane travelling in opposite direction collided with stationary tanker and breached the rear compartment of the trailer aluminium tanker.	Diesel (UN 1202, 3, II)	Major (3,500 litres)	Yes	No	Built-up road	None	15

4.4 Local news reports

A search for local news reports involving tanker incidents which occurred in the UK between 2009 and 2014 was carried out using the BBC news website. The main aim of the search was to identify the magnitude of potential underreporting of ADR incidents by comparing the results from news reports with official ADR reports provided by DfT. Initially, only reports involving the spillage of flammable liquids were recorded. However, due to the lack of results this produced, all news stories involving the words 'tanker' and 'accident' were then included in the search.

Table 19 below provides a summary of the 59 identified UK news reports on tanker incidents. Details of each individual news report may be found by referring to Table C-1 (spillage cases) and Table C-2 (non-spillage cases) in Appendix C.1. References for each report are provided in Appendix C.2.

Table 19. Summary of incidents reported by local news reports.

	Spillage	Flammable liquid	Injury	Collision	Tanker overturn	of which	Led to spillage
Number of cases	25	34	31	37	22		14
% of cases	42%	56%	53%	63%	37%		64%

4.4.1 Analysis of news reports

It would be unrealistic to expect that all incidents involving tankers on UK roads would be identified using this approach. News reports were mainly produced for tanker incidents which were notable for a particular reason. This may be because:

- The tanker shed its load during the incident, particularly if large quantities were spilled or the load was a dangerous substance and posed a threat to the public.
- The accident caused roads to be closed and caused severe congestion or delays.
- The accident had a high severity including fatalities or injuries.

42% of the reported cases were found to be spillage incidents, with 80% of those cases involving flammable liquids. There may be a bias towards reporting events involving flammable liquids due to the more serious consequences of spilling this type of load; increased presence of emergency services and higher chance of road closures.

A tanker overturned in 37% of the news incidents. Of these incidents, 64% were then reported to have spilled their load. This implies that up to seven out of ten rollover events might lead to spillage, although the news reports might be biased towards more severe cases.

Casualties occurred in 53% of incidents reported in the news articles. This implies that for every 100 injury tanker accidents there could be 89 non-injury accidents. However, all values estimated using this data have a high degree of uncertainty due to the bias in reporting exceptional cases and potential exaggeration by the media.

In terms of accidents specifically involving articulated road fuel tankers, the news reports show there were a minimum of 6, possibly 7, overturning incidents over the last four years. One involving a gas oil tanker in 2011, 2 aviation fuel, 1 diesel and 1 petrol tanker

in 2012, and 1 ethanol¹⁸ and 1 (possible) in 2013, where the exact load was not stated but one report into the incident described as "fuel". There have been no incidents, so far, in 2014 and there were none in 2010.

4.4.2 Comparison of news reported incidents with ADR incident reports submitted to DfT

Of the four reported ADR Incidents occurring and reported to the DfT between 2009 and 2013 (Table 17), only three matching local news stories were found. These were analysed to examine how well they correlated with each other and to determine whether there were significant levels of underreporting of incidents by operators between 2009 and 2013. It was noted that some of the incident forms were incomplete and some questions appeared to be misunderstood, especially for questions surrounding injuries caused by the incident. Additionally, some forms were filled out before sufficient information was known by the operator about the cause of failure of the tank, preventing any lessons being learnt from the incident.

2009 – Empty tanker collision

An operator reported an incident to DfT where an empty tanker collided with another vehicle on a rural road. No BBC news story was found providing information on this incident.

2012 – Crook of Devon fatal crash

The local news story describing the incident correlated well with the ADR incident form.

2013 – Tanker overturned on A-road

Both the ADR data and the local news story state that a tanker carrying ethanol overturned and spilled some of its load. However, the local news described the amount of ethanol spilled as 'up to 38000 litres' which is the capacity of the tanker involved in the incident. However, the operator estimated the loss of ethanol to be roughly 2,206 litres. The operator did not fill in any details on injuries due to the incident and reported that no emergency services or other authorities attended the scene. However, the news article stated that the driver suffered head injuries and was taken to hospital and the scene was attended by the fire and rescue service. The article provides supporting video and images of fire and ambulance crews attending the scene.

2013 – Tanker rupture

Both the ADR data and the local news story described the same incident of a crane rupturing the rear section of a tanker trailer, causing a fuel spill. The operator stated the fuel was diesel on the ADR incident form. However the BBC news story initially described the fuel as petrol, until a second article was published four days later identifying the fuel as diesel. The operator stated that 3,500 litres of diesel had been lost, whereas the BBC news article stated that 'about 7,500 litres' had been spilled. The article also indicated that there was some environmental damage as diesel spilled into a nearby brook. This was not indicated on the ADR incident form.

¹⁸ An industry stakeholder confirmed that tankers used to transport ethanol were of the same basic design as those used to carry road fuels, hence its inclusion here.

4.5 In-depth truck accident databases

Road Accident In-Depth Studies (RAIDS) is an in-depth investigation study that will provide a unique source of data on accident causation and consequences, contributing vital evidence to underpin the development and implementation of countermeasures to reduce risk and mitigate injuries. RAIDS incorporates the historic data from previous in-depth accident studies, including the Heavy Vehicle Crash Injury Study (HVCIS) and Truck Crash Injury Study (TCIS).

From the literature, collisions involving overturning and collisions with other large vehicles or rigid structures were identified as being of particular interest. Collisions involving chemical spills, fuel leaks or fire were also considered relevant.

4.5.1 Heavy Vehicle Crash Injury Study (HVCIS)

HVCIS is a collection of data coded by TRL from a sample of police fatal collision reports for collisions between 1995 and 2008 that involved at least one commercial vehicle (goods vehicle over 3.5t, buses/coaches/minibuses, and "other motor vehicles" such as agricultural vehicles, mobile cranes etc.).

Table 20 summarises the HGVs (goods vehicles with GVW>7.5t) that are recorded in the database and the number of which are tankers.

Table 20. Summary of HGVs in RAIDS Database (HVCIS).

Vehicle Type	All	Tankers
Articulated	1139	75 (6.6%)
Rigid	1062	37 (3.5%)
Other *	96	0 (0.0%)
Total	2297	112 (4.9%)

* Drawbar combinations and solo tractor units

Closer analysis of the 75 collisions involving articulated tankers showed that 10 (13.3%) involved overturning. The circumstances of the overturning collisions were:

- Four overturning collisions occurred on bends where excessive speed was factor (travel speed of 34 miles/h and 55 miles/h recorded for 2 of the 4 vehicles).
- Three overturns occurred prior to impact after corrective or evasive steering/braking (travel speed of 54 miles/h and 58 miles/h recorded for 2 of the 3 vehicles).
- One overturn occurred turning left at roundabout.
- Two overturns were as a result of the tanker leaving the carriageway.

The load being carried at the time of the collision was known in nine cases. Two were carrying fuel and three others were carrying loads that could be classified as dangerous goods under ADR.

- A chemical spill was recorded for 1 of 9 cases (where load was known). This suggests that chemical spills from articulated tankers are rare in fatal accidents, with this collision accounting for less than 0.1% of all the articulated HGVs in the database and 1.3% of articulated tankers.

- Fire was recorded for two of the ten cases. Although the cause of fire was not specified, one of the vehicles was a fuel tanker where the impact involved a large vertical drop and compartment rupture was likely. The second collision involved an overturned tanker being struck by an on-coming HGV and therefore tank rupture was a possible.

The descriptions of the remaining 65 collisions were reviewed to identify any other cases that may be of interest. There were five collisions where tanker was impacted from rear by another large vehicle, although in 2 cases there was another vehicle in-between the rearmost vehicle and the tanker:

- One tanker unladen at the time of the collision.
- Of remaining four collisions, all of them were carrying loads that may be classified as dangerous under ADR. There was one collision where a chemical spill recorded, although this was not fuel.
- The age of the tanker was unknown in all five cases
- Analysis of impact speeds, where known, showed that the closing speeds at impact were 31mile/h, 37mile/h, 40mile/h and 53mile/h¹⁹. In the fifth collision the travel speed was known for both vehicles and the closing speed was calculated at 12mile/h.
- The collision resulting in chemical spillage was the impact with the closing speed of 53mile/h, although a small car was in between the two HGVs involved in the collision which is likely to have affected the interaction between the two HGVs.

4.5.2 Truck Crash Injury Study (TCIS)

TCIS is a sample of collision data coded by officially-appointed vehicle examiners from vehicle inspections between 1995 and 2009. The database contains data relating to collisions of all severities from non-injury to fatal.

The study classifies HGVs as tractor units, rigid HGVs or trailers. The following analysis was restricted to rigid HGVs and trailers only. Table 21 summarises the vehicles by their classification.

Table 21. Summary of HGVs in RAIDS Database (TCIS).

Vehicle Type	All	Tankers
Trailer	588	11* (1.9%)
Rigid	1217	31 (2.5%)

* One trailer was specifically described as draw-bar and therefore excluded from further analysis.

The injury severity of the ten collisions involving tanker trailers were four fatal, two serious and four slight. The year of manufacture was known for five of the trailers, the age of the trailers at the time of the accidents were four, nine, eleven, thirteen and fourteen years old.

¹⁹ Collision involved HGV colliding with rear of car and pushing it into the rear of the tanker in front.

Of the ten TCIS tank trailers:

- Four of the collisions were solely overturning after failure to negotiate bend.
- Two collisions involved overturning after some kind of corrective or evasive steering/braking.
- Two collisions involved impacts to the rear of the tanker. One of these was hit by a light commercial vehicle. The second case involved an HGV colliding with the rear of a car and pushing it into the rear of the tanker, which is the same collision identified in the HVCIS data.

Where the loading status of the trailer was known, eight of nine trailers were laden at the time of the collision:

- There were four hazardous loads; three flammable and one explosive.
- One chemical spill was recorded. The tanker was 14 years old. This was the same collision involving a chemical spill as identified in the HVCIS data.
- There was one case where there was specific mention of damage to pipes after impact with barrier anchor. This trailer was 11 years old.

5 Stakeholder surveys

5.1 UK industry

Initially, key contacts in the UK fuel tanker industry, from operators and repair organisations, were identified by participants in the various work packages and the Department for Transport. An email questionnaire (reproduced in Appendix B) was distributed to all of them (to six individual companies and one trade body). A summary of the responses is presented here.

Respondents did not generally provide precise accident involvement statistics to a common definition. Rates provided varied from 1.5 – 5 per million vehicle kilometres, but these usually included mainly very minor incidents (e.g. low speed manoeuvring or cracked wing mirrors). Where figures were provided for more serious incidents such as overturns and spillages, frequencies were generally very low; typically historical rollover frequencies of 1 in every 150 – 400 vehicle years and major spillage resulting from 20-25% of those.

With regard to accident typology, respondents reported on the one hand rear and side impacts while being parked as well as low speed manoeuvring collisions, all of which were low severity accidents. On the other hand single vehicle roll-overs were mentioned, which were more severe and resulted in fuel spillage in 1 out of 4 cases. The amount of spilt fuel was limited; however, the stakeholder mentioned high impact roll-overs as an accident type that was frequently associated with fuel loss. Other respondents mentioned limited fuel spillage (up to 50 litres) from impacts affecting valves and pipework or general malfunction of valves.

Repair costs resulting from incidents varied widely depending on the type of damage: Repair of dents, including degassing and repainting one panel was estimated to cost approximately £1,000 (up to £3,000 if damage was more substantial). A total tank replacement after a more severe accident was estimated at £50,000 to £60,000. Associated environmental clean-up costs might run to £200,000.

The vehicle types in use varied between the respondents without a clear trend becoming obvious. Reported vehicles were articulated vehicles with three or six axles (plated at between 26 and 44 tonnes) as well as two- or three-axle rigid vehicles (from 3.5 tonnes to 26 tonnes). Respondents reported use of predominantly aluminium tanks for fuel; however, a small number of stainless steel tanks were also in use. The tanks are usually of the banded design, though use of the “stuffed” designs was also quite commonplace.

Where known, all the tankers were reported as being fitted with some form of vehicle stability function (e.g. ESC- Electronic Stability Control) and the general rarity of rollovers was thought to be at least in part related to that fact.

Tanker operations were reported to be most often at full load (by weight not volume, 38,000 to 41,000 litres typically) or empty, though some journeys at partial loads were also made (e.g. individual compartments emptied at separate delivery locations).

Respondents agreed that ADR regulations are an important factor in their procurement decisions. One stakeholder pointed out that ADR governed the vessel, but the pumping and discharge equipment, flow meters, etc. were generally selected by the user.

In the latter stages of the project, further feedback was provided by a stakeholder on the numbers of road fuel tankers in use in the UK and on their perceived safety relative to

other types of FL-registered vehicles. This feedback suggests that fuel tankers constitute about 25% to 30% of all six-axle articulated FL-registered vehicles, which would equate to around 1,000 – 1,200 vehicles on UK roads.

The stakeholders also suggested that petroleum road fuel tankers are relatively more safe than other FL-vehicles, in that they are more likely to be fitted with modern braking systems and anti-rollover technology, as well as having tank designs that provide lower centres of gravity than some other tankers (e.g. circular). A major oil company provided data, however, confirming that they had experienced one rollover of a road fuel tanker within their UK fleet in recent years, and one other case involving a vehicle working under contract to them. They also confirmed that, globally, their vehicles have been involved in at least 20 rollover incidents per annum.

5.2 International experts

In a later phase of the project, an amended version of the questionnaire was distributed among 50 international experts in tank safety via email (reproduced in Appendix B). The scope of the questions was extended so as to acquire data on potential under-reporting of accidents. Despite a sufficient timescale and an email reminder, the number of replies was limited. The results are summarised here.

The accident involvement rates reported per distance travelled ranged from 0.25 to 1.0 accidents per million vehicle kilometres. The lower-end of this range might be subject to under-reporting of incidents. Data from Finland suggests an accident involvement rate of 3.4 accidents per 100 registered vehicles per annum, based on reported accidents only.

No numbers were provided to distinguish between severe (e.g. injurious) and damage-only accidents. Data from Spain gave an indication of the frequency of spillage incidents of dangerous goods in the country (see Table 22). Between 2002 and 2011, on average, 36.6 cases of load spillage from dangerous goods tankers occurred annually in Spain. Figures on the relevant fleet size could not be obtained.

Table 22. Load spillage cases in Spain from tankers carrying dangerous goods

Year	Number of incidents
2002	35
2003	35
2004	39
2005	45
2006	34
2007	53
2008	38
2009	45
2010	21
2011	21
Average	36.6

The accident types that were reported as being most common were front and rear impacts involving other vehicles and single vehicle roll-overs. Loss of load occurred in 23% of reported accidents in Finland, i.e. in a total of 3 out of 13 cases, none of which led to fire or explosions. Two of these incidents resulted in leakage from damaged manhole or other cover (ca. 1000 litres); one minor spillage (ca. 50 litres) resulted from damage during the rescue operation. Minor leakages from pumps, pipework and hoses were reported by a UK stakeholder.

No ADR or RIDDOR reports relevant for the scope of this study were submitted by stakeholders. However, it can be inferred from the replies that differing interpretations of ADR reporting requirements exist (e.g. as to whether a tanker overturn requires an ADR report in any case or not).

Under-reporting of incidents was seen as a potential problem in Finland, although no official evidence of under-reporting existed. For Spain, no under-reporting was expected by stakeholders because incident reports have to be filed by two independent entities (the operator of the tanker and traffic police), which can be used for cross-comparisons. In order to improve reporting levels, the focus was put on user-friendliness in general and aligning or combining the reports required by ADR and RIDDOR. It was also suggested to introduce the Spanish system of dual, independent reporting by operator and police.

No evidence has been found to indicate that failures of circumferential welds have played any significant role in real-world fuel spillage incidents, although none of the non-compliant tankers are known to have been involved in such incidents in the UK.

6 Discussion

As described earlier, WP3's stated objectives were to:

- Task 1 - Determine representative rollover and collision loads; and
- Task 2 - Identify regulatory implications and potential amendments.

The following sections discuss and summarise how the results of the various activities described in detail in the preceding Chapters fulfil those objectives, what evidence gaps remain and the potential for further work to enhance and strengthen the overall research programme and regulatory environment.

6.1 Real-world accident characterisation

The aim of Task 1 was to provide background intelligence on fuel tanker accidents, e.g. their frequency and how often rollovers and rear impacts lead to fuel spillage and/or tank rupturing, and in what specific circumstances. This was intended to help define the overall risks associated with tank rupture and inform the test and modelling work to be completed in the other work packages, ensuring that the simulated conditions are broadly realistic.

Tank rupture was thought, at the outset of the project, likely to be rare, so the research net was cast wide and involved an international review of multiple sources:

- i. Published international research literature (from 1995 – 2014)
- ii. DfT statistics/records (including STATS19 data, ADR and RIDDOR reports)
- iii. Local news media articles
- iv. Detailed (in-depth) truck accident databases (RAIDS)
- v. Stakeholder survey (of tanker operators and repairers)

From STATS19 data it can be seen that FL vehicles are involved in 1.58 injurious collisions per 100 registered vehicles per annum, which is almost 20% lower than the rate of all 6-axle artics.

The international literature, statistics, media articles, in-depth databases and stakeholder survey responses all point to the importance of rollover as a contributory factor in major fuel spillage incidents. They also suggest that rear impacts from other heavy vehicles are often a contributory factor for more minor spillages. The annual rollover involvement rate of FL vehicles is 0.11 per 100 registered vehicles per annum (STATS19 data), which is 43% lower than the rate of all 6-axle artics.

Recent trends suggest that articulated vehicle rollovers are becoming less frequent. This is most likely attributed to the increased penetration of preventative technologies and safer driving interventions throughout the vehicle fleet. Rollovers of FL-registered artics are rare, with anything between zero and seven cases being identified within STATS19 over each of the last seven years, without any apparent consistent downward (or upward) trend. Major spills associated with overturning incidents are also reducing in frequency. However, technologies and driver training cannot prevent all rollovers and such incidents do still happen. Taking into account that damage-only accidents are not recorded in STATS19, it was estimated that each year 5 to 7 collisions involving rollovers of articulated six-axle FL vehicles occur in GB.

The analysis of collision typology (e.g. distribution of accident severities, road class, time of day, or weather) did not reveal any marked differences between FL vehicles and all 6-axle artics (apart from the reduced collision involvement and overturning rates).

For an overturn to result in major spillage, the evidence gathered indicates that a combination of overturning and sliding is usually involved, with rupture of the tank arising from scraping or puncturing impacts with road-side objects and structures. A simple, low speed overturn by 90 degrees onto a rigid flat surface without sliding or other secondary impacts, as used in Work Package 1 (WP1) to validate a mathematical model of the said tankers, appears to be very unlikely to lead to fuel spillage.

No evidence has been found to indicate that failures of circumferential welds have played any significant role in real-world fuel spillage incidents, although none of the non-compliant tankers are known to have been involved in such incidents in the UK.

In overturning without sliding, previous testing reported in the international literature suggests roll rates of 100 – 150 deg/s (1.75 – 2.60 radians/s) are likely at the point of impact of the tank with the ground. For the testing and modelling carried out in WP1, a simple tilt and topple test achieving a roll rate at impact within this range would appear, therefore, to be a realistic representation of that scenario. Other research indicates that deformations in the nominal diameter of the tank shell of 35-80 mm would be within the range of expectations.

Where an overturn is followed by sliding and impact (in the area of the tank's roof) with vertical road-side objects or structures, previous research suggests that sliding speeds at impact of around 4 to 7 m/s (15 to 25 km/h) would be realistic (velocity component in the direction perpendicular to the vertical surface/structure).

Fuel spillage incidents appear to be highly complex, involving various factors and secondary impacts. This means it is not possible to identify a single "average" accident scenario. This is compounded by the general paucity of detailed information on specific accidents, particularly the exact tank failure mechanisms and/or damage patterns.

It should also be emphasised that much of the earlier research reviewed relates to tanks used in other countries, often many years ago, so caution is needed when translating the results into UK tanks in use in 2014.

6.2 Potential regulatory implications

6.2.1 Under-reporting

This study revealed just 10 ADR incident reports from the nine-year period from 2005 to 2013 inclusive regarding flammable liquid tanker accidents. This is just above only 1 incident per year being currently reported on average, whereas other data from GB (STATS19) and Germany suggests there could be as many as 5 or 7 spillage incidents each year involving such vehicles.

The reporting rates under RIDDOR appear to be higher with 8 reported incidents in the three-year period from 2011 to 2013 inclusive (2.7 per year). Since October 2013, however, HSE have advised that under new legislative provisions, operators are not always required to report under RIDDOR, but only file an ADR report, unless there is an unintentional release of 500 kg or more of flammable liquid. Stakeholders suggest that the amended requirements to file RIDDOR reports might be mis-interpreted by operators in a way that they are not required to report some incidents at all.

The review of news reports on tanker incidents identified 18 cases involving load spillage of flammable liquids (minor and major) in the 5-year period from 2009 to 2013. The number of ADR incident reports submitted to DfT for the same period amounts to only 4 cases. Although not all of the minor cases would have been required to be reported, this is a further indication that under-reporting of ADR incidents might be present.

The exact reporting requirements are detailed in ADR section 1.8.5 and summarised in Chapter 4 of this report. These criteria may explain much of the apparent under-reporting, in that incidents, even rollovers, quite rarely lead to loss of load in these quantities or lead to injuries of the threshold severity levels and relating to the dangerous good carried (i.e. injuries sustained from the traffic accident alone are not considered in this instance). However, TRL's interpretation of the further explanations in the ADR Regulation is that all overturns should be reported. Only 5 overturning incidents have actually been reported in ADR incident reports over the last nine years. This is the equivalent of 0.6 per year whereas STATS19 data shows that at least 3.7 overturning incidents involving articulated flammable liquid tankers occur per year (and this only includes overturns where injury occurred).

These numbers indicate quite significant under-reporting under ADR requirements.

In order to improve the level of reporting, the following ideas could be considered:

- Enhanced guidelines and training for operators might be necessary to increase reporting rates. These guidelines might encourage all overturning incidents to be reported, for example, regardless of whether any load is spilt or, indeed, whether any load was being carried at the time.
- A dual reporting system of some kind. This was identified by stakeholders to ensure high reporting levels in Spain, where the police and operators both have to file a report. This does not necessarily have to require both parties to fill in the same form or report to the same level of detail.
- An ongoing periodic review of local news media articles, for example once every 1–3 months, to identify new cases that appear to involve an ADR vehicle, especially overturning. Researchers (or DfT) could then obtain details of the FL vehicle involved from the local police traffic officers send reminders for submitting an incident form, if not done already.
- A web-based reporting system ensuring data from all reports are in a central repository that is readily accessible and assessable.

Future research would also benefit from a higher level of detail in the incident reports. The analysis carried out for the present study suggested that the following information would be particularly useful:

- Vehicle, trailer and tank manufacturer's details, and dates; and
- Full description of the tank (e.g. number of compartments and their capacities) and of any damage and its likely cause.

6.2.2 Tank material

This apparent under-reporting makes it particularly difficult to assess the relevance of tank material to spillage risks, because ADR Incident Reports are typically the only source of information regarding tank material. German research from the 1990s

indicates that stainless steel tanks are likely to be much more resistant to puncturing in an overturn with sliding incident than aluminium tanks. UK Incident Report data seems to confirm this, with both the two tanks with known material involved in reported overturning incidents leading to major spillage being aluminium; while a stainless steel tank in such an incident did not rupture. The numbers are too small to draw strong conclusions, but there is at least an indication that aluminium tanks may be more prone to rupturing than those constructed from stainless steel.

This issue may be exacerbated by the current ADR requirements (described in more detail in section 3.4). Tanks designed to provide protection against damage in a simple (non-sliding) overturn, by being equipped with strengthening partitions and surge-plates, are allowed to use thinner shell materials. This may well make them more susceptible to penetrating/tearing damage in incidents where overturning is accompanied by sliding along the ground and secondary impacts with roadside objects. The detailed STATS19 data review and other evidence gathered indicate these types of impacts are the most common cause of major fuel spillage.

6.2.3 Vehicle fuel tanks

Dutch research has suggested that the running fuel tanks of ADR vehicles (i.e. those for propelling the vehicle rather than the load carried) could usefully be better designed and protected to reduce the risk of fuel leakage after an accident. UK incident data also indicates that fuel spills of this nature do happen, at least once over recent years in flammable liquid carrying vehicles and, given the suggested scale of under-reporting, perhaps much more frequently. While the UK incident did not lead to any further risks, e.g. from fire, the need to reduce risks of any spillage of flammable materials in close proximity to an ADR flammable liquid tanker seems obvious. In that context, a study to identify, develop and prove cost-effective ADR fuel tank protection/leak prevention systems may be worthy of further consideration.

6.2.4 Protection of fuel-carrying pipework

Similarly, minor spills seem quite commonplace from pipework on ADR vehicles, particularly when they are involved in rear impacts with other heavy vehicles. Cost effective protection systems may be worthy of consideration here, too. It is fair to highlight, however, that Autonomous Emergency Braking Systems (AEBS) are soon to become mandatory fitment for almost all new heavy trucks (categories N2 and N3) in Europe. These systems are designed to significantly mitigate or even prevent rear shunt type accidents, so the risks of fuel spills from rear impacts (as from rollovers following the introduction of UN(ECE) Regulation No. 55 and mandatory stability control systems) may well naturally decline further over the coming years.

6.3 Implications for future testing and modelling work

Of most direct relevance to WP3, WP1 includes the physical testing and modelling of a rollover impact. Primarily to facilitate the correlation of the model with results from the physical test(s), the first step is based on a simple, quasi-static topple test, that is one with no forward velocity and only just sufficient sideways force to cause a rollover (by ninety degrees onto a flat rigid surface).

The analysis to-date within WP3 indicates that such a rollover event in the real world would be unlikely to lead to a significant loss of load from the tank. A roll rate at impact

with the ground in the range 100 to 150 deg/s (1.75 to 2.6 rad/s) would be realistic, and crush deformations up to 35 – 80 mm should be anticipated.

Extending the testing and modelling work to cover other relevant impact scenarios that do involve a significant risk of load loss, however, is likely to be much more complex. Three major mechanisms are indicated to interact in quite complex ways to induce such risks; rollover, sliding and tearing. It may well not be feasible to devise a single test that achieves all three, so a step-by-step approach may be appropriate. This could, for example, involve a simple overturn (perhaps made more severe than the quasi-static case already investigated by dropping from a greater height or imposing a roll-inducing force at the start), a slide, and a penetrating impact test (perhaps by using a pendulum impactor). Where an overturn is followed by sliding and impact (in the area of the tank's roof) with vertical road-side objects or structures, previous testing research suggests that sliding speeds at impact of around 4 to 7 m/s (15 to 25 km/h) would be realistic (velocity component in the direction perpendicular to the vertical surface/structure).

A review of existing regulatory mechanisms (described in section 3.4) identified two existing performance-based test procedures that may at least form starting points for the development of more stringent requirements for road fuel tankers, to further reduce the risks of major spillage in complex, but realistic, rollover events. These are the static rollover test used in UN(ECE) Regulation No. 66 and the front pillar pendulum impactor test used in UN(ECE) Regulation No. 29. The frontal impact pendulum test procedure within Regulation No. 29 was also assessed but was found not to be readily usable as a rear impact test for tankers.

The static rollover test used in Regulation No. 66 is very similar to that used in WP1, but somewhat more severe in that it involves toppling from a height of 800 mm above a simulated flat, horizontal, solid ditch. It could thus be a good representation of the first phase of a complex rollover incident – one involving enough energy for the tanker to roll by slightly more than 90 degrees prior to impact with the ground.

The front pillar test in Regulation No. 29 seems to be a reasonable representation of an overturned vehicle sliding into a large roadside object such as a tree. Modifying the procedure slightly to drop the 1,000 kg impactor onto the roof of a tank, from a height of about 3 m, could realistically simulate part of a complex rollover incident where the tanker overturns onto its side and slides out of the original curve and impacts with a large tree or similar roadside object at a speed of about 7.7 ms⁻¹. The research literature suggests such a speed would represent severe real-world tanker rollover incidents.

The pass/fail criteria for both these UN(ECE) Regulations are based on maintenance of an occupant survival space. Such criteria would, of course, be inappropriate for a tank, but a “no loss of product” requirement might be feasible.

No existing regulatory mechanisms were identified, however, that might be useful starting points in addressing the issue of penetration/tearing damage from smaller roadside objects, as an overturned tank slides along the ground. Thicker shell thicknesses would seem to be the simplest remedial measure, but this would obviously increase the cost, add to the unladen weight and so reduce the operational efficiency/productivity of the tank. An alternative approach may be to develop requirements for some form of light but resilient protective outer layer for those parts of the sides of the tank at greatest risk, at least, say for the 1 o'clock to 4 o'clock and 8 o'clock to 11 o'clock clock-face regions when the tanker is upright.

A simpler approach may be feasible, however, if actually it is only the final (penetrating impact) phase that really involves a heightened risk of tank rupture, and this risk is not affected by any pre-existing roll and/or slide damage. In that scenario, a pendulum test may be all that is needed, though the size, shape and impact energy of the impactor, as well as the impact angle and location on the tank, would need to be carefully considered.

However, although such a test may be useful as a simulation of what is probably the main cause of tank rupturing in real-world conditions, it may not be well suited to testing the integrity of circumferential weld seams. For that, a high speed rollover test may be better, if a low speed rollover proves to be inadequate. The US research described earlier in this report suggests that rollovers can be severe enough to cause the tank to roll by more than ninety degrees before it hits the ground, so as well as the UN(ECE) Regulation No. 66 test, a vertical drop test of a tank onto its roof, perhaps from a height in the range 1 – 2 metres, could be considered representative of some real-world scenarios. In this context, a modified version of the static roof strength test in UN(ECE) Regulation No. 29 might also be relevant and would likely be simpler to implement and carry out than a dynamic drop test. The accident data evidence, however, suggests that full overturns by 180 degrees may be very rare.

6.4 Risks and incident probabilities

Feedback from industry indicates that, when operating, petroleum road fuel tankers are predominantly six-axle articulated vehicles, delivering some 180 tonnes of fuel per day (6 loads of roughly 30 tonnes each) to forecourts, and travelling some 220,000 km each per year in the process. Based on official fuel consumption statistics from the Department for Energy and Climate Change (DECC)²⁰, and feedback from industry stakeholders, the overall UK road fuel tanker fleet required to deliver this fuel, under these average operating conditions (allowing for some shortfall in vehicle and driver availability) is estimated to be approximately 1,000 – 1,500 vehicles. The 220 non-compliant tankers would thus account for roughly 15 – 20% of the UK fleet.

The detailed review of STATS19 injury accident data, alongside evidence from Germany and the UK on the frequency of non-injury accidents involving tankers relative to injury accidents, indicates that, on average, every 100 six-axle, FL-registered tankers are likely to be involved in around 2.4 to 3.2 collisions each year severe enough to cause an injury or tow-away damage. There are likely to be around 0.1 to 0.2 incidents of rollover each year per 100 vehicles (i.e. one every 5 to 10 years, or probability of rollover for any one vehicle in a year of 0.1 – 0.2%) and perhaps as many as 0.16 incidents each year per 100 vehicles involving spillage of load (most but not all of which from rollover incidents).

All things being equal, by the same calculation methods, it can also be estimated that the 220 or so of the non-compliant tankers originally operating on GB roads were likely to be involved in up to between 5 and 7 severe collisions per year; of which one rollover collision would have occurred up to every 2.2 years on average. A reasonable expectation would be that a collision of a non-compliant tanker involving spillage could be expected to occur once every three years or so. In the event, for example, that the

²⁰ Digest of UK Energy Statistics

population of non-compliant tankers were reduced to 120 vehicles²¹, this risk would fall to one incident severe enough to cause a spillage approximately once every 5 or 6 years.

It is possible that factors such as the low centre of gravity of petroleum tankers (compared to other types of tanker), a greater focus on driving standards and driver safety within the industry, and greater investments in vehicle-based safety technologies amongst the major oil company fleets, all together lead to accident, rollover and spillage frequencies somewhat lower than those experienced by other types of FL-registered articulated vehicles. This hypothesis could not be fully tested during the research. The safety record of petroleum fuel tankers may well be better, on average, than these other tankers, but no amount of safety interventions can be certain to eliminate all risks.

As an absolute minimum, articulated petroleum road fuel tankers have been found from the review of local news media articles to have overturned in 6 separate incidents in the UK over the last four years (2011 – 2014). If the UK fleet of such vehicles is around 1,000 – 1,500, as stakeholders and our own estimates suggest, then this implies a rollover frequency of no less than 0.1 per 100 registered vehicles per year (an individual probability of rollover of 0.1% per vehicle per year, based on 1.5 rollovers per year from 1,500 vehicles). This would provide a lower bound estimate for the 220 non-compliant tankers of an overturn incident involving them likely once every 4.5 years on average (once every 8.3 years for a 120 vehicle fleet). For all petroleum road fuel tankers, an overturn would be likely at a minimum average frequency of approximately one per year.

An alternative way of expressing this risk of rollover is to consider the probabilities of one or more of the non-compliant tankers overturning in any given period of time. If the probability of any one tanker NOT overturning in any one year is 99.9% (i.e. $100 - 0.1$), then the probability of 220 tankers all NOT overturning in any one year = $0.999^{220} = 0.80$. If the non-compliant tankers are likely to overturn at the same (lower bound) overall average frequency as all petroleum road fuel tankers, then there is thus only a 20% chance ($1 - 0.8$) of one or more of them experiencing a rollover in any one year. If there are actually somewhat fewer than 220, then this probability would be lower still. The probability of the 120 tankers thought to still be in use on UK roads going 6 years, for example, without any of them overturning is $0.999^{(120 \times 6)} = 0.999^{720} = 0.49$; equivalent to a 51% chance of at least one overturning in 6 years. As a further example, over a period of 9 years, this probability rises to 66%.

It is important to stress that these estimates are based on averaged probabilities and long-term risks. Rollovers are undoubtedly rare events, so it is statistically quite within the bounds of probability and chance that none of the non-compliant tankers actually get involved in an overturning incident for a period of several years. It is clear, however, that one or more would be likely to be involved at some stage, and that a “zero-risk” should not be assumed.

Some stakeholders consulted during this research have suggested that the rollover risks for the non-compliant tankers might be even lower than the lower bound estimates made above, perhaps by a factor of two (equivalent to a rollover event once every 10 years or so on average, for a 220 vehicle fleet). No supporting evidence has been provided, but as a sensitivity analysis, if the probability of an individual non-compliant tanker

²¹ At the time of drafting this report (November 2014), it was estimated that the UK fleet of non-compliant tankers had reduced to 120 vehicles (from 220 at the outset of the research).

overturning in any one year were actually 0.05% (rather than 0.1%), then the probability of none of the 120 of them overturning in any one year would be = $0.9995^{120} = 0.94$, implying a 6% chance of one or more rollovers in that period. Over a six year period, this probability would rise to 30%, and over 9 years it would be 42%. So while the absolute rollover probabilities based on estimates provided by industry stakeholders may be somewhat lower than those suggested if the rollover risk is no less than 0.1% (as indicated by the research), they are of the same order of magnitude.

Further examples of the rollover probabilities calculated for the non-compliant tankers for various periods (from 1- 12 years), for the two assumed fleet size scenarios (220 and 120 vehicles), and for the two basic rollover frequencies (0.1%, as indicated to be a suitable lower bound by the research, and 0.05%, as suggested by some stakeholders) are given in Table 23.

Table 23. Rollover probabilities for various non-compliant tanker fleet scenarios.

Scenario	Probability of at least one non-compliant tanker rollover incident in each period				
	1 year	3 yrs	6 yrs	9 yrs	12 yrs
220 vehicles, 0.1% risk per annum	20%	48%	73%	86%	93%
220 vehicles, 0.05% risk per annum	10%	28%	48%	63%	73%
120 vehicles, 0.1% risk per annum	11%	30%	51%	66%	76%
120 vehicles, 0.05% risk per annum	6%	16%	30%	42%	51%

7 Conclusions

The following conclusions can be drawn from the research completed in Work Package 3:

- The evidence gathered from international literature, statistics, in-depth databases and stakeholder survey responses makes clear that rollover is the major cause of serious hazardous material spillage in real world use, but the exact tank integrity failure mechanisms have not been well researched/reported.
- Sliding of the overturned tanker is also implicated, especially where roadside obstructions either tear through the tank shell or are involved in secondary impacts with the tank's roof area.
- For the simple, quasi-static rollover test and modelling, roll rates at impact with the ground of 100 to 150 deg/s (1.75 to 2.60 rad/s) would seem to be realistic based on US research. Deformation damage of 35 to 80 mm should be anticipated. The analysis to date indicates that such a rollover event in the real world would be unlikely to lead to a significant loss of load from the tank.
- No evidence has been found to indicate that failures of circumferential welds have played any significant role in real-world fuel spillage incidents, although none of the non-compliant tankers are known to have been involved in such incidents in the UK.
- For the more complex sliding and secondary impact condition, the US research also suggests sliding speeds at impact of around 4 to 7 m/s (15 to 25 km/h) would be realistic (velocity component in the direction perpendicular to the vertical surface/structure).
- The analysis of collision typology did not reveal any marked differences between 6-axle articulated vehicles licensed to carry flammable liquids (FL-registered) vehicles and all 6-axle artics in indicators such as distribution of accident severities, road class, time of day, or weather.
- The collision involvement rate of these FL vehicles, however, was found to be reduced: Six-axle articulated FL vehicles (> 7.5 tonnes mgw) are involved in 1.58 injurious collisions per 100 similar vehicles per annum, which is almost 20% lower than the rate of all 6-axle artics (also > 7.5 tonnes mgw). The annual rollover involvement rate of such FL vehicles is 0.11 per 100 registered vehicles per annum (STATS19 data), which is 43% lower than the rate of all 6-axle artics.
- Taking into account damage-only accidents (based on estimates from German data and news reported incidents), a full estimate for GB would thus be that there are around 81 to 108 collisions each year involving 6-axle FL vehicles >7.5 tonnes mgw and severe enough to cause an injury or tow-away damage. 5 to 7 of the collisions involve the FL vehicle rolling over.
- There were approximately 220 of the non-compliant tankers originally operating on GB roads, out of a total 6-axle articulated FL vehicle tanker fleet of around 3,400 vehicles registered (on average between 2007 and 2012). Assuming these non-compliant tankers have similar usage characteristics and are thus likely to have similar involvement rates to all such FL tankers, it can therefore be estimated that these non-compliant tankers were likely to be involved in up to 7 collisions per year severe enough to cause an injury or tow-away damage. This would include one rollover collision occurring every 2.2 years, on average.

- As an absolute minimum, articulated petroleum road fuel tankers have been found from the review of local news media articles to have overturned in 6 separate incidents in the UK over the last four years (2011 – 2014). If the UK fleet of such vehicles is around 1,000 – 1,500, as stakeholders and our own estimates suggest, then this implies a rollover frequency of no less than 0.1 per 100 registered vehicles per year (0.1%). This provides a lower bound estimate for the 220 non-compliant tankers of a rollover incident involving them likely once every 4.5 years on average.
- An alternative way of expressing this risk of rollover is to consider the probabilities of one or more of the non-compliant tankers overturning in any given period of time. If the 220 non-compliant tankers are likely to overturn at the same (lower bound) overall average frequency as all petroleum road fuel tankers, then there is only a 20% chance of one or more of them experiencing a rollover in any one year. For the 120 non-compliant tankers thought (at the time of drafting this report) to still be in use on UK roads, there is estimated to be a 51% chance of at least one overturning in the next 6 years, and a 66% probability when a period of 9 years is considered.
- Some stakeholders consulted during this research have suggested that the rollover risks for the non-compliant tankers might be even lower than the lower bound estimates made above, perhaps by a factor of two. No supporting evidence has been provided, but as a sensitivity analysis, if the probability of an individual non-compliant tanker overturning in any one year were actually 0.05% (rather than 0.1%), then over a six year period, the probability of at least one rollover incident involving one of the 120 non-compliant tankers would be 30%, and over 9 years it would be 42%. So while the absolute rollover probabilities based on estimates provided by industry stakeholders may be somewhat lower than those indicated by the research, they are of the same order of magnitude.
- Accident statistics from GB suggest that in recent years, the involvement rate of tankers in collisions involving rollover has reduced. This is probably as a result of interventions such as stability control technology fitment, fleet telematics devices and better driving standards, but some rollovers still happen, even amongst major oil company fleets.
- Based on German records on frequency of load spillage, it could be anticipated that there might be up to 5 spillage incidents involving 6-axle FL vehicles >7.5 tonnes mgw per annum in GB. If the likelihood of spillage in a collision was identical for the 220 non-compliant tankers, a collision of a non-compliant tanker involving spillage could be expected to occur approximately once every three years.
- The analysis of STATS19 data (police-recorded injury accidents), RIDDOR reports and local news reports on tanker accidents involving spillage of flammable liquids indicates a high probability of quite significant under-reporting of ADR incidents to DfT. The best available estimate is that only around 10% of the incidents that should be reported (albeit based on a strict interpretation of the ADR requirements) are actually reported; of the 5 to 7 rollover incidents involving FL vehicles likely to be occurring each year in GB, only 0.6 per year are currently being reported as ADR incidents.
- In order to improve the level of reporting, the following ideas might be considered: Enhanced guidelines and training for operators; a dual reporting system; an ongoing periodic review of local news media articles; and a web-based central data repository.

Future research would benefit from additional information on tank, vehicle, and damage in the incident reports.

- In-depth GB accident data shows that load spillage and fire are uncommon, even in collisions that result in fatalities.
- Possible regulatory enhancements include (tractor unit) fuel tank design/location, tank material specifications to better protect against penetration/tearing damage as overturned tankers slide along the ground, and greater impact protection for tanker pipework.
- Extending the testing and modelling work of other Work Packages to cover other relevant impact scenarios that do involve a significant risk of load loss (i.e. beyond a simple, quasi-static topple test), is likely to be complex. Three major mechanisms are indicated to interact in quite complex ways to induce such risks; rollover, sliding and tearing. It may not be feasible to devise a single test that achieves all three, so a step-by-step approach may be appropriate.
- A review of existing regulatory mechanisms identified two existing performance-based test procedures that may at least form starting points for the development of more stringent requirements for road fuel tankers, to further reduce the risks of major spillage in complex, but realistic, rollover events. These are the static rollover test used in UN(ECE) Regulation No. 66 and the front pillar pendulum impactor test used in UN(ECE) Regulation No. 29. The frontal impact pendulum test procedure within Regulation No. 29 was also assessed but was found not to be readily usable as a rear impact test for tankers.
- A simpler approach may be to only assess the final (penetrating impact) phase that really involves a heightened risk of tank rupture, assuming that this risk is not affected by any pre-existing roll and/or slide damage. In that scenario, a pendulum test may be all that is needed, though the size, shape and impact energy of the impactor, as well as the impact angle and location on the tank, would need to be considered carefully.
- However, although such a test may be useful as a simulation of what is probably the main cause of tank rupturing in real-world conditions, it may not be well suited to testing the integrity of circumferential weld seams. For that, a high speed rollover test may be better, if a low speed rollover proves to be inadequate.
- It should also be emphasised that much of the earlier research reviewed relates to tanks used in other countries, not necessarily complying with ADR, and often many years ago, so caution is needed when translating the results into UK tanks in use in 2014.

Appendix A Literature Search

Results of literature searches (1995 – 1999 and 2000 – 2014)

tanker OR "tank trucks" OR "liquid cargo handling"	AND	road	AND	incident OR rollover OR "roll over" OR collision OR spillage OR rupture
Date limits: 1995 – 1999. Sources: TRID (http://trid.trb.org/) and Google Scholar (http://scholar.google.co.uk/). Search completed 19/2/14 by Stuart Benjamin.				

- (1998). THE DYNAMICS OF TANK-VEHICLE ROLLOVER AND THE IMPLICATIONS FOR ROLLOVER-PROTECTION DEVICES: 72 p.

The purpose of this study was to outline requirements for cargo tank rollover-protection devices, typically affixed to the top of tank vehicles, which are meant to protect manhole covers, valves and other tank openings during rollover events. The project was analytical in nature. Conventional vehicle simulations were used to examine the dynamics of the rollover of tank vehicles up to the point of crash impact. Additional computer-based analyses were then used to broadly characterize the force-deflection qualities required of rollover-protection devices to be effective in such events. This report begins with a discussion of the background for and philosophy of the project. Two technical sections follow which address the dynamics of tank-vehicle rollover and the implied requirements for protection devices, respectively. The final section of the main text presents conclusions and recommendations. Other technical materials are appended.
- Aquaro, M. (1999). Stability Analysis of Partially Filled Tanker Trucks Using a Finite Element Modeling Approach, West Virginia University.

http://wvusolar.wvu.edu:8881/exlibris/dtl/d3_1/apache_media/L2V4bGlicmlzL2R0bC9kM18xL2FwYWNoZV9tZWVpYS8yMDYzMg==.pdf
- Aquaro, M., V. H. Mucino, et al. (1999). "A finite element modeling approach for stability analysis of partially filled tanker trucks." Training 2014: 04-07.

The rollover threshold for a partially filled tanker truck carrying fluid cargo is of great importance due to the catastrophic nature of accidents involving such vehicles, particularly when payloads are toxic and flammable. In this paper, a method for determining the threshold of rollover stability of a specific tanker truck is presented using finite element analysis methods. This approach allows the consideration of many variables which had not been fully incorporated in past models, including nonlinear spring behavior and tank flexibility. The program uses simple mechanical pendulums to simulate the fluid sloshing affects, beam elements to match the torsional and bending stiffness of the tank, and spring damper elements to simulate the suspension. The finite element model of the tanker truck has been validated using data taken by the U.S. Army Aberdeen Test Center (ATC) on a M916A1 tractor/ Etnyre model 60PRS 6000 gallon trailer combination. ATC tested the actual tanker truck both statically and dynamically to provide data as inputs for the finite element model. The output from the computer model corroborates the real truck measurements, thus validating the method of analysis. The approach will be expanded to include a double lane change derived from a cycloidal path.

4. Bergan, A. T., R. J. Bushman, et al. (1998). Intelligent truck rollover advisory systems. Intelligent Systems & Advanced Manufacturing, International Society for Optics and Photonics.
To address the serious problem of truck rollover accidents on freeway exit ramps a system was developed and implemented by the Federal Highway Administration (FHWA), a private consultant Bellomo-McGee, and a system integrator International Road Dynamics. The system utilizes several existing technologies to determine vehicle weight, vehicle type, vehicle speed, and vehicle declaration. The system uses the information gathered to evaluate each vehicle on a freeway exit ramp to determine if they are in danger of a rollover accident and provides a warning to vehicles in potential danger. The system was implemented at three sites in the Washington DC area that had a history of rollover accidents. A three year independent evaluation was conducted on behalf of the FHWA to determine the effectiveness of the system. The evaluation shows that the system has been effective in reducing speeds and reducing accidents at the three sites that were chosen and shows that the systems are economically beneficial.
5. Carse, R. (1998). Tanker explosions.
No abstract available.
6. Cleminson, K. and G. Lock (1997). "ROAD TANKER ROLL-OVER." *IMPACT (ITA1) 6(2)*: p. 27-29.
This article presents some of the findings of a study of tanker roll-overs in the UK, conducted by Frazer Nash Consultancy and commissioned by the Health and Safety Executive. Although tanker roll-overs are not common, surprisingly many occur in apparently normal driving conditions. The study first surveyed operators of tankers to find out how many roll-overs occurred. The annual rate of roll-over of articulated tankers in the UK was found to be about 20, or about 1 in every 300 vehicles. Large petroleum tanker fleets, operating 3+2 axle combinations, seem to be especially liable to roll-over; 2+2 semi-trailers are also more liable than usual. As simulations reveal very little difference between the stabilities of different goods vehicles, the results suggest that the driver's awareness, or 'feel', of his vehicle may give him a false sense of well-being with 3+2 and 2+2 combinations, which are about as liable to roll over as others. Simulations suggest that a semi-trailer tanker swerving to avoid an obstacle is more likely to lose directional control and traction than roll over immediately. For tankers carrying liquid cargoes, large ullage (free space at the top of the tank) alone could increase the risk of roll-over. Use of tanks with compartments reduces this risk.
7. Coates, A. C. (1997). REPAIR OF THE CHELSEA STREET BRIDGE AFTER COLLISION WITH A TANKER.
The Chelsea Street Bascule Bridge in Boston was hit by a freighter severing the bottom chord of the truss. The loss of 9 inches of length in the severed chord caused the truss to rotate 3.5 ft. vertically and 2.3 ft. horizontally. A system of temporary supports and jacks was designed and installed to restore the bridge geometry and to replace the damaged members. The objective of the project was to repair the bridge in place so that the truss did not have to be dismantled and reassembled.
8. Dorn, M. R. (1996). "ROAD TANKER DESIGN: RESISTANCE TO ACCIDENTAL DAMAGE." HSE CONTRACT RESEARCH REPORT 101: 49 p.
This report presents the final phase of a study investigating the impact resistance of road tankers for the carriage of hazardous goods. The study aimed to estimate the probability of rupture of a typical tanker, when subjected to various impact scenarios, identify the effect on this probability of changes to tank material, thickness, and baffle spacing, and conduct an initial investigation into the effect of side protection. It considered only impact with rigid

objects. Initially, five impact scenarios were chosen, to investigate the effect of various impact sites and impactors: (1) rear impact from an ISO container travelling at 15m/s; (2) side impact from an ISO container travelling at 15m/s; (3) tanker roll onto a low roadside object, with roll velocity 4.52m/s; (4) tanker rolled onto its side and sliding at 15m/s into a kerb at angle 45 degrees; and (5) tanker roll onto a high roadside object, with roll velocity 4.52m/s. The DYNA3D simulation software was used to conduct the computer simulation studies. First, a basic DYNA3D model of a representative tanker was constructed. Then the model was modified to suit the specific impact scenarios. Several conclusions and recommendations are presented.

9. Goh, C. B., C. B. Ching, et al. (1995). "Risk analysis for the road transportation of hazardous chemicals in Singapore—a methodology." *Journal of loss prevention in the process industries* 8(1): 35-39.

A methodology has been developed for the risk analysis of road transportation of hazardous chemicals in Singapore. The analysis was applied to a case study of liquefied petroleum gas transportation by road tankers. The transportation of liquefied petroleum gas via two existing routes was studied in detail, and the corresponding societal risks were evaluated and compared.

10. Hatfield, B. (1996). "Rock-n-roll ... then slide." *Truck Australia* 12(2): 25-27.

No abstract available.

11. Ibrahim, I., M. El-Nashar, et al. (1998). "Ride behaviour of trucks transporting liquids." *International Journal of Heavy Vehicle Systems* 5(3-4): 3-4.

Liquid motion in partially filled containers generates slosh forces and moments which affect the ride behaviour and stability of fluid cargo trucks. The main objective of the paper is to investigate the ride behaviour of trucks carrying two spherical fluid containers. A mathematical model of a medium weight truck has been formulated which takes into account the physical and dynamic characteristics of the fluid cargo. In this model, the fluid cargoes in both tanks are simulated as nonlinear pendulums with specific damping coefficients. The Runge-Kutta method has been used to solve the nonlinear equations of motion of the vehicle system in the time domain. The vehicle is excited by two sources at the same time. The first is a vertical harmonic excitation expressing road irregularities. The second is a relatively small longitudinal deceleration in the direction of motion. The partial filling ratio and liquid cargo viscosity are shown to play major roles in the vehicle ride behaviour. Finally, result analysis and discussions are made.

12. Ibrahim, I. M. (1999). "Anti-slosh damper design for improving the roll dynamic behavior of cylindrical tank trucks." (SP-1486): 21-27.

No abstract available.

13. Kang, X., S. Rakheja, et al. (1999). "Optimal tank geometry to enhance static roll stability of partially filled tank vehicles." (SP-1486): 29-40.

No abstract available.

14. Kendall, K. (1995). *TRUCK ACCELERATION STUDY: FINAL REPORT*: 38 p.

In response to an Alberta accident involving a collision between an oil tank truck and a freight train, the Transportation Safety Board recommended that provincial authorities require that tank trucks placarded for the transport of dangerous goods stop at all public crossings before proceeding. As a result, Transport Canada conducted a study of truck acceleration times across a test area simulating the crossing and clearing of one to four sets of railway tracks.

The study was performed to ascertain the time for a truck/trailer to accelerate from a stopped position to a fixed distance further down the road. The time-to-distance analysis is used to determine whether the truck/trailer can successfully cross an at-grade railway crossing within the railways' 10-second sight-line rule for visibility at road/railway crossings in Canada. This report presents the results of the truck/trailer acceleration trials.

15. Liu, P. (1999). Analysis, Detection and Early Warning Control of Dynamic Rollover of Heavy Freight Vehicles, Concordia University.
http://www.collectionscanada.gc.ca/obj/s4/f2/dsk1/tape8/PQDD_0021/NQ43566.pdf
16. Mueller, C., J. Grandel, et al. (1998). "NEUE MOEGELICHKEITEN DER UNFALLSIMULATION DURCH OPTISCHE, FERNGESTEUERTE FAHRZEUGFUEHRUNG." *Automobiltechnische Zeitschrift* 100(1): 8-13.
Um die passive Sicherheit weiter zu verbessern, werden vermehrt Crashversuche durchgefuehrt. Dies gilt insbesondere fuer Versuche, die ueber die gesetzlich vorgeschriebenen Tests hinausgehen. Der hier notwendige Forschungsbedarf wird vermehrt die Durchfuehrung von realitaetsnahen Crashversuchen, auch mit bewegten Fahrzeugen, erfordern. Um diesem Bedarf gerecht zu werden, wurde von Dekra und Daimler-Benz gemeinsam eine optische, ferngesteuerte Fahrzeugfuehrung entwickelt. Ein wichtiges Ziel dabei war auch die Realisierung einer flexiblen Querfuehrung in Verbindung mit dem Seilantrieb auf der Dekra-Crashanlage in Neumuenster. Bei Einbeziehung der Laengsregelung koennen die Fahrzeuge mit eigener Motorkraft gecrasht werden. Diese Art der Versuchsdurchfuehrung bietet sich beispielsweise fuer die Durchfuehrung von Fahrzeug/Fahrzeug-Crashversuchen mit hoechster Genauigkeit oder fuer Ueberschlagversuche an. Der Beitrag gibt einen Ueberblick ueber den Aufbau des optischen, ferngesteuerten Fahrzeugfuehrungssystem sowie die optische Querfuehrung, den Lenkakuator und die Laengsregelung. Daran anschliessend werden Anwendungsbeispiele fuer das neue System gegeben. Diese beinhalten unter anderem Crashversuche mit Tankfahrzeugen, Omnibus-Umsturzversuche und Fahrzeug/Fahrzeug-Kreuzungskollisionen.
17. Mueller, T., J. De Pont, et al. (1999). "Heavy vehicle stability versus crash rates." A report prepared for The Land Transport Safety Authority.
<http://ternz.co.nz/Publications/Heavy%20Vehicle%20Stability%20Versus%20Crash%20Rates.pdf>
18. Park, S., B. Gilmore, et al. (1998). "Simulation of nonlinear dynamics of liquid filled fuel tanker shell structure subjected to rollover collision with validation." *Journal of Mechanical Design* 120(4): 573-580.
The transport of hazardous materials in truck cargo tanks can cause severe environmental damage as a result of the tank's failure during a collision. Impact due to collision involves the transient dynamic response of the tank, fluid and their interaction. This paper develops a design oriented computational approach to predict the dynamic transient response of the tank shell structure subjected to impact loads during crash accidents. In order to compute the fluid and structural interaction, the finite element formulations for the added mass to the structure are developed and integrated with DYNA3D, a nonlinear dynamic structural finite element code, and they are validated by pendulum impact experiment. This paper presents the lumping process required by the added mass approach for cargo tanks under impact conditions. Thus, due to its efficiency the computer based approach provides a design tool for fluid filled thin walled structures in general and cargo tanks subjected to an impact situation. The structural performance of cargo tank shell construction is investigated. This research will contribute to improvement in design, modeling, and analysis techniques for crashworthiness

and integrity of liquid mechanical structure systems which are subjected to impulsive loads like those found in vehicle collisions.

19. Pilipchuk, V. and R. Ibrahim (1999). Simulation of liquid sloshing impact in moving structures. *Dynamics of Vibro-Impact Systems*, Springer: 141-150.

This paper examines the nonlinear modal interaction between liquid hydrodynamic impacting with an elastic support structure. The liquid impact is modeled based on a phenomenological concept by introducing a power nonlinearity with a higher exponent. A special saw-tooth time transformation (STTT) technique is used to analytically describe the in-phase and out-of-phase strongly nonlinear periodic regimes. Based on explicit forms of analytical solutions all basic characteristics of the nonlinear free and forced response regimes such as time history, amplitude-frequency dependencies and nonlinear parametric resonance curves are estimated. The response behavior reveals that high frequency out-of-phase nonlinear mode takes place with a relatively small tank amplitude and is more stable than the in-phase oscillation mode under small perturbations. The in-phase mode has relatively large tank amplitudes and does not preserve its symmetry under the periodic parametric excitation.

20. Rompe, K. and G. Heuser (1996). "THESEUS - TANKFAHRZEUG MIT HOECHSTERREICHBARER SICHERHEIT DURCH EXPERIMENTELLE UNFALLSIMULATION." *Automobiltechnische Zeitschrift* 98(3): 154-161.

Das Bundesministerium fuer Bildung, Wissenschaft und Forschung hat seit 1990 das Forschungsprojekt "THESEUS" - Tankfahrzeuge mit hoechst erreichbarer Sicherheit durch experimentelle Unfallsimulation - gefoerdert. Ausgehend von der detaillierten Analyse von 231 Tankfahrzeugunfaellen wurden Tankfahrzeug-Crashversuche und Tankfahrzeug-Umsturzversuche durchgefuehrt. Diese Messungen an kompletten Fahrzeugen wurden durch Untersuchungen an Tankfahrzeugkomponenten und begleitende komplexe Berechnungen der Versagensmechanismen ergaenzt. Parallel dazu wurde die statische Kippstabilitaet von Tankfahrzeugen auf einer Kippbruecke ermittelt. In dynamischen Fahrversuchen, ergaenzt durch rechnerische Simulation, wurden Ursachen und konstruktive Moeglichkeiten zur Vermeidung des Umkippens als haeufigste Unfallursache und Gefahrgutaustritt analysiert. Als Ergebnis wurden Massnahmen zur Erhoehung der Sicherheit der Tankfahrzeuge ermittelt und zum Teil einer Nutzen/Kosten-Betrachtung unterzogen. Titel in Englisch: Theseus - achieving maximum possible road transport tanker safety by means of experimental accident simulation.

21. Salem, M. I., V. H. Mucino, et al. (1999). "Review of parameters affecting stability of partially filled heavy-duty tankers." *Measurement* 2017: 06-12.

Partially filled tanker trucks are susceptible to rollover instabilities due to fluid sloshing. Due to the catastrophic nature of accidents involving the rollover of tanker trucks, several investigations have been conducted on the parameters affecting stability of partially filled heavy-duty tankers. Since stability of heavy-duty tankers undergoing on-road maneuvers such as braking, and/or lane changing has been an issue that concerned many researchers for a long time, a literature review has been conducted which underlines the most important contributions in this field. This review covers work done in the field of fluid-structure interaction, yaw and roll stability of heavy-vehicles, and fluid-vehicle dynamic interaction. In addition, vehicle stability issues are addressed such as jack-knifing, side slipping, vehicle geometry and container geometry among others. Several mechanical models that have been proposed to simulate the fluid sloshing motion effects are also covered in this review as well as experimental work done in this field. Approaches to assess the stability of tanker trucks vary significantly based on the assumptions made on the above mentioned issues. However, for partially filled tanker-trucks, the approaches available for stability assessment have yet to be generalized in order to include various maneuvers, vehicle and road configurations.

22. Strickland, R. R. and H. W. McGee (1998). "Evaluation results of three prototype automatic truck rollover warning systems." *Transportation Research Record: Journal of the Transportation Research Board* 1628(1): 41-49.

Three prototype Automatic Truck Rollover Warning Systems (ATRWS), located in Virginia and Maryland, were evaluated over three years to assess how the ATRWS performed and to determine the cost-effectiveness. More specifically, the requirements of this evaluation were to (1) evaluate performance and maintenance requirements, (2) evaluate the effectiveness of the ATRWS on speed reduction of detected trucks traveling at or near their rollover speed or maximum safe speed, and (3) evaluate any improvements in safety resulting from the systems. Based on truck classification and speeds as measured by the ATRWS, it was concluded that these systems do affect truck speed reduction. The results showed that for all three ATRWS sites (five lanes total), a speed reduction was observed when the fiber optic sign was activated. The results also showed that this speed reduction was usually higher than the speed reductions of trucks that did not activate the sign. In fact, for the first and second evaluation periods, an overall 29.0 and 21.7 percent speed reduction from Stations 2 to 3 and Stations 5 to 6 was observed. These percentage speed reductions equate to approximate speed reductions at the Springfield, McLean, and Beltsville ATRWS sites of 4.6 km/h (2.9 mph), 3.9 km/h (2.4 mph), and 2.3 km/h (1.4 mph) for the first evaluation period. The second evaluation period had similar speed reductions.

23. Van Manen, P. (1996). "CONDITIONS AFFECTING ROLL-OVER OF ROAD TANKERS." HSE CONTRACT REPORT NO.102: 96 p.

This report presents the results of a study of the roll-over of road tankers in the UK. The study aimed to compile information about the liquid-produce road tankers currently used in the UK, and compare the roll stability of the various types of vehicles used to haul liquid loads. Tanker operators and manufacturers of trailers and tractors were surveyed, and it was found that there are six main types of vehicles used to transport liquids in the UK. The comparative roll stabilities of different road tankers were assessed, by simulating the behaviour of each of them when travelling at progressively faster speeds round a typical roundabout and while conducting a double lane-change manoeuvre. Investigations were made of the effect of different tank configurations and of 'ullage', the free space at the top of the tank. The surveys collected information about: the similarities and differences of vehicle combinations used, the range of liquid freight carried, and the numbers of tanker accidents recorded in the last three years. Seven aspects of tanker travel and operation were identified as deserving greater attention. An appendix outlines the computer simulation approach used.

24. Wang, J. and F. M. Council (1999). "Estimating truck-rollover crashes on ramps by using a multistate database." *Transportation Research Record: Journal of the Transportation Research Board* 1686(1): 29-35.

Currently, among other intelligent transportation system applications, there is an increased interest in using an "in-vehicle warning system" to mitigate truck-rollover crashes on interchange ramps. Because the cost of installing the system in an entire truck fleet would be significant, a basic question is how large a safety problem is addressed. This study was an attempt to estimate the annual national frequency and cost of large-truck accidents on interchange ramps that result in rollovers. Using tabular analysis of a five-state database, the estimate was that approximately 11 percent of total truck involvements are on interchange ramps and that between 44 and 52 percent of the incidents result in rollovers. Both urban and rural locations present significant problems that could be addressed by an in-vehicle warning system. Combining this information with General Estimates System figures for total national truck crashes, it is estimated that there are between 4,400 and 5,000 truck rollovers on ramps

each year nationwide. The annual economic cost of these rollovers is between 405 million and 460 million. These data provide both information to safety engineers on the size of a significant truck safety problem and a base for a meaningful cost-benefit analysis of installing the in-vehicle warning system. Although available data do not allow a detailed cost-benefit analysis, a simplified analysis of "breakeven costs" indicates that such a device is highly dependent on the level of effectiveness, ranging from approximately 300 per truck to 3,200 per truck.

25. Winkler, C. B. (1998). "The dynamics of tank-vehicle rollover and the implications for rollover-protection devices."

<http://deepblue.lib.umich.edu/handle/2027.42/1264>

tanker OR "tank trucks" OR "liquid cargo handling"	AND	road	AND	incident OR rollover OR "roll over" OR collision OR spillage OR rupture
Date limits: 2000 – 2014. Sources: TRID (http://trid.trb.org/) and Google Scholar (http://scholar.google.co.uk/). Search completed 19/2/14 by ERW.				

1. (2000). "THE ART OF LIVING DANGEROUSLY." COMMERCIAL MOTOR 192(4888): p. 12-13.
 - a. Skids, jack-knives, and rollovers of lorries may have become rarer as vehicle technology has improved, but they can happen more easily than is often supposed. This article discusses how far driver training could prevent accidents of this type, and describes the one-day anti-rollover and anti-lock braking system (ABS) lorry skid training by International Road Safety Training (IRST). This course shows heavy goods vehicle (HGV) drivers the boundaries of a lorry's capability, and at the same time improves their skills. The article's authors were invited to join twelve drivers to learn emergency reaction techniques from drivers who had become trainers. The trainers' first message to the group was that emergency reaction techniques go completely against what most drivers imagine to be appropriate to an emergency. Two myths are that high speed causes rollovers and that it is not possible to brake at high speeds. In the training, a 41t tanker with outrigger wheels is driven on a skidpan. When driven in a figure of eight, the lorry is lifted onto an outrigger at an amazingly low speed, in a sudden movement with no recovery. Sudden braking training showed the drivers how to brake without overturning or hitting the obstacle head-on. They mastered the appropriate techniques without injury and with damage to only one vehicle, in a 360 degree spin.

2. (2001). "A CAPTAIN AND A FIRE FIGHTER DIE FROM INJURIES IN INDIANA TANKER ROLLOVER: THE N.I.O.S.H. REPORT." Accident Reconstruction Journal 12(3): p. 55-57.
 - a. On October 28, 1999, a 57-year-old Captain and a 23-year-old firefighter/driver died from injuries suffered in a tanker rollover accident occurring after response to a mutual aid call for assistance on a grass fire threatening nearby structures. On February 9, 2000, 2 inspectors from NIOSH, Division of Safety Research, began an investigation into this incident. This article provides an in-depth review of their report and its findings.

3. (2001). "TANKER ROLLOVER RESULTS IN THE DEATH OF TEXAS VOLUNTEER FIRE FIGHTER. THE N.I.O.S.H. REPORT." Accident Reconstruction Journal 12(5): p. 20-22.
 - a. This article reports on a National Institute for Occupational Safety and Health (NIOSH) investigation into an accident in which a volunteer fire fighter died in a tanker

truck rollover accident. The accident occurred when the victim, responding to a call in the tanker truck, rounded a curve and dropped the passenger side wheels off the road onto the shoulder. The victim oversteered and lost control in attempting to steer the truck back onto the road. The vehicle skidded across the roadway, flipped and rolled to a stop. The truck was originally a utility truck, but had been modified to be used as a tanker truck for water supply. The truck was top-heavy and had a short wheelbase. The NIOSH report includes several recommendations based on this incident: (1) Fire departments should ensure that all operators of emergency vehicles be familiar with the vehicle and its design; (2) Fire departments should ensure that operators of emergency vehicles operate them in a safe manner to minimize the potential for a skid; (3) Fire departments should ensure that all fire fighters riding in emergency vehicles are wearing and belted securely by seat belts; and (4) Fire departments should develop and implement standard operating procedures for operation of emergency vehicles.

4. (2002). HIGHWAY ACCIDENT BRIEF: HIGHWAY-RAIL GRADE CROSSING COLLISION, BLUM, TEXAS, NOVEMBER 13, 1997: 2 p.
 - a. On November 13, 1997, the driver of a 1998 Ford tank truck hauling propane drove onto the railroad tracks at a passive grade crossing on Hill County Road 1130 in Blum, Texas, and was struck by a freight train. The propane tanks and the truck's fuel tank ruptured at impact, causing a fire. The truck driver and codriver were ejected and fatally injured. The truck driver had been taking prescription medicine for diabetes. The train's horn had been sounding; audibility testing revealed that it could not be heard in the truck cab. Sight distance was limited at this crossing; however, because the driver was hauling hazardous materials, he was required to stop, look, and listen for trains. The National Transportation Safety Board determined that the probable cause of the accident was the truck driver's failure to yield to the approaching freight train.

5. (2003). Hazardous Materials Accident Brief: South Charleston, West Virginia, Dana Transport, Inc., MC-307 Cargo Tank Catastrophic Structural Failure of Cargo Tank Involving 5,152 Gallons of Polypropylene Glycol, January 5, 2002: 8p.
 - a. About 11:36 a.m., on January 5, 2002, a tractor/cargo tank semitrailer was leaving the Bayer Corporation's South Charleston, West Virginia, chemical plant. (The cargo tank consisted of three independent but connected tanks.) The vehicle had stopped at a traffic signal just beyond the plant, at the intersection of Montrose Drive and MacCorkle Avenue. When the vehicle started to cross McCorkle Avenue, the cargo tank failed catastrophically between the front and center tanks and broke in two. The tanks were not breached, and no cargo was released. (The cargo tank contained 5,152 gallons of polypropylene glycol.) No one was killed, injured, or evacuated as a result of the accident. The intersection, however, was closed for 7 hours. Damage, cleanup, and lost revenues were estimated at \$18,000. The National Transportation Safety Board determines that the probable cause of this accident was a combination of fatigue failure caused by incomplete welding on the tie bands and of the extensive corrosion of the frame.

6. (2004). "Volunteer Fire Fighter Killed and an Assistant Chief Injured in Tanker Truck Crash. The NIOSH Report." Accident Investigation Quarterly(40): pp 42-44.
 - a. On November 19, 2001, a volunteer firefighter was killed and the assistant chief was injured when the assistant chief lost control of the tanker truck he was driving on a steep mountain road. The truck left the road going downhill a steep slope and came to rest upside down, with both victims trapped inside. The National Institute for Occupational Safety and Health (NIOSH) investigated the incident. Based on their investigation, NIOSH issued two recommendations for fire departments, regarding semiannual driver training and the need to reinforce standard operating procedures for the use of seat belts in emergency vehicles.

7. (2007). "NTTC Annual Conference report." Bulk Transporter 70(1): p. 27-36 : ill.

- a. Viva vegas : NTTC conference, trade show draw record turnout. -- Challenging issues : growing problems will impact trucking productivity and US economy. -- FMCSA's Quade : research evaluates approaches to decrease cargo tank rollover. -- Financial outlook : truck fleets could struggle as economy slows. -- Better ways : plans developed to improve carrier/shipper efficiency. -- Code changes : trailer repairs, Canadian underride guards in spotlight. -- Technology efficiency : software programs cover all aspects of carrier operations.
8. (2009). Hazardous Materials Accident Brief: Collision of Cargo Tank Truck and Automobile and Subsequent Fire, Upper Pittsgrove Township, New Jersey, July 1, 2009: 7p.
 - a. On July 1, 2009, about 1:46 a.m., a 2002 Kenworth tractor pulling a 1989 Fruehauf MC-306 cargo tank semitrailer (the cargo tank truck) was traveling eastbound on U.S. Route 40 in Upper Pittsgrove Township, New Jersey, when it was struck by a 2002 Mitsubishi Diamante (the automobile) traveling northbound on Commissioners Pike. The automobile driver failed to obey a stop sign equipped with flashing red lights and collided with the external loading lines on the passenger side of the cargo tank truck. Loading line 4 was ruptured and about 13 gallons of gasoline were released as the automobile became wedged beneath the cargo tank truck and was dragged about 500 feet. A postcrash fire consumed the automobile, killing the driver; the cargo tank truck also was damaged. The Daretown Volunteer Fire Department arrived within 15 minutes and extinguished the fire. Property damage was about \$27,000. At the time of the accident, it was dark, and the temperature was 67° F. There were light winds and clear skies. Rain had been observed in the hour before the collision; however, it was not a factor in the accident. The National Transportation Safety Board determines that the probable cause of the July 1, 2009, vehicle collision and fire in Upper Pittsgrove Township, New Jersey, was the failure of the automobile driver to obey a stop sign equipped with flashing red lights. Contributing to the severity of the accident was a fire that resulted from the release of gasoline from a cargo tank loading line that was ruptured during the collision.
 9. (2009). "NTTC Cargo Tank Maintenance Seminar." Bulk Transporter 71(8): p. 28-38 : ill.
 - a. Panel presentation : ounce of prevention worth pound of cure in tight economic survival. -- Members of Congress to address old, new transportation bills. -- Regs coming : PHMSA, FMCSA working on plans affecting tank truck industry. -- Weighty topics : tips, updates presented on industry cargo tank issues. -- Design improvements : Brenner, Walker pursue enhanced aerodynamics for tanks. -- ATA's Moskowitz reviews strategies for lowering fuel costs. -- Straight truck operations demand more rollover attention.
 10. (2009). "Volunteer Fire Fighter Dies in Louisiana Tanker Crash. The NIOSH Report." Accident Investigation Quarterly(53): pp 35-38.
 - a. In March 2008, a volunteer firefighter was fatally injured in Louisiana after the tanker truck he was driving left the roadway and overturned. This report summarizes the National Institute for Occupational Safety and Health investigation of the accident. It was determined that the truck was going too fast to negotiate a 90° turn in the road. Based on the investigation, seven recommendations are offered: (1) fire departments should ensure that tankers are driven at a safe and reasonable speed; (2) fire departments should ensure that firefighters are familiar with the location of the roads in their coverage area; (3) fire departments should consider staffing tankers with a minimum of 2 firefighters; (4) fire departments should consider supplying responding units with maps or verbal directions to incident scenes, using computer aided dispatch or global positioning system devices; (5) fire departments should develop oversight of their preventive maintenance program for fire apparatus; (6) fire departments and fire service training organizations should consider additional driver training for firefighters on safe tanker driving and operations; and (7) fire departments and fire apparatus manufacturers should ensure that tankers meet all the requirements of National Fire Protection Association standards for automotive fire apparatus.
 11. (2010). "Hearing covers tank rollover prevention." Traffic safety (Chicago, Ill.) 10(10): p. 1 : ill.

12. (2011). Highway Accident Report: Rollover of a Truck-Tractor and Cargo Tank Semitrailer Carrying Liquefied Petroleum Gas and Subsequent Fire, Indianapolis, Indiana, October 22, 2009: 107p.
 - a. On October 22, 2009, about 10:38 a.m. eastern daylight time, a 2006 Navistar International truck-tractor in combination with a 1994 Mississippi Tank Company MC331 specification cargo tank semitrailer (the combination unit), operated by AmeriGas Propane, L.P., and laden with 9,001 gallons of liquefied petroleum gas, rolled over on a connection ramp after exiting Interstate 69 (I-69) southbound to proceed south on Interstate 465 (I-465), about 10 miles northeast of downtown Indianapolis, Indiana. The truck driver was negotiating a left curve in the right lane on the connection ramp when the combination unit began to encroach upon the left lane, occupied by a 2007 Volvo S40 passenger car. The truck driver responded to the Volvo's presence in the left lane by oversteering clockwise, causing the combination unit to veer to the right and travel onto the paved right shoulder. The truck driver's excessive, rapid, evasive steering maneuver to return the combination unit to the roadway triggered a sequence of events that caused the cargo tank semitrailer to roll over, decouple from the truck-tractor, penetrate a steel W-beam guardrail, and collide with a bridge footing and concrete pier column supporting the southbound I-465 overpass. The collision entirely displaced the outside bridge pier column from its footing and resulted in a breach at the front of the cargo tank that allowed the liquefied petroleum gas to escape, form a vapor cloud, and ignite. The truck driver and the Volvo driver sustained serious injuries in the accident and postaccident fire, and three occupants of passenger vehicles traveling on I-465 received minor injuries from the postaccident fire. Major safety issues were identified in this investigation related to cargo tank rollover prevention. As a result of its investigation, the National Transportation Safety Board has issued safety recommendations to the U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Pipeline and Hazardous Materials Safety Administration, National Highway Traffic Safety Administration, Federal Highway Administration, and American Association of State Highway and Transportation Officials.

13. (2012). "Cargo Tank Rollover Force Verification." Accident Reconstruction Journal: pp 21-27.
 - a. In order to improve the crashworthiness of cargo tank motor vehicles that carry hazardous materials, this study investigates the effects of a rollover crash on the rollover protection devices on the tops of these vehicles. Full-scale experiments were conducted to quantify the pre-impact dynamics of rollover crashes of loaded cargo tank motor vehicles and compared with the results of dynamic simulations conducted in a previous study. A small single-unit cargo tank vehicle was fitted with a roll cage so that it could withstand a crash, and it was rolled over four times. A cargo tank semitrailer was rolled over once. The five maneuvers leading to the rollovers were selected to approximate maneuvers that had been simulated in the earlier study. This provided a diverse set of rollover conditions and allowed comparison of the experimental to the simulated results. Vehicle motion was recorded by an onboard inertial navigation system combined with a global positioning system receiver. The crashes were recorded by video cameras from several angles on the ground and, in most cases, by one or more cameras on the vehicle. The semitrailer was instrumented with strain gages and string potentiometers to measure the deflections of the tank and the rollover protection devices during impact. The velocity measurements in this study can provide quantitative guidance concerning the performance requirements of rollover protection devices. The measurements of the semitrailer deformation will serve as a case study of how the particular design of rollover protective devices performed during a crash of known conditions. The experimentally measured roll rates at the moment of impact were within the range of those calculated during the simulations. A comparison of the experimentally measured values with the results of the dynamic simulations corroborated the simulations' order of magnitude.

14. (2012). Hazardous Materials Accident Summary Report: Cargo Hose Rupture and Release of Anhydrous Ammonia During Offloading of a Werner Transportation Services Cargo Tank Motor Vehicle at the Tanner Industries Plant, Swansea, South Carolina, July 15, 2009: 28p.
 - a. On July 15, 2009, about 8:00 a.m., a cargo transfer hose ruptured shortly after transfer of anhydrous ammonia began from a Werner Transportation Services, Inc. cargo tank truck to a storage tank at the Tanner Industries, Inc. facility in Swansea, South Carolina. A white cloud of anhydrous ammonia, a toxic-by-inhalation gas, moved from the parking lot of the facility across U.S. Highway 321 to a largely wooded area, where it eventually dissipated. About the same time, a motorist traveling north on the highway drove into the ammonia cloud, apparently tried to get away from the cloud, then got out of her car and died of ammonia poisoning. Seven people went to the Lexington Medical Center emergency department complaining of respiratory problems and dizziness; all seven patients were treated and released the same day. The anhydrous ammonia cloud caused temporary discoloration of vegetation in the area, including the leaves on the trees. Residents in the area sheltered in place, and U.S. Highway 321 was closed until about 2:00 p.m. on the day of the accident. The Lexington County Fire Service arrived on scene about 8:07 a.m. Property damage and losses were limited to the ruptured hose and about 6,895 pounds of the anhydrous ammonia that was released. The National Transportation Safety Board determined that the probable cause of the accident was Werner Transportation Services, Inc.'s use of a cargo hose assembly that was not chemically compatible with anhydrous ammonia.

15. (2013). Cargo Tank Trucks: Improved Incident Data and Regulatory Analysis Would Better Inform Decisions about Safety Risks: 57p.
 - a. Cargo tank trucks deliver gasoline and other flammable liquids daily for consumer use. Trucks are loaded and unloaded through external bottom lines that, after loading, may contain up to 50 gallons of liquid and are known as "wetlines." Concerns have been raised about the safety of wetlines, since a collision may rupture them, releasing flammable liquid and possibly causing fatalities and property damage. The Pipeline and Hazardous Materials Safety Administration (PHMSA) is responsible for regulating the safe transportation of hazardous materials and has proposed rules prohibiting the transport of flammable liquids in wetlines. In 2012, The Moving Ahead for Progress in the 21st Century Act required the U.S. Government Accountability Office (GAO) to examine this issue. This report discusses (1) the extent that PHMSA's data reliably identify wetline safety risks, (2) options for addressing wetline safety risks, and (3) how well PHMSA has assessed the costs and benefits of addressing these risks through regulation. The Department of Transportation's (DOT) PHMSA incident data cannot be used to reliably identify risks from incidents involving collisions with and spills from tank trucks' bottom lines ("wetlines") because the incidents are not specifically identified in PHMSA's database and the data contain inaccuracies. PHMSA requires carriers to report hazardous material incidents, but the reporting form does not specifically capture wetline incidents. PHMSA officials identify wetline incidents through a resource-intensive process of reviewing carrier-reported incident narratives and other information. However, GAO found that the narratives do not always clearly indicate whether an incident is wetline related and that information about the consequences of incidents, including fatalities, is not always accurate. PHMSA has made efforts to improve its data, such as adding quality checks, but this has not affected how wetline incidents are reported, and inaccuracies remain. One technology to purge liquid from wetlines exists, but use of this system is limited, and industry and safety stakeholders expressed concerns about it, such as concerns about the safety of retrofitting existing trucks with the device and its cost. Although other options have been proposed to address wetline risks, none has been pursued, and there are concerns about their safety and feasibility as well. For example, wetlines could be drained at loading terminals, but this creates issues over storing the drained fuel and whether it could be resold. PHMSA analyzed the costs and benefits of its proposed 2011 rule to prohibit transportation of flammable liquids in unprotected wetlines, but did not account for uncertainties in its analytical assumptions and limitations in the underlying incident data. For example, PHMSA's analysis overstated the number of fatalities the proposed rule would prevent when considering actual past

incidents. Furthermore, PHMSA based its cost analysis on the assumption that carriers would install a certain type of wetline purging system, but its limited adoption makes that cost uncertain. Federal guidance recommends that agencies account for uncertainty in regulatory analysis, such as limitations in PHMSA's data and uncertainty in its assumptions. Without having done so, PHMSA's analysis may not accurately represent the costs and benefits of its proposed rule. DOT should improve its wetline incident data by requiring carriers to specifically report wetline incidents and by improving its information on incident consequences. DOT should also address uncertainty in the assumptions and data underlying its regulatory cost-benefit analysis.

16. Abelson, P. (2012). "Playing it safe." Public Works 143(1): pp 21-22.
 - a. Due to costs, many public fleets do not use crash avoidance systems, early warning devices or stability control for their trucks. This article aims to show the value of these systems and how they can pay for themselves if they prevent only one incident.
17. Akhmetov, Y., et al. (2013). "Reference trajectory generation for control in single-unit heavy vehicle: focus on rollover prevention." International Journal of Heavy Vehicle Systems 20(1): 1-18.
18. An, K., et al. (2012). The Study of Evaluation About Safety Performance of Transportable Pressure Vessel. ASME 2012 Pressure Vessels and Piping Conference, American Society of Mechanical Engineers.
19. Arant, M. O. N. (2010). Assessing the effect of chassis torsional stiffness on the accuracy of heavy vehicle understeer and rollover modeling, Clemson University.
20. Berardinell, S. and S. C. Wertman (2008). Fatality Assessment and Control Evaluation (FACE) Report: Volunteer Fire Fighter Dies in a Tanker Crash in Louisiana: 15p.
 - a. On March 28, 2008, a 33-year-old male volunteer fire fighter (the victim) was fatally injured after the tanker truck he was driving left the roadway and overturned. The victim was enroute to a structure fire, took an unfamiliar route, and failed to negotiate a 90DG curve to the right. The tanker left the roadway rolling onto the driver's side then slid through a ditch into a row of pine trees crushing the cab. The victim was extricated by emergency personnel, air-lifted to a local medical center, and later pronounced dead. NIOSH investigators concluded that, in order to minimize the risk of similar occurrences, fire departments should: (1) ensure that tankers are driven at a safe and reasonable speed; (2) ensure that fire fighters are familiar with the location of the roads in their coverage areas; (3) consider staffing tankers with a minimum of two fire fighters; (4) consider supplying responding units with maps or verbal directions to incident scenes, using computer aided dispatch (CAD) or a global positioning system (GPS) device; (5) develop oversight of the preventive maintenance program for fire apparatus.
21. Billing, J. R., et al. (2005). An assessment of tank truck roll stability, Technical Report CSTT-HVC-TR.
22. Birk, A. (2013). "Cost-Effective Application of Thermal Protection on LPG Road Transport Tanks for Risk Reduction Due to Hot BLEVE Incidents." Risk Analysis.
23. Boulton, M. (2000). "Risk management of LPG transport activities in Hong Kong." Journal of hazardous materials 71(1): 85-100.
24. Button, N. P. and P. M. Reilly (2000). "Uncertainty in incident rates for trucks carrying dangerous goods." Accident Analysis & Prevention 32(6): 797-804.
25. Bysh, I. N. and Dorn, M. R. (1996). "The Generation of Internal Pressure in Tanker Rollover." HSE contract research report No. 109/1996, Frazer-Nash Consultancy Limited

26. Cammarata, A., et al. (2011). "Load movement control system for rollover risk reduction of tanker trucks." International Journal of Heavy Vehicle Systems 18(3): pp 303-321.
 - a. In this paper a proposal for a control system that provides liquid cargo movement from one side to another is made. The system acts to minimise the effects of lateral load transfer and fluid oscillation. This consists of a main tank, two lateral tanks, regulators and a set of electropumps effecting the movement of the fluid. According to literature, in order to assess the risk of rollover, a normalised lateral load transfer has been used. Simulations of the lateral load transfer response have also been carried out to assess the improvements in lateral stability of the vehicle.
27. Carrera, M., et al. (2010). "Behaviour of Rear Underrun Protection System on Car-to-tank Vehicle Impact Used for Fuel Transportation." International Journal of Heavy Vehicle Systems 17(3/4): pp 199-215.
 - a. This article describes how the European legislation for rear underrun protection systems on heavy vehicles specifies a series of criteria that must be fulfilled in order that these devices can be homologated. The different models of devices that are used as rear underrun impact protection in tank vehicles for fuel transportation are an example of these criteria. Basically, the homologation tests based on this regulation consist in the quasi-static application of a load series at different points of the structure. In analyzing the guidelines, a number of questions about their validity may be raised with respect to, for instance, how efficient a homologated system of these characteristics is in real collision. This paper compares the behavior of a rear underrun impact protection system, incorporated into a tank vehicle, to the behavior of the same device when a car hits it at different collision speeds.
28. Casasanta, J. D. (2010). Rollover stability analysis of commercial semi-tanker trucks utilizing a trammel pendulum model to simulate fluid sloshing: xv, 121 p.
29. Cheli, F., et al. (2013). "Simulation of sloshing in tank trucks." International Journal of Heavy Vehicle Systems 20(1): 1-18.
30. Cheli, F., et al. (2013). "Simulation of sloshing in tank trucks." International Journal of Heavy Vehicle Systems 20(1): pp 1-18.
 - a. Tank trucks dynamics can get worse because of fluid sloshing in partially filled tanks. During braking manoeuvres, fluid sloshing may lead to load transfers causing rear wheels to lock up and loss of directional control, while during turning or lane changes, it may cause rollover. In this paper, a methodology for evaluating the interaction between fluid sloshing and vehicle dynamics is proposed. The fluid and the tank are modelled using the computational fluid dynamics code FLUENT, based on the Navier–Stokes equations and incorporating the Volume of Fluid (VOF) and the moving mesh techniques. The motion of the tank is determined based on the response of a 14 degrees of freedom vehicle model subjected to the forces due to the fluid sloshing. Straight line braking manoeuvres and lane change manoeuvres have been carried out to evaluate the effects of fill level, baffles and tank shape.
31. Childs, I. R., et al. (2000). "The Brisbane-Gladstone Transport Corridor: identification of risk and vulnerability for the bulk transport of dangerous goods." Australian Journal of Emergency Management, The 15(4): 54.
32. Chondros, T., et al. (2007). "An approximate method for the evaluation of the roll stiffness of road tankers." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 221(12): 1499-1512.
33. Chondros, T. G. (2010). "Road Tanker-bus Rear Impact Collision with Four Fatalities Investigation Report." International Journal of Heavy Vehicle Systems 17(3/4): pp 407-441.
 - a. This article describes how a 55-passenger motor coach which was operated by a local food-industry and carrying 14 passengers was traveling on the two-lane national road EO-90 Chania-Iraklion westbound, in the island of Crete, Greece in June of 2006. A road tanker consisting of a two-axle tractor and a three-axle semitrailer

aluminum tanker, loaded with JETA1 fuel was traveling westbound on the same national road on the same day. As the bus approached milepost 64.7 km, it slowed down to the right side of the highway for a passenger to depart and while restarting the oncoming road tanker collided with the rear of the bus. Three passengers and the truck driver were killed, and six passengers were seriously injured. The accident investigation and reconstruction were in accordance with the application of the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) and the criteria which could be adopted to judge risk acceptability are discussed in the article.

34. Di Cristoforo, R. and C. Blanksby (2006). A method for quantifying the relative risk of rollover of two road freight options.
- a. Two proposed heavy vehicle configurations were being considered for the transportation of dangerous goods in remote Western Australia. A research project was established to quantify the relative risk of rollover of the two options taking into account not only the reduced dynamic stability of the larger configuration but the reduced exposure of the larger configuration that resulted from the reduced number of required trips. The assessment was based on the risk of both steady-state rollover and dynamic rollover due to rearward amplification. For a known rear trailer rollover threshold and a known rearward amplification, the critical steer axle lateral acceleration input for dynamic rollover could be determined. A recent field operational test conducted by the University of Michigan Transportation Research Institute (UMTRI) characterized a fleet of cryogenic tankers operating in the State of Michigan in terms of the probability distribution of steer axle lateral acceleration resulting from driver input. This information was used to quantify the relative risk of the critical steer axle lateral acceleration input being exceeded. The analysis first showed that the smaller configuration posed less risk, but minor design changes to the larger configuration allowed it to be seen as the preferred option.
35. Erhard, A., et al. (2010). "Vibrations- und Stossbelastungen an IBCs und Tankfahrzeugen / Vibration and impact stresses at IBCs and tank trucks." MP MATERIALPRUEFUNG - MP MATERIALS TESTING 52(1/2): 63-70.
- a. Je nach Ausfuehrung und Zustand des Feder-/Daempfungssystems eines Fahrzeuges spuert der menschliche Koerper unterschiedliche Stoss- und Vibrationsbelastungen, die die Schmerzgrenze erreichen koennen. Diese dynamischen Belastungen werden auch auf Ladung, zum Beispiel auf die Gefahrgutumschliessungen und auf das Gefahrgut, uebertragen. Derartige Belastungen koennen durch entsprechende Stapelung und Sicherung der Ladung in ihren Auswirkungen gemindert werden. Fuer andere Belastungen, zum Beispiel den Stoss durch einen Auffahrnfall, sind Schutzsysteme am Heck des Fahrzeugs gefordert. Bei Tankfahrzeugen kann eine Beschaedigung des Tanks durch einen solchen Auffahrschutz gemindert werden. Die Bundesanstalt fuer Materialforschung- und -pruefung hat Vibrationsmessungen an Lastkraftwagen durchgefuehrt und deren Ergebnisse mit den Ergebnissen des Vibrationstests an einem Intermediate Bulk Container (IBC) verglichen. Berechnungen zum Auffahrschutz an Tankfahrzeugen werden Messergebnissen gegenuebergestellt. (A) ABSTRACT IN ENGLISH: The different types of stresses like impact or vibration by driving in the streets or cross the country are well known to the daily life. Depending on the construction and the condition of the spring /damping system of the vehicle, a painful stress in the human body sometimes may occur. Such dynamic stresses are certainly also transferred to the load, in this particular case the containment systems as well as to the hazardous materials. An effective cargo securing equipment reduces the interaction of the load significantly. However, not only the spring/damping system is important, also other suitable technical protection methods related to the vehicle are relevant. For impacts by rear end collision other prevention techniques are required. To avoid rear end damage by tank trucks tailgate protection can help. Results measured in a field test compared with results measured by the vibration tests at an intermediate bulk container (IBC) are part of this paper. A further part deals with the calculations for rear end protection compared with measured data. (A)

36. Gertsch, J. and O. Eichelhard (2003). "Simulation of dynamic rollover threshold for heavy trucks." Simulation 1: 3385.
37. Goldman, R., et al. (2001). "Rollover dynamics of road vehicles: Literature survey." International Journal of Heavy Vehicle Systems 8(2): 103-141.
38. Han, D., et al. (2012). "The Study of Tanker Semi-trailer's Steering Stability on the Fluid-Structure Interaction." Procedia Environmental Sciences 12: 1082-1088.
39. Ibrahim, I., et al. (2003). "Effect of laterally banked roadways on the rollover threshold of partially filled road tankers." SAE paper: 01-3387.
40. Ito, T., et al. (2004). "Empirical analysis on hazardous material transportation using road traffic census and accident data." City Logistics 3: 245-258.
41. Johnson, S. L., et al. (2007). Development of a Human Performance Simulation Model to Evaluate In-Vehicle Information and Control Systems in Commercial Trucking Operations: 111p.
 - a. The number of both crashes and fatalities involving large trucks has steadily been decreasing due to improved safety features (seat belt use, air bags, better brakes, etc.). Many safety professionals contend that to continue the improvement trend, it will be necessary to utilize "active" safety systems (e.g., adaptive cruise control, roll stability, collision warning, etc.). The passive systems are effective at reducing the severity and consequences of accidents; whereas the goal of active systems is to avoid accidents before they occur. Some of the "driver assistance" systems only provide a warning to the driver when an incident occurs while more advanced systems also record the occurrences or even provide active vehicle control (e.g., steering, braking, etc.). The proposed research specifically addresses the human factors issues associated with devices that are intended to reduce the potential of heavy truck accidents that are associated with running off the road, inadvertently moving into the adjacent lane and side collisions. Iteris, a manufacturer of a lane departure detection system states that 40% of all traffic fatalities are related to unintentional lane departure. An economic study determined that unintended lane departure account for approximately 16% of total maneuver related accident costs. These personal and financial costs affect both the trucking industry and society as a whole. The Large Truck Crash Causation Study Interim Report published by the Federal Motor Carrier Safety Administration indicates that the frequency, severity and costs of these accidents are predominantly associated with human error rather than road conditions or equipment malfunction. Pomerleau et al. (1999) found that 76% of the accidents occurred on straight roads and 73% occurred when the weather was clear. The causes of lane departure and side collision accidents are most often attributed to one or a combination of three factors: fatigue; inattention; or driver distraction. Although fatigue and inattention have received the most attention, driver distraction associated with in-vehicle information systems in becoming an increasingly important issue for commercial trucking operations. The objectives of lane departure and side-collision avoidance systems are twofold: (1) reduce the number of accidents; and (2) reduce driver workload. A number of products using different technologies (optical, radar, infrared, etc.) have been developed to reduce inadvertent or inappropriate lane departures and many more are in various stages of development. The methods of alerting the driver include audition (i.e., rumble strip sound) visual displays and haptic (i.e., vibration of steering wheel or seat). The criteria for when to alert the driver also varies (i.e., line crossing, time-to-line crossing, tolerance limits, etc.). Some equipment manufacturers are conducting studies that collect anecdotal data that support the use of the devices based on driver surveys and testimonials. However, recent controlled studies have obtained results that are not consistent with the manufacturers' conclusions. As with any detection system, there is a trade-off between sensitivity and the number of false alarms which can reduce effectiveness, as well as the drivers' trust and acceptance. There is a need for independent statistically reliable and valid information that trucking organizations can use to make

decisions as to the cost effectiveness of the current systems and to provide recommendations as to the characteristics of the systems that can increase their effectiveness and user/driver acceptance in operational settings. The proposed effort will address four specific issues related to driver assistance devices that are designed to reduce the frequency and severity of lane departure and side collision accidents. (1) Does the use of the devices actually reduce the incidents and severity of crashes or near crashes? (2) Does the use of these devices modify driver behavior either positively (i.e., by increasing attention) or negatively (i.e., as a "crutch" that results in reduced attention)? (3) Does the effectiveness of these devices differ depending upon the characteristics of the drivers (i.e., new or experienced) or the driving scenario (long-haul vs. short-haul, flatbed, tanker, etc.)? (4) From the management standpoint, how can the data from these systems most effectively be used to positively modify driver behavior and provide user/driver acceptance of the systems?

42. Kang, X., et al. (2001). "Effects of tank shape on the roll dynamic response of a partly filled tank vehicle." Vehicle System Dynamics 35(2): 75-102.
43. Kirkpatrick, S. W. and R. W. Klopp (2000). Hazard assessment for pressure tank cars involved in accidents.
44. Knee, H. B., et al. (2005). "Heavy Truck Rollover Characterization: New Generation Single Tires vs. Standard Duals." Draft Report-National Transportation Research Center, Inc., Knoxville, TN.
45. Lacey, R. F. and J. A. Cole (2003). "ESTIMATING WATER POLLUTION RISKS ARISING FROM ROAD AND RAILWAY ACCIDENTS." QUARTERLY JOURNAL OF ENGINEERING GEOLOGY AND HYDROGEOLOGY 36(2): p. 185-192.
 - a. A method is presented for estimating the frequency of spillage of toxic liquids from road tanker accidents. The calculation requires information about the vehicular flow of tankers, their accident rate and the probability that an accident will result in a spill. The available sources of input data are discussed. Railway goods traffic, either involving liquids transported in tanker wagons, or hazardous freight packed in individual containers as part wagon loads, is amenable to similar analysis but relevant input data are much more difficult to obtain. For any type of spill, the estimation of frequency should be accompanied by surface and groundwater pathway analyses, to assess the consequential damage to the aquatic environment and any possible hazard to public water supplies. This paper serves as an outline of a subject calling for more thorough study, for which improved databases, geared to the needs of risk assessment, would be strongly desired. (A) This paper was discussed by T C Atkinson in Quarterly Journal of Engineering Geology and Hydrology (2003), 36(4) pp 367, with the authors' reply provided on pp 367-8 of the same issue.
46. Lack, J. G. T. and M. K. M. Dzimko "WHEELSET/RAIL GEOMETRIC CHARACTERISTICS ASSESSMENT WITH REGARD TO WHEELSET ROLLING."
47. Langwieder, O.-I. K. "TANKER TRUCKS IN THE CURRENT ACCIDENT SCENE AND POTENTIALS FOR ENHANCED SAFETY."
48. Leggate, H., et al. (2001). COUNTING THE COSTS OF TANKER ACCIDENTS.
 - a. All the evidence indicates that over 99.98 per cent of all oil carried by sea reaches its destination without incident and that tanker casualty rates compare more than favourably with those recorded for other modes of transport. In spite of these positive statistics, there is increasing world-wide intolerance of incidents involving all types of tankers because of their impact in terms of loss of life and environmental pollution. The result of this has been an intensification of regulation on a national, regional, and international level, the obvious example being the US response to Exxon Valdez which spawned OPA 90, and the acceleration in IMO regulation. This investigation uses both a time series and cross sectional approach to analyse accidents from 1965 to 2000 in order to identify trends in terms of quality and characteristics of the tonnage

and their product as indicated by the number of casualties and the extent of pollution spillage. The preliminary findings suggest that small and ageing vessels are the worst offenders and that pollution is on the increase. There are, however, some striking anomalies in the 1970s which warrant further investigation. Such analysis serves to highlight the important issues of safety and the environment for the tanker industry. For the covering abstract see ITRD E115303.

49. Li, T. and Y. Jingtao (2011). Analysis on liquid-tanker vehicle liquid and solid coupling collision simulation. Digital Manufacturing and Automation (ICDMA), 2011 Second International Conference on, IEEE.
50. Li, X.-s., et al. (2013). "Study on driving stability of tank trucks based on equivalent trammel pendulum for liquid sloshing." Discrete dynamics in nature and society 2013.
51. Martin, A., et al. (2010). "Rollover stability of tank trucks, test and calculation requirements based on ECE 111 regulation." International Journal of Heavy Vehicle Systems 17(3): 276-300.
52. McNally, S. (2007). "Officials cite training, technology, design to reduce tank truck rollover crashes." Transport Topics(3771): p. 11.
53. Miller, E. (2009). "DOT would report on tanker rollovers under bill approved by House panel." Transport Topics(3873): p. 2+ : ill.
54. Miller, E. (2010). "NHTSA eyes stability systems to prevent tanker rollovers." Transport Topics(3907): p. 1+ : ill.
55. Miller, E. (2011). "NTSB issues rollover recommendations aimed at improving tank truck safety." Transport Topics(3957): p. 2, 25.
56. Oggero, A., et al. (2006). "A survey of accidents occurring during the transport of hazardous substances by road and rail." Journal of hazardous materials 133(1): 1-7.
57. Panyako, J., et al. "Load Level Effects on Accident Prevalence among Transit Petroleum Road Tankers' in Kenya." Reduction and Conflict Resolution for Sustainable Development: 257.
58. Papadogiannis, A., et al. (2010). "Road tankers axles load share design." International Journal of Heavy Vehicle Systems 17(3): 256-275.
59. Pape, D., et al. (2009). U19: Heavy Truck Rollover Characterization (Phase-B) Final Report: 416p.
 - a. The Heavy Truck Rollover Characterization Study - Phase-B builds on the results of prior phases of research. Phases 1 and 2 (funded by the Federal Highway Administration) involved heavy truck rollover characterization for a tractor and box-trailer; and Phase-A involved the characterization of a tractor and flatbed-trailer. Phase-B of the Heavy Truck Rollover Characterization Study included on-track testing utilizing New Generation Single Wide-Based Tires (NGSWBTs) and standard dual tires; the use of a Volvo VT830 class-8 tractor (the same tractor that was used in Phase-A); the use of three LBT tanker-trailers (two for characterization and one for test-track testing); and a Bendix Electronic Stability Control (ESC) system on the tractor and tanker-trailer. Characterization was conducted by both Michelin and WMU. The standardized torsional stiffness testing developed by Michelin in Phase-A and the procedure developed by WMU were utilized for characterization of the respective tanker-trailers at Michelin and WMA. The tanker-trailer at Michelin was also characterized on Michelin's Kinematics and Compliance (K&C) test rig. The purpose of the characterization efforts was to generate detailed K&C data about the tanker-trailer that could be utilized in selected vehicle dynamics models. Phase-B also

involved the development of a vehicle dynamics model of the tractor and tanker-trailer in TruckSim(R) or an equivalent vehicle dynamics model. WMU also continued with the development of their solid, finite element, and kinematic models, and will apply them to make initial design recommendations to be considered in Phase-C of this research.

60. Pape, D. B., et al. (2012). Role of Human Factors in Preventing Cargo Tank Truck Rollovers, Transportation Research Board: 69p.
 - a. This report analyzes the root causes of the major driver factors contributing to cargo tank truck rollovers and proposes safety, management, and communication practices that can be used to minimize or eliminate driver errors in cargo tank truck operations. The research focuses on three critical areas of practice that can be quickly implemented and will have long-lasting benefits for motor carriers of all sizes across the tank truck industry. These areas of practice, examined through case studies, include (1) rollover-specific driver training and safety programs, with particular attention to a program on heavy vehicle rollover prevention from VicRoads (the state government roads authority in Victoria, Australia), the components of a good overall safety program, and tips for investigating rollovers to prevent their recurrence; (2) the use of behavior management techniques using on-board technology, direct observation (driver ride-along), training, and other tools and methods to manage driver behavior based on a survey of current technology and interviews with operators who demonstrated successful behavior management processes; and (3) the use of fitness-for-duty management practices in fatigue management, general health and wellness, scheduling and dispatching strategies, and distracted driving prevention.
61. Pape, D. B., et al. (2007). "Cargo tank roll stability study." Final report, Contract No. GS23-F-0011L, Batelle 30.
62. Pape, D. B., et al. (2008). "Benefits and costs of four approaches to improving rollover stability of cargo tank motor vehicles." Transportation Research Record: Journal of the Transportation Research Board 2066(1): 114-121.
63. Pape, D. B., et al. (2008). "Benefits and Costs of Four Approaches to Improving Rollover Stability of Cargo Tank Motor Vehicles." Transportation Research Record: Journal of the Transportation Research Board(2066): pp 114-121.
 - a. Four broad approaches to decreasing the number of cargo tank rollovers were evaluated: driver training, electronic stability aids, improvements in design of the vehicle itself, and highway design. A study of rollover crash statistics confirmed many expectations, but a few of the factors were not as strong as might have been expected. The portion of rollovers that occur on freeways is 15% to 20%. A driver error of one kind or another (e.g., decision or performance error) figures in about three-fourths of cargo tank rollovers. Inattention and distraction account for about 15%. Evasive maneuvers were a factor in 5% to 10% of rollovers. Drivers must be trained to appreciate the diverse causes for rollovers and to anticipate the situations that lead to them. Adherence to viable work and rest schedules is crucial. Electronic stability aids automatically slow the truck when it rounds a curve too fast. They can be remarkably effective in preventing this scenario. However, crash statistics and anecdotal accounts consistently show many other factors that can lead to rollovers. Significant reductions in rollover rates can be achieved with modest changes in vehicle stability. Cargo tank trailers of improved stability are currently available for some cargoes. When mountainous terrain or other factors dictate highway designs that can contribute to rollovers, drivers need to be made aware through signage or dispatch instructions. A comprehensive benefit–cost analysis, conducted from a societal point of view during a 20-year window, projected that the improvements will be cost beneficial.
64. Pauwelussen, J. and D. Linardatos (2008). Predict the road to prevent roll-over, using the navigation database. Intelligent Vehicles Symposium, 2008 IEEE, IEEE.

65. Pearson, D. F. (2005). "Compartmentalizing Tanker Truck Safety Design: Minimizing the Potential for Fires from Collisions." Ethnicity & Disease 15(3): pp S4-94-95.
- a. This article reports on a study that collected data on Alabama accident rates and experimentation on different types of dry foams and heavy inert gases being exposed to fire. The authors sought to determine what type of techniques should be used to construct a prototype (mock tanker truck), including what type of techniques should be used to puncture the truck and what materials should be used to simulate the truck. According to Alabama accident data, a total of 2258 accidents involving heavy transport trucks carrying hazardous cargo have occurred in the state during the past five years. Of these accidents, 202 involved overturning of the vehicle with 33 resulting in fires or explosions, five resulting in spills of hazardous materials, and 91 cases of hazardous cargo becoming separated from the truck. The authors conclude that simulation studies that could prevent fires to tankers as a result of a collision may result in considerable cost savings.
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69. Prem, H., et al. (2008). Rollover crash analysis of a road tanker with self-steer axles. Proceedings of the International Conference on Heavy Vehicles, IST, Ltd, Paris France, John Wiley & Sons.
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71. Romero, J., et al. (2005). "Natural sloshing frequencies of liquid cargo in road tankers." International Journal of Heavy Vehicle Systems 12(2): 121-138.
72. Romero, J., et al. (2007). Modelling of liquid cargo-vehicle interaction during turning manoeuvres. 12th IFToMM World Congress. Besançon (France).[Links].
73. Romero, J., et al. (2010). "Experimental study on sloshing and non-sloshing road cargoes dynamics." International Journal of Heavy Vehicle Systems 17(3): 301-330.
74. Romero, J., et al. (2006). "Analysis of lateral sloshing forces within road containers with high fill levels." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 220(3): 303-312.
75. Romero, J. A., et al. (2013). "A Methodology to Assess Road Tankers Rollover Trend During Turning." SAE International Journal of Commercial Vehicles 6(1): 93-98.
76. Romero Navarrete, J. A., et al. (2003). DISPOSITIVOS DE PROTECCION DE AUTOTANQUES ANTE VOLCADURAS ASPECTOS NORMATIVOS DE DISEÑO, Instituto Mexicano del Transporte: 93.
- a. En este trabajo se presenta un análisis de los aspectos normativos y de diseño, aplicados a las protecciones ante volcaduras de vehículos tipo autotanque, proponiendo mejoras en el diseño de estos equipos como en las normas a que están sujetos. Se incluye un análisis de la normatividad estadounidense y mexicana con relación a estos equipos, identificando los elementos comunes y discrepancias. Con base en simulaciones de volcaduras reportadas por la Universidad de Michigan, se propone una norma de efectividad ante volcaduras para estos dispositivos, basada en la velocidad de impacto en las tres direcciones (tridimensional). Los elementos

normativos propuestos incluyen algunas características geométricas de los dispositivos, proponiendo dos niveles de protección. También, se analizan los factores que influyen en la tendencia a la volcadura de los autotanques, estableciendo parámetros geométricos y de rigidez determinantes en los componentes vehiculares. Los resultados de las simulaciones muestran que las características geométricas de los camiones son las que mayormente definen su tendencia a volcarse. Se obtiene que una combinación óptima de los factores geométricos y de rigidez puede disminuir, hasta en un 50 por ciento, la tendencia de los vehículos a sufrir volcaduras. Se ofrecen conclusiones y recomendaciones, tablas y figuras relacionadas y la bibliografía consultada. Abstract: To avoid liquid cargo spills due to damages caused to man-holes and fittings. A mounted on the top of their tanks, tank trucks are equipped with rollover ar protection devices (RPD). If the cargo consists of any dangerous substance, failure of such protection devices can have serious consequences. Du in part to accidents in which RPD's have failed, there exists the international perception that the present RPD's designs, lack the need characteristics to provide an effective and sufficient protection. This work present an analysis of the present designs for RPDs, including the development of a conceptual design of a new RPD, which is thought would provide a better protection during tank crashing against road and streets equipments. It is also presented an analysis of the current regulations in México and USA, identifying some common characteristics and differences. Using rollover simulation results reported by The University of Michigan, a draft standard is proposed for RPDs performance, considering three-dimensional impact velocities. To identify ways to improve the vehicle's dynamic performance, computer simulation is used for evaluating the influence of vehicle's geometrical and stiffness characteristics on vehicle's rollover trend. Results show that geometric characteristics are the more influential factors affecting vehicles rollover trend, and that an optimal combination of factors can represent a reduction of up to 50 percent in the vehicle's rollover trend.(A)

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 - a. This research project studied causes and possible remediation inspection strategies to prevent failures for anhydrous ammonia (NH₃) nurse tanks. Nurse tanks are steel tanks used to transport NH₃ locally over public roadways and farm fields. Many of the reportedly 200,000 nurse tanks in use in the United States are 3 to 5 decades old. Several tank failures have occurred in recent years. Nurse tank failures can injure workers and bystanders by way of chemical burns, frostbite, suffocation, and physical injuries caused by the catastrophic force of rupture. This research study addressed this problem by: surveying the technical literature on nurse tank properties and case studies of tank failures; examination of 20 used nurse tanks by metallography, glow discharge spectroscopy, neutron diffraction analysis of residual stresses, ultrasound, and fluorescent dye penetrant examination for cracks. It exposed 56 specimens of the commonly used tank steel, stressed in tension, while either immersed in liquid NH₃ or exposed to pure NH₃ vapor, for 7 months to study the initiation and growth of stress corrosion cracks. This research further confirms that stress corrosion cracking is the greatest threat to nurse tank integrity. Recommendations for best inspection practices are presented on how to reduce the risks associated with nurse tank failures.
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80. Sampson, D. J. and D. Cebon (2003). "Achievable roll stability of heavy road vehicles." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 217(4): 269-287.
81. Senyard, M. (2010). "Haul road maintenance." QUARRY MANAGEMENT 37(9): 17-18.

- a. This article outlines the actions necessary to maintain haulage roads in quarries. Continual attention to the maintenance of these roads improves production, extends tyre life and reduces overall operating costs. The chief cause of problems is spillage from off-highway haulage lorries, so it is important that a motor-grader is deployed on site to continually maintain haulage routes and remove loose debris. Poor road maintenance practices also increase rolling resistance, defined as the pressure exerted on the tyres by a road's riding surface. Once a road deteriorates, assuming that it was properly constructed in the first place, it takes considerable time to repair it to an acceptable condition. It is important to match the right grader and water tanker units to the quarry's haulage routes. A neglected road will require more intensive remedial action and a larger grader to cut and grade final levels. The characteristics of grader equipment are described. Regular watering of the roads helps to maintain compaction and suppress dust, which is a safety issue, but over-watering risks washing the fines out of the road. Special design considerations for gravel roads to prevent accidents are outlined.
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83. Shen, X., et al. (2013). "Analysis on tank truck accidents involved in road hazardous materials transportation in China." Traffic Inj Prev(just-accepted).
84. Shojaeefard, M., et al. "Enhancing Rollover Threshold of an Elliptical Container Based on Binary-coded Genetic Algorithm."
85. Toumi, M., et al. (2009). "Impact of liquid sloshing on the behaviour of vehicles carrying liquid cargo." European Journal of Mechanics-A/Solids 28(5): 1026-1034.
86. Wasfy, T. M., et al. (2007). Experimental validation of a coupled fluid-multibody dynamics model for tanker trucks, DTIC Document.
87. Wislocki, J. (2003). "DOT CONSIDERS PROTECTING WET LINES FROM RUPTURE." Transport Topics.
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- a. In this paper, transient forces and roll moment caused by fluid slosh within partly filled circular and conical cross-section tanks, subject to a time-varying lateral acceleration field, are evaluated numerically and compared with those estimated from a quasi-static formulation. Variations in the center of mass coordinates, vertical and lateral forces, and roll moment are applied to the roll-moment model of a 6-axle tractor-semi-trailer articulated tank vehicle for analysis of the steady-turning rollover threshold. Results show that the magnitudes of transient lateral force and roll moment approach significantly higher values than those estimated from the quasi-static formulations. However, the mean values of the force and moment are similar to those predicted from the quasi-static solution. The steady-turning rollover-threshold accelerations of the vehicle combination with partly filled tanks are thus considerably lower when transient slosh forces and moment are considered in the moment equilibrium, especially for intermediate fill volumes. Results further show that static roll stability

limits of the combination with a conical cross-section tank are much higher than that with a circular cross-section tank.

91. YongQing, J., et al. (2010). The Research of Classification Method for Significant Risk of Hazardous Chemical Tanker which in Transit. Optoelectronics and Image Processing (ICOIP), 2010 International Conference on, IEEE.
92. Yu, H., et al. (2008). "Heavy duty vehicle rollover detection and active roll control." Vehicle System Dynamics 46(6): 451-470.

Appendix B Stakeholder surveys

During the course of the project, two stakeholder surveys were carried out in March and August 2014 respectively. The following questionnaires were distributed by email:

First questionnaire, sent 3rd March 2014:

“Dear tanker safety expert,

As you may already be aware, the Department of Transport (Steve Gillingham, cc’d) is looking into various issues concerning the safety of fuel tankers operating on UK roads. As part of that review, TRL (the Transport Research Laboratory) have been tasked with obtaining information on accident frequencies, severities and characteristics. I am writing to you as someone we understand to be an important stakeholder with relevant expertise, in the hope that you might be able to provide useful information, data and/or advice.

Below I have set out some of the key questions we hope you can assist us with. Please try to answer as many of them as you are able.

Your responses will be treated in strict commercial confidence – this study is aiming to derive a broad, high-level overview of the likely situation in the UK, not single out individual organisations or operations. A direct response via email reply would be ideal, though if you wish to forward your own incident data, incident reports and/or investigation reports, that would also be very welcome, by email or post. I am also very happy to discuss matters with you over the phone, or even via a face to face meeting, if one or other of these options suits you better. Responses are needed by no later than Monday 10th March 2014.

Accidents/Incidents

Q1. How frequently do fuel (petrol/diesel) tankers get involved in accidents? If possible, expressing this in terms of a rate per million vehicle miles, or per 100 vehicles per year, would be really useful. Please also distinguish, if possible, between serious (injury) accidents and damage-only cases.

Q2. What are the most common accident types? For example, single vehicle roll-over, rear impact from another heavy vehicle, side impact from a passenger car, etc.

Q3. How frequently do accidents result in loss/escape/spillage of fuel from the cargo tank?

Q4. How much fuel is typically spilt and what are the consequences, e.g. frequency of fire or explosion?

Q5. What mechanisms cause fuel to be spilt, e.g. mechanical damage to pipes/valves, tank puncturing or rupturing?

Q6. What sorts of accidents tend to be more frequently associated with fuel-loss cases?

Q7. What are the typical repair costs? We would be particularly interested in repairs to the tank, e.g. for dents, splits, tears or puncture holes.

Q8. Are you able to provide copies of incident reports, such as those compiled under ADR reporting requirements and/or investigation reports? If so, please do (any incidents since 2000 would be of particular interest).

Vehicles

Q1. What sorts of tanks do you generally use/work with, and how many, e.g. steel or aluminium, banded or stuffed tank design, rigid/artic/drawbar, axle configurations, gross vehicle weights, etc?

Q2. What proportion of the vehicles you operate/work with are fitted with a vehicle stability function such as ESC or some other form of electronic roll stability system (RSS)?

Q3. Can you provide any information relating to how effective such systems have been in preventing roll-over accidents?

Q4. Do your tankers generally operate either at near full or empty, or do they spend much of their time with a partial load only?

Q5. To what extent do the current ADR regulations influence your decisions regarding the vehicles you use/work with and the technologies fitted to them?

Other information sources

Q1. Can you suggest other sources of expertise who may be able to help? Please provide contact details if possible."

Second questionnaire, sent 7th August 2014

"Dear tank safety expert

As you may already be aware from the paper transmitted by the Government of the United Kingdom at the Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods in Bern, 17–21 March 2014, the UK competent authority, the Department for Transport (John Mairs and Steve Gillingham, cc'd), is looking into various issues concerning the safety of road fuel tankers operating in the UK. As part of that review, TRL Ltd (the Transport Research Laboratory) has been tasked with obtaining information on accident frequencies, severities and characteristics. I am writing to you as someone we understand to be an important stakeholder with relevant expertise, in the hope that you might be able to provide some useful information, data and/or advice.

We are aware of the RID/ADR Joint Meeting's Working Group on developing a multimodal database on events involving the transport of dangerous goods. The UK has been unable to participate in the work of this working group so far, however, we will share the results of the questionnaire with the Working Group when the Contracting Parties are informed of the findings of the review.

Below I have set out some of the key questions with which we hope you can assist. Please try to answer as many of them as you are able.

Your responses will be treated in strict confidence – this study is aiming to derive a broad, high-level overview of the likely situation in the UK and in other comparable countries, not single out individual organisations, countries or operations. A direct response via email reply would be ideal,

though if you wish to forward your own incident data, incident reports and/or investigation reports, that would also be very welcome, by email (please copy to Michelle Tress, cc'd). I am also very happy to discuss matters with you over the phone if that option suits you better. We would very much appreciate responses as soon as you are able but in any event by no later than Friday **5th September 2014** if at all possible.

The UK Department for Transport are planning to present the key findings of this research to the relevant ADR expert group at its meeting in March 2015.

Accidents/Incidents

Q1. Can you provide any information (e.g. for your country or company) on how frequently road fuel (petrol/diesel) tankers get involved in accidents? If possible, expressing this in terms of a rate per million vehicle miles, or per 100 vehicles per year, would be very useful. Please also distinguish, if possible, between serious (injury) accidents and damage-only cases.

Q2. What are the most common accident types? For example, single vehicle roll-over, rear impact from another heavy vehicle, side impact from a passenger car, etc.

Q3. How frequently do accidents result in loss/escape/spillage of fuel from the cargo tank?

Q4. How much fuel is typically spilt and what are the consequences, e.g. frequency of fire or explosion?

Q5. What mechanisms cause fuel to be spilt, e.g. mechanical damage to pipes/valves, tank puncturing or rupturing?

Q6. What sorts of accidents tend to be more frequently associated with fuel-loss cases?

Q7. What are the typical repair costs? We would be particularly interested in repairs to the tank, e.g. for dents, splits, tears or puncture holes.

Q8. Are you able to provide copies of incident reports, such as those compiled under ADR reporting requirements and/or investigation reports, or other official statistics on road fuel tanker accidents in your country? If so, please do (any incidents since 2000 would be of particular interest).

ADR Incident Reporting

Q9. Is there any evidence that serious incidents involving significant loss of load or load-related injuries are not being officially reported (in accordance with ADR Regulations) in your country?

Q10. Is there evidence that non-spill incidents that could involve a high risk of spillage, including overturns, are not being reported in your country?

Q11. What can you suggest should be done to improve the reporting levels?

Other information sources

Q12. Can you suggest other sources of expertise who may be able to help? Please provide contact details if possible."

Appendix C News reported tanker incidents

C.1 News reports

Table C-1. News reported tanker incidents involving load spillage, from 2009

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2009	Motorway chaos after M6 tanker spillage	Bitumen and diesel spillage closes motorway. Tanker lost its load. No collision or rollover.	Flammable liquid	No	No	Non built-up, motorway	Not reported	16
2010	Human excrement pours on to road in Evesham	Sewage tanker crashes into central reservation and spills entire load.	Other liquid	Yes	No	Non built-up, non motorway	No	17
2010	Lorry driver 'lucky to be alive' after Coventry crash	Tanker carrying 20000 litres of lactose concentrate overturned and spilled load. Minor hand injury to driver.	Other liquid	Yes	Yes	Non built-up, non motorway	Yes	18
2010	Overturned lorry spills milk over road near Warminster	Lorry carrying 22000 litres of milk overturned and spilled its contents onto the road.	Other liquid	No	Yes	Non built-up, non motorway	Not reported	19
2010	Overturned milk lorry closes the A37 near Ston Easton	Tanker carrying 29000 litres of milk overturned on the A37.	Other liquid	No	Yes	Non built-up, non motorway	No	20
2010	Oil tanker hit by car crashing through Malvern garden	Car crashes into tanker. 1000 litres of heating oil spilt.	Flammable liquid	Yes	No	Unknown	Not reported	21
2011	Tanker spill causes A14 closure in Cambridgeshire	Tanker crashes with lorry. Leaks ethanol on the A14.	Flammable liquid	Yes	No	Non built-up, non motorway	Not reported	22

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2011	Kerosene spilled in tanker crash in East Meon	Tanker overturned and spilled 2000 litres of kerosene.	Flammable liquid	No	Yes	Non built-up, non motorway	Not reported	23
2011	Strathaven road closed after tanker overturns	Tanker overturned and spilled 150 litres of gas oil through six relief valves on top of the tanker.	Flammable liquid	No	Yes	Non built-up, non motorway	Yes	24
2011	Bleach and oil spill closes road into Northampton	Tanker crossed through central reservation and overturned. Spills bleach and oil.	Other liquid	Yes	Yes	Non built-up, non motorway	Not reported	25
2011	M1 shut after tanker crash in South Yorkshire	Tanker carrying waste yeast overturned after colliding with a motor caravan. Driver was taken to hospital but injuries were not thought to be serious.	Other liquid	Yes	Yes	Non built-up, motorway	Yes	26
2011	M6 reopens near Preston after tanker spillage	15 tonnes of flammable solvent spilled on motorway. No accident or rollover. Tanker driver taken to hospital due to inhaling fumes.	Flammable liquid	No	No	Non built-up, motorway	Yes	27
2012	Exclusion zone set up after tanker driver dies in Crook of Devon crash	Tanker involved in collision and ended up on its side. Aviation fuel spilled. Tanker driver killed. Mercedes sprinter driver had minor injuries.	Flammable liquid	Yes	Yes	Non built-up, non motorway	Yes	28
2012	A483 Llandeilo road closed after diesel spill at Ffairfach	Crashed fuel tanker spills 2000 litres of diesel.	Flammable liquid	Yes	No	Non built-up, non motorway	Not reported	29

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2012	Bristol road closed after tanker fuel leak	Tanker leaked aviation fuel.	Flammable liquid	No	No	Built-up	Not reported	30
2012	Tanker spillage clean-up in Kirkharle will take weeks	Tanker overturned in a ditch and spilled 27000 litres of aviation fuel in Northumberland.	Flammable liquid	No	Yes	Non built-up, non motorway	Not reported	31
2012	A48 SDR in Newport closed after tanker overturns	Tanker carrying waste oil overturned in Newport. Small spillage.	Other Liquid	No	Yes	Non built-up, non motorway	No	32
2012	Fuel tanker jack-knives on A38 leaking diesel on to road	Fuel Tanker jack-knifed and overturned, and leaked up to 38000 litres of diesel.	Flammable liquid	No	Yes	Non built-up, non motorway	Not reported	33
2012	Road closed after tanker accident	4000 litres of unleaded petrol spilled. Road closed. Additional info shows that tanker overturned on A38 while being towed.	Flammable liquid	No	Yes	Non built-up, non motorway	Not reported	34
2013	A14 reopened after tanker crash	Fuel tanker overturns and spills 38000 litres of ethanol. Driver suffered head injuries.	Flammable liquid	No	Yes	Non built-up, non motorway	Yes	35
2013	Diesel spillage at Sandwich after oil tanker crash	Fuel tanker carrying red diesel overturned on an icy road. Article says tank did not spill but pressure of oil in valves caused it to leak into a watercourse.	Flammable liquid	No	Yes	Non built-up, non motorway	No	36

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2013	'Biggest chemical spill' closes M62 in East Yorkshire	Tanker overturned and spilled toxic and flammable chemicals on M62.	Flammable liquid	No	Yes	Non built-up, motorway	Not reported	37
2013	M62 in West Yorkshire closed following tanker crash	Lorry collided with rear of tanker causing it to leak a small amount of flammable liquid. Lorry driver had a leg injury - air ambulance required.	Flammable liquid	Yes	No	Non built-up, motorway	Yes	38
2013	Haverfordwest petrol spill clean-up after tanker crash	Petrol tanker collided with crane. 'Substantial amount' of petrol spilt onto road. Additional info link states 7500 litres of diesel spilled. 15000 litres originally on board tanker.	Flammable liquid	Yes	No	Non built-up, non motorway	No	39
2014	Tanker spills 1,000 litres of petrol at services	Tanker was hit by a lorry. A thousand litres of petrol spilt at petrol service station in Basingstoke.	Flammable liquid	Yes	No	Non built-up, motorway services	Not reported	40

Table C-2. News reported tanker incidents *not* involving load spillage, from 2009

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2009	Man hurt in sewage lorries crash	Man seriously injured in a crash involving two lorries and two cars and a sewage tanker.	Other	Yes	No	Non built-up, non motorway	Yes	41
2009	One dead in 'devastating' crashes	Two fuel tankers, two lorries and a car collide.	Flammable liquid	Yes	No	Built-up	Yes	42
2009	Bridge reopens after diesel spill	Tanker spills 350 litres of diesel (likely from running fuel tank, i.e. no load spillage). Leak began whilst tanker crossed a bridge. No collision or rollover.	Flammable liquid	No	No	Non built-up, non motorway	Not reported	43
2010	Major north Wales road to close 'for days' after crash	Crash between a tanker, a lorry and a car. Two people killed. Tanker driver suffered minor head injuries.	Unknown	Yes	Unknown	Non built-up, non motorway	Yes	44
2010	Severe delays after Dartford crossing fuel tanker crash	Fuel tanker crashes in Dartford tunnel. Tanker driver suffered minor injuries.	Flammable Liquid	Yes	No	Tunnel	Yes	45
2010	Suffolk train crash tanker driver jailed	Sewage tanker collided with a train. 21 people were injured.	Other	Yes	Yes	Non built-up, non motorway	Yes	46
2010	Man killed in three-lorry crash on A9 named	Crash involving two lorries and a tanker. Lorry driver killed, tanker driver suffered serious leg injuries.	Unknown	Yes	Yes	Non built-up, non motorway	Yes	47

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2010	Lorry accident in Harlow causes fuel slick	Diesel fuel spill after lorry crashes into traffic island (likely from running fuel tank, i.e. no load spillage). 10 litres of fuel spilt. Tanker damaged bollard, pavement and lamppost.	Flammable liquid	Yes	No	Built-up	Not reported	48
2010	Motorway section shut after gas tanker overturns	Tanker carrying LPG overturned.	Other ADR	No	Yes	Non built-up, motorway	Not reported	49
2011	Driver killed in M40 tanker crash	Man died in crash involving a gas tanker and two vans. Another driver suffered a broken leg. The tanker driver was unhurt. No gas escaped from tanker even though it received substantial damage.	Other ADR	Yes	No	Non built-up, motorway	Yes	50
2011	Man charged over fatal A41 crash in Hertfordshire	Petrol tanker, van and several cars collided. One person died, nine people were injured.	Flammable Liquid	Yes	No	Non built-up, non motorway	Yes	51
2011	M1 shut after tanker crash in South Yorkshire	Tanker carrying more than 20 tonnes of yeast overturns after crashing. Tanker driver taken to hospital with minor injuries.	Other	Yes	Yes	Non built-up, motorway	Yes	52
2011	Diesel spill closes M3 during rush hour	Fuel tanker collides with van and a car. Spilled 500 litres of diesel (likely from running fuel tank, i.e. no load spillage). No serious casualties.	Flammable liquid	Yes	No	Non built-up, motorway	No	53
2012	M1 northbound closed by four-lorry crash	Cement tanker collides with three lorries. Two injured, one seriously.	Other	Yes	No	Non built-up, motorway	Yes	54

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2012	Sewage tanker crash blocks B4337 between Cross Inn and Llanrhystud	Lorry full of raw sewage overturned. No content spilt.	Other	Unknown	Yes	Non built-up, non motorway	unknown	55
2012	Lincolnshire man dies in petrol tanker crash	Car collided with petrol tanker. Car driver killed.	Flammable liquid	Yes	No	Unknown	Yes	56
2012	Two dead as tanker and car collide in County Tyrone	Accident between tanker and killed resulted in two fatalities.	Unknown	Yes	No	Built-up	Yes	57
2012	A470 in Powys partly shut after gas tanker crash	Gas tanker half full of gas overturns in field.	Other ADR	Unknown	Yes	Non built-up, non motorway	Unknown	58
2012	M6 closed in Warwickshire after chemical tanker fire	Chemical tanker caught fire after suffering a tyre blow-out. Ten people were treated for breathing difficulties and taken to hospital.	Other ADR	No	No	Non built-up, motorway	Yes	59
2012	A34 shut after tanker spills diesel	Tanker spilled 50 litres of diesel (likely from running fuel tank, i.e. no load spillage). No detail on cause of spill.	Flammable liquid	No	No	Non built-up, non motorway	Not reported	60

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2013	A9 tanker crash victim is former Scotland youth rugby player	Head-on collision between a car and a whisky tanker. Car driver killed. Tanker driver uninjured.	Other	Yes	No	Non built-up, non motorway	Yes	61
2013	West Sussex crash: Milk tanker driver injured	Milk tanker overturned. Tanker driver suffered serious injuries.	Other	Unknown	Yes	Non built-up, non motorway	Yes	62
2013	Biker Adam Smart dies after A38 tanker crash	Motorcyclist collided with the rear of a waste tanker. Motorcyclist killed.	Other	Yes	No	Built-up	Yes	63
2013	Three killed in North Yorkshire road crashes	Milk tanker overturned on the A1. Driver suffered serious injuries.	Other	Unknown	Yes	Non built-up, non motorway	Yes	64
2013	Woman killed in North Yorkshire collision with tanker	Oil tanker collides with Rover 25. 1 fatality.	Flammable Liquid	Yes	No	Built-up	Yes	65
2013	Cyclist dies after collision with oil tanker in Failand	Oil tanker collides with cyclist, killing cyclist	Flammable Liquid	Yes	No	Non built-up, non motorway	Yes	66
2013	Aylesbury house hit by milk tanker	An articulated milk tanker has crashed into the side of a house in Aylesbury. there were no reported casualties and the tanker was empty at the time	None	Yes	No	Built-up	No	67

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2013	Firefighters still at scene of Aberdare tanker crash	Back wheels of tanker carrying 16000 litres of liquid petroleum gas hit service bridge bridge at Rhondda Cynon Taf and causing a small amount of damage.	Other ADR	Yes	No	Built-up	No	68
2014	Woman killed in Dumfries bypass crash	Three vehicle crash involving a fuel tanker, a Volkswagen Tiguan and a Ford Ka. One fatality.	Flammable Liquid	Yes	No	Built-up	Yes	69
2014	Van driver injured in tanker crash on A9 near Dornoch	A van driver was taken to hospital with serious injuries after his vehicle was involved in a head-on collision with a petrol tanker.	Flammable Liquid	Yes	No	Non built-up, non motorway	Yes	70
2014	M4 reopens after tanker crash in Newport's Brynglas tunnels	Lorry hit the rear of a tanker in the Brynglas tunnels in Newport. Tanker was carrying sand and there was no hazardous material involved.	Other	Yes	No	Non built-up, motorway	No	71
2014	Man dies in A595 car and tanker crash	Car driver dies after head on collision with milk tanker. Tanker driver was not injured.	Other	Yes	No	Non built-up, non motorway	Yes	72
2014	Four die in tanker crash on A44 near Aberystwyth	Two men and two women die following a collision involving a car, a van and a fuel tanker on A44 in Wales. Infant taken to hospital in a serious condition.	Flammable Liquid	Yes	No	Non built-up, non motorway	Yes	73

Date	News story title	Summary	Load	Collision	Overturn	Road type	Casualties	Ref.
2014	Man dies in Market Drayton milk tanker crash	A man died in a crash involving a milk tanker and a van on a Shropshire road. The van driver died at the scene. The milk tanker driver suffered minor injuries.	Other Liquid	Yes	No	Built-up	Yes	74

C.2 References

The ID of each reference relates to Table C-1 and Table C-2.

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C.3 Summary of news reports

2009: Motorway chaos after M6 tanker spillage

<http://www.discovermanchester.co.uk/2009/10/motorway-chaos-after-m6-tanker-spillage.html>

"Motorway chaos after M6 tanker spillage

A STRETCH of the M6 in Cheshire has been closed in both directions after a diesel and bitumen spillage.

The M6, one of the country's busiest motorways, was shut shortly after 1.30am on Tuesday after a tanker lost its load across the north and south carriageways between junction 18, Holmes Chapel, and 19 at Tabley. [...]"

2009 - Bridge reopens after diesel spill

http://news.bbc.co.uk/1/hi/wales/north_west/8378123.stm

"Bridge reopens after diesel spill

One of the two crossings over to the island of Anglesey has reopened after being closed following a diesel spill from a tanker. [...]"

A spokesman for the agency said the leak began whilst the lorry was crossing the bridge, and an estimated 350 litres of fuel had escaped. [...]"

2010 – Lorry accident in Harlow causes fuel slick

<http://www.harlowstar.co.uk/News/Lorry-accident-in-Harlow-causes-fuel-slick.htm>

"Lorry accident in Harlow causes fuel slick

HAZARDOUS fuel was spilt onto a Harlow road after a lorry crashed into a traffic island leaving a trail of destruction in its wake.

Motorists had to dodge 10 litres of diesel that leaked from a heavy goods vehicle onto Elizabeth Way after the crash at 4.30pm on Tuesday.

The vehicle was abandoned by the driver after causing damage to a bollard, pavement and a lamppost. [...]"

2010 - Oil tanker hit by car crashing through Malvern garden

<http://www.bbc.co.uk/news/uk-england-hereford-worcester-11717574>

"Oil tanker hit by car crashing through Malvern garden

A car has crashed into a tanker in Worcestershire spilling about 1,000 litres (219 gallons) of heating oil.

The people carrier crashed through a garden and hit an oil tanker driving along Rhydd Road, Malvern, at about 1735 GMT on Monday, fire crews said. [...]"

damage to wildlife and hedgerows."

2010 - Motorway section shut after gas tanker overturns

<http://www.bbc.co.uk/news/uk-12032219>

"Motorway section shut after gas tanker overturns

The M25 was closed in both directions on Sunday morning between junctions five and six, causing long delays, after a liquid petroleum gas tanker overturned at 0900 GMT.

The section was reopened at around 1600 GMT, seven hours after the accident occurred. [...]"

2011 - Tanker spill causes A14 closure in Cambridgeshire

<http://www.bbc.co.uk/news/uk-england-cambridgeshire-12252446>

"Tanker spill causes A14 closure in Cambridgeshire

The A14 in Cambridgeshire is expected to be closed in both directions for up to seven hours because a tanker is leaking its load of ethanol.

The tanker crashed with a lorry on the Spittalls roundabout at Huntingdon at about 1230 GMT.

Cambridgeshire Fire and Rescue Service says it has set up a 200m (656ft) exclusion zone for public safety. [...]"

2011 - Kerosene spilled in tanker crash in East Meon

<http://www.bbc.co.uk/news/uk-england-hampshire-12355362>

"Kerosene spilled in tanker crash in East Meon

A tanker has overturned, spilling up to 2,000 litres of heating oil on a Non built-up, non motorway road in Hampshire.

Police and fire and rescue crews were called to Coombe Road near East Meon after the tanker ended up on its side shortly before 1000 GMT. [...]"

Hampshire Police said the driver of the tanker was unhurt. [...]"

2011 - Strathaven road closed after tanker overturns

<http://www.bbc.co.uk/news/uk-scotland-glasgow-west-13126442>

"Strathaven road closed after tanker overturns

Emergency services have "stabilised" a tanker which overturned during a delivery in South Lanarkshire, spilling some of its 35,000 litres of gas oil.

The tanker came to rest on its side in a field, on the B743 near Strathaven, just before 0630 BST.

The driver was treated for shock and minor injuries and the road is expected to remain closed for some time. [...]"

Strathclyde Fire and Rescue said about 150 litres of gas oil had escaped from six relief valves on top of the tanker. [...]"

2011 - Bleach and oil spill closes road into Northampton

<http://www.bbc.co.uk/news/uk-england-northamptonshire-13774259>

“Bleach and oil spill closes road into Northampton

A chemical spill caused by a lorry crash has closed the A45 near Northampton in both directions.

The vehicle crossed through the central reservation and overturned between Kislingbury and Harpole at 0100 BST. [...]

2011 – Diesel spill closes M3 during rush hour

<http://www.gethampshire.co.uk/news/local-news/diesel-spill-closes-m3-during-5350035>

“Diesel spill closes M3 during rush hour

DRIVERS experienced major delays after a busy stretch of motorway was closed on Thursday morning.

Police were on the northbound carriageway of the M3 between junctions 6 at Basingstoke and 5 at Hook following a collision in which a fuel tanker spilt around 500 litres of diesel.

The incident happened just before 8.30am and involved an articulated lorry, a van and a car.

The tanker driver was left shaken but no one was seriously injured. [...]

2011 – M6 reopens near Preston after tanker spillage

<http://www.bbc.co.uk/news/uk-england-lancashire-15537971>

“M6 reopens near Preston after tanker spillage

A stretch of the M6 has reopened in Lancashire after a tanker spilled 15 tonnes of a flammable substance on to the carriageway.

The spillage happened on the northbound carriageway near junction 31 at Preston at about 10:20 GMT on Tuesday.

Waste solvent cascaded for several hundred metres across the carriageway as the tanker drove uphill. [...]

Police said the driver of the tanker was taken to hospital after inhaling fumes from the substance. [...]

2012 - Exclusion zone set up after tanker driver dies in Crook of Devon crash

<http://www.thecourier.co.uk/news/exclusion-zone-set-up-after-tanker-driver-dies-in-crook-of-devon-crash-1.49714>

“Exclusion zone set up after tanker driver dies in Crook of Devon crash

The driver of a lorry carrying aviation fuel has been killed in an accident in Kinross-shire, sparking a major emergency response.

A Mercedes Sprinter van was involved in a collision with an oil tanker on the A977 at Crook of Devon at 4.30pm on Monday. The oil tanker trailer ended up on its side while the cab broke free, coming to rest in a nearby field.

Emergency services rushed to the scene as fuel spilled from the tanker, with Tayside Fire and Rescue setting up an exclusion zone.

The tanker was believed to have been carrying highly flammable aviation fuel, prompting emergency services to treat the accident as a "major incident".

Emergency vehicles stayed at the A977 Main Street at Crook of Devon throughout the night in preparation for the worst-case scenario, should the fuel have ignited.

Extricating casualties was a long and drawn-out process. The Mercedes driver was taken by ambulance to Queen Margaret Hospital in Dunfermline having suffered only minor injuries.

Sadly, the driver of the oil tanker was pronounced dead at the scene. [...]

Tayside Police said the eastbound van collided with the westbound tanker, resulting in the tank being thrown on to its side. Due to the hazardous nature of the spill, crash investigators were joined at the scene by teams from the Scottish Environment Protection Agency and the Vehicle and Operator Services Agency. [...]

The A977, though a relatively minor route, has become a thoroughfare for large vehicles travelling between the Clackmannanshire and Kincardine bridges and the M90. There have long been safety concerns about the road's suitability for heavy traffic. [...]"

2012 - A483 Llandeilo road closed after diesel spill at Ffairfach

<http://www.bbc.co.uk/news/uk-wales-south-west-wales-16949948>

"A483 Llandeilo road closed after diesel spill at Ffairfach

A road in Carmarthenshire is closed in both directions after a fuel tanker crash caused a 2,000-litre diesel spillage, say emergency services.

Mid and West Wales Fire and Rescue Service said it was called to the A483 at Ffairfach, Llandeilo, at 12:33 GMT.

An environmental protection unit helped secure the lorry's diesel tank, while the Environment Agency was dealing with the spillage. [...]"

2012 - A34 shut after tanker spills diesel

<http://www.bbc.co.uk/news/uk-england-oxfordshire-17148038>

"A34 shut after tanker spills diesel

A dual carriageway in Oxfordshire was closed for about 12 hours after a tanker spilled 50 litres of diesel on to the road. [...]

The carriageway had to be resurfaced following the spillage. [...]"

2012 - Bristol road closed after tanker fuel leak

<http://www.bbc.co.uk/news/uk-england-bristol-18267238>

"Bristol road closed after tanker fuel leak

A road has been closed after a "significant amount" of aviation fuel leaked from a tanker lorry in Bristol, the fire service has said.

The fuel is thought to have entered a drain, but there is no evidence it has entered the water course.

The incident happened in Hallen Road at about 06:20 BST.

A South Gloucestershire Council spokeswoman said they would be carrying out emergency repairs to the road surface on Thursday. [...]"

2012 - Tanker spillage clean-up in Kirkharle will take weeks

<http://www.bbc.co.uk/news/uk-england-tyne-18517229>

"Tanker spillage clean-up in Kirkharle will take weeks

The clean-up of 27,000 litres of aviation fuel spilt in Northumberland is expected to take several weeks, according to the Environment Agency.

The A696 near Kirkharle was closed for more than 30 hours after a tanker overturned into a ditch on Monday. [...]"

Lynn Charlton, who farms the land that is now being drained, said the road had a "notorious bend" which had been the site of a number of crashes."

2012 - A48 SDR in Newport closed after tanker overturns

<http://www.bbc.co.uk/news/uk-wales-south-east-wales-18951371>

"A48 SDR in Newport closed after tanker overturns

A lorry carrying waste oil has overturned on the A48 Southern Distributor Road in Newport.

South Wales Fire Service sent 14 appliances to the scene just before 07:50 BST on Monday after first reports suggested the vehicle was on fire.

The Environment Agency, Gwent Police and the ambulance service also attended. The driver escaped unharmed.

Police say the overturned tanker has now been moved and the road has reopened.

Oil was transferred from the stricken lorry to another vehicle. [...]"

2013 - Fuel tanker jack-knives on A38 leaking diesel on to road

<http://www.bbc.co.uk/news/uk-england-cornwall-20721627>

"Fuel tanker jack-knives on A38 leaking diesel on to road

A fuel tanker has jack-knifed and is leaking up to 38,000 litres of diesel on the A38 in Cornwall, the fire service has said.

The fuel tanker became detached from the cab at 18:55 GMT at Tideford.

The Environment Agency said it was a "potentially serious incident" and there was concern about a watercourse.

About 18 firefighters are at the scene and the A38 has been closed by Devon and Cornwall Police. It is not yet known if anyone is injured."

2013 - Road closed after tanker accident

<http://news.uk.msn.com/uk/road-closed-after-tanker-accident>

"Road closed after tanker accident

One of the main road routes in and out of Cornwall is likely to remain partially closed for much of Friday after a fuel tanker shed its load on Thursday night.

Police were called to the A38 near Tideford, between Saltash and Liskeard, shortly before 7pm after the tanker, which was being towed at the time, slipped and hit the road.

Around 4,000 litres of unleaded petrol was said to have leaked from the fractured container as workers toiled through the night to prevent any major pollution to the River Tidy, which runs through the village of Tideford, and connects with the Tamar separating Devon and Cornwall. [...]"

2013 - A14 reopened after tanker crash

<http://www.bbc.co.uk/news/uk-england-20969530>

"A14 reopened after tanker crash

An overturned fuel tanker caused part of the A14 in Cambridgeshire to be closed in both A 12-mile stretch of the A14 has been reopened nearly 12 hours after a chemical tanker overturned.

Up to 38,000 litres of ethanol leaked on to the road when the crash happened close to Junction 15 near Keyston, Cambridgeshire, at about 06:30 GMT. [...]"

The driver, a man in his 40s, was taken to hospital after suffering head injuries in the accident.

Cambridgeshire Fire and Rescue Service said 40 people helped to clear up the spill, with the Environment Agency trying to stop the flammable liquid seeping into drains.

A spokesman said a "significant amount" of the substance had flowed into the drains, but luckily it could be easily diluted with water."

2013 - Diesel spillage at Sandwich after oil tanker crash

<http://www.bbc.co.uk/news/uk-england-kent-21128591>

"Diesel spillage at Sandwich after oil tanker crash

A fuel tanker carrying 13,000 litres of red diesel has overturned on an icy road and ended up in a ditch in Kent.

Police, fire teams and the Environment Agency were called to the incident in Richborough Road, Sandwich, at about 11:50 GMT.

Sandbags have been used to block off a stream that runs through the ditch and to contain the oil if it all spills, an Environment Agency spokeswoman said. [...]

The tanker driver was unhurt in the crash, she said.

Environment Agency officer Jon Griffin tweeted that the tank had not spilt but the pressure of the oil in the valves had caused it to leak into the watercourse. [...]"

2013 - 'Biggest chemical spill' closes M62 in East Yorkshire

<http://www.bbc.co.uk/news/uk-england-humber-21397306>

"'Biggest chemical spill' closes M62 in East Yorkshire

Part of the M62 motorway in East Yorkshire was closed for a second night because of a chemical spillage.

A tanker overturned on Friday evening between junction 34 near Selby and junction 35 near Goole.

A 300m (980ft) cordon was put in place around the scene, which the fire service said was the "biggest chemical spill in the region for a decade".

The Highways Agency said the tanker was leaking a "toxic and flammable chemical". The road has now reopened.

It said 80 firefighters from nine stations were involved in the operation. [...]"

2013 – M62 in West Yorkshire closed following tanker crash

<http://www.bbc.co.uk/news/uk-england-leeds-22571322>

"M62 in West Yorkshire closed following tanker crash

A lorry driver has been airlifted to hospital after a crash between his vehicle and a tanker that closed the M62 motorway.

The crash happened on the eastbound carriageway just before 13:00 BST between junctions 26 and 27 near Birstall, West Yorkshire. [...]

West Yorkshire Fire Service said a large goods vehicle had run into the back of a chemical tanker.

Flammable liquid

Mick Smith, from the fire service, said the driver of the lorry had leg injuries and was rescued by up to 20 firefighters.

A cordon was put up at one point after a small leak of flammable liquid from the tanker. [...]"

2013 - Haverfordwest petrol spill clean-up after tanker crash

<http://www.bbc.co.uk/news/uk-wales-south-west-wales-23722353>

"Haverfordwest petrol spill clean-up after tanker crash

A clean-up operation has been taking place after a petrol tanker was ruptured when it was in a collision with a crane in Pembrokeshire.

No-one was hurt in the crash on the A4076 at Haverfordwest on Friday morning but a substantial amount of fuel has spilled into the road. [...]"

2014 – Tanker spills 1,000 litres of petrol at services

http://www.romseyadvertiser.co.uk/news/basingstoke/11317483.Tanker_spills_1_000_litres_of_petrol_at_services/

"Tanker spills 1,000 litres of petrol at services

A THOUSAND litres of petrol spilled out of a tanker last night after it was hit by a lorry.

Fire crews from Basingstoke, Winchester and Newbury were called to the Tot Hill services on the A34 at 6.30pm last night to clear the spillage.

Crew manager Ewen Ross, from Basingstoke fire station, said: "The petrol tanker was delivering fuel to the services and another lorry clipped the back of the tanker and cracked it. There was 1,000 litres of petrol spilled. [...]"