Frequencies of Oil Spills during Transfer between Ship and Shore

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This paper presents an estimate of the frequency of oil spills during cargo transfer to/from oil tankers in ports. This new estimate is needed because published transfer spill frequencies are based on data collected in the 1980s. Transfer practices have improved since then, so the existing values may result in over-estimation of the risks.

The new frequency is based on spill reports from crude oil and oil product tankers world-wide during 1992-2010. The analysis only uses spills over 1 tonne, because smaller spills are incompletely reported. It also looks at trends to help predict current frequencies. The results are expressed as a frequency-spill size distribution for individual transfer operations.

The new frequency is much lower than previous estimates. The paper evaluates whether this change is consistent with historical trends, to help decide whether it is a realistic estimate of current risks. It also considers relative frequencies in different geographical regions, which may indicate possible under-reporting. Finally, it highlights factors that may cause individual operations to differ from the average.

Key words: Risk analysis; oil spills; oil tankers; ports; leak frequencies

Introduction

Loading or unloading an oil tanker in port involves the transfer of thousands of tonnes of flammable liquids through hoses or articulated arms linking the ship to the onshore storage facility. Leaks during this transfer operation may result in spills into the marine environment, which may be difficult or expensive to clean up. There is also the possibility of fire, explosion or toxic impacts on workers and even, in extreme cases, members of the public. In sensitive environments, oil spills during transfer can adversely affect the reputation and profitability of the companies involved.

To manage these risks, companies need to understand the frequency (or likelihood) of oil spills during transfer. Most operators have had little or no experience of spills, and therefore rely on industry-wide average leak frequencies. Alternatively, the frequency can be estimated through expert judgement or predictive techniques such as fault tree analysis. But these techniques require calibration against actual experience. Therefore, any risk analysis of an oil transfer operation needs an estimate of the frequency of spills drawn from industry-wide historical experience.

The most commonly used sources of transfer spill frequencies for oil tankers in ports are:

- Failure rate and event data for use within risk assessments (HSE 2012).
- Reference Manual BEVI (RIVM 2009).

These sources might appear to be reasonably up-to-date and supported by knowledgeable government authorities. In reality they are derived from data collected in the 1980s or even earlier. They have not changed in more than 30 years since they were first proposed.

For example, the failure rates for articulated arms published by HSE (2012) are judgemental adjustments of a study performed by the author, whose results were published by ACDS (1991). The frequencies were based on spills reported to HSE during 1981-86, combined with an estimate of cargoes transferred. The frequency for arms was derived from one leak of liquefied gas. Thus, the frequency reflects experience in the 1980s, and was extremely uncertain when first proposed. Subsequent adjustments have tended to conceal this.

The sources of the values published by RIVM (2009) have proved difficult to trace. The rupture frequencies are derived from the COVO study (Rijnmond Public Authority 1982), which refers to older studies during the 1970s. No specific dataset has been identified, and it is likely that they are based on judgemental adoption of values from other industries from the 1960s or perhaps earlier.

Since these values were first proposed, transfer equipment and safety management practices have improved. Millions of oil cargoes have been safely transferred, and occasional spills have occurred. To date, no-one has made any systematic analysis of this experience. As a result, the industry still bases its safety management on data collected more than 30 years ago, and on judgements made by persons unknown.

This paper attempts to develop better estimates of transfer spill frequencies, based on documented data. It focusses on transfers of crude oil and liquid oil products.

Oil Transfer Spill Data

Data Source

The tanker industry is very competitive, and operators suffer significant reputation damage each time a spill occurs. As a result, they tend to keep spill reports confidential. Nevertheless, organisations that are involved in managing maritime safety find such information useful, and so some reports do reach the public domain. This paper relies exclusively on these reports.

DNV GL has used the following main sources:

- IHS (formerly Lloyd's Register Fairplay, LRF) Casualty Database.
- Lloyd's Casualty Reports (LCR).
- Center for Tankship Excellence (CTX) database.
- Major Hazard Incident Data Service (MHIDAS) database.
- International Oil Pollution Compensation Funds (IOPCF) annual reports.

Searchable sources used generic terms such as "tanker" and "spill", followed by manual selection of transfer spills, because the term "transfer spill" is not standardised, and so the events can be described in many different ways.

The data collection only used incidents involving a known ship/location and date, so that duplicate reports could be combined.

The International Tanker Owners Pollution Federation (ITOPF) maintains a database of oil spills from tankers, covering not only published sources, but also information from vessel owners, insurers and ITOPF staff. It publishes summary statistics (e.g. ITOPF 2018), but these do not give current transfer spill frequencies, and the individual spills are confidential and so cannot be combined with DNV GL's data.

Data Selection

Events that are relevant for oil transfer operations were selected using the following criteria:

- Spills of crude oil or liquid petroleum products. Liquefied gases were excluded as DNV GL is analysing them separately. Chemicals and vegetable oils were excluded as there is no useful data on the number of transfers.
- Spills of bulk cargo. Spills of bunker fuel oil, lubricating oil and waste oil were excluded as they are not consistently recorded and there is no data on the number of transfers.
- Spills from seagoing tankers. Tank barges and harbour tankers below 100 gross tonnage (GT) were excluded as there is no useful population data for them.
- Spills occurring in ports or at single-buoy moorings near-shore. Crude oil loading at offshore installations and ship-to-ship transfers were excluded, as they involve different hazards.
- Spills associated with transfer operations. This included spills associated with connection/disconnection and overflow of the ship's tanks.
- Spills originating from transfer equipment (arms or hoses), on-board piping (manifolds, pipes, valves, fittings etc) or tank vents (due to overflow). This excluded leaks from onshore tanks, fixed pipelines, transfer pumps and vessel storage tanks (unless due to overflow).
- Spills exceeding 1 tonne. This referred to the quantity of oil released to the marine environment or burned in a fire. Smaller spills were excluded as they were incompletely reported. Oil contained on board the vessel (e.g. by deck scuppers or in pump rooms) was also excluded from the data, unless burned in a fire.
- Spills occurring between 1992 and 2010 (arbitrary dates corresponding to readily available data sources).

Transfer Spills

To illustrate the data collection, Table 1 shows the 18 largest spills, all exceeding 100 tonnes. Even among these relatively large spills, there is a lack of information about the cause of the event, and hence some uncertainty about whether they are properly within the scope defined above. Nevertheless, since 72% of the spills occurred in the first half of the data period, the table clearly shows an improving trend.

Table 1 Transfer Spills Over 100 tonnes, 1992-2010

DATE	SHIP NAME	SPILL (tonnes)	EVENT DESCRIPTION	LOCATION
12 Oct 92	Presidente Arturo Umberto Illia	600	Crude oil spill due to tanker's bow rupturing hose during unloading	Puerto Belgrano, Argentina
19 May 93	Prime Trader	113	Overflow of fuel oil from ship's holding tank due to misaligned valve while discharging	Jacksonville, USA
11 Apr 94	Endeavor II	600	Crude oil leak through sea valve below waterline during unloading	Sao Sebastiao, Brazil
21 Apr 94	Alva Sea	250	Fuel oil leak from shore valve followed by rupture of hose	Cristobal, Panama
22 Jul 95	Jahre Spray	270	Crude oil spill when storm blew vessel off dock and ruptured hoses	Philadelphia, USA
8 Mar 96	Bunga Kesuma	780	Crude oil spill due to shore hose burst during loading	Bintulu, Malaysia
9 Aug 96	Kriti Sea	300	Crude oil spill due to "pipe failure" caused by loose moorings in thunderstorm while unloading	Corinth, Greece
30 Oct 96	Once	135	Crude oil spill while unloading at SBM	Gulf of Thailand
16 Jan 97	Campo Duran	150	Fuel oil spill due to valve left open	Buenos Aires, Argentina
31 Dec 97	Ocean Success	300	Crude oil spill due to valve failure while loading	Zhanjiang, China
13 May 99	Unknown	355	Oil spill while loading - no details	Baja California, Mexico
28 Jun 99	Chanda	233	Crude oil spill due to breakaway coupling failure on floating hose	Port Stanvac, Australia
3 Aug 99	Laura D'Amato	300	Crude oil leak through open sea valves during discharge (possibly sabotage)	Sydney, Australia
26 Sep 01	Averity	162	Diesel oil spill during loading in dock due to valve error	Stanlow, UK
21 Nov 04	Good Hope	1000	Crude oil spill during loading - no details	Alexandria, Egypt
25 Dec 07	Presidente Arturo Umberto Illia	216	Pipe fault while loading at SBM contaminated discharged ballast	Comodoro Rivadavia, Argentina
18 Jan 08	Minerva Helen	200	Oil spill due to defect	Copenhagen, Denmark
29 Jul 08	Pantelis	280	SBM hose detached while loading	Skikida, Algeria

Table 2 Transfer Spills, 1992-2010

SHIP TYPE	SPILL SIZE (tonnes)			TOTAL
	1-10	10-100	>100	≥1 tonne
Crude oil tankers	24	13	12	49
Oil product tankers	42	13	6	61
Oil/chemical tankers	3	1		4
Chemical tankers	6	1		7
Total	75	28	18	121

Table 2 shows the overall numbers of spills in the dataset. There were 121 spills, 40% of which were on crude oil tankers and 50% on oil product tankers. Most spills were small, with 62% in the range 1-10 tonnes, 23% in the range 10-100 tonnes and 15% over 100 tonnes.

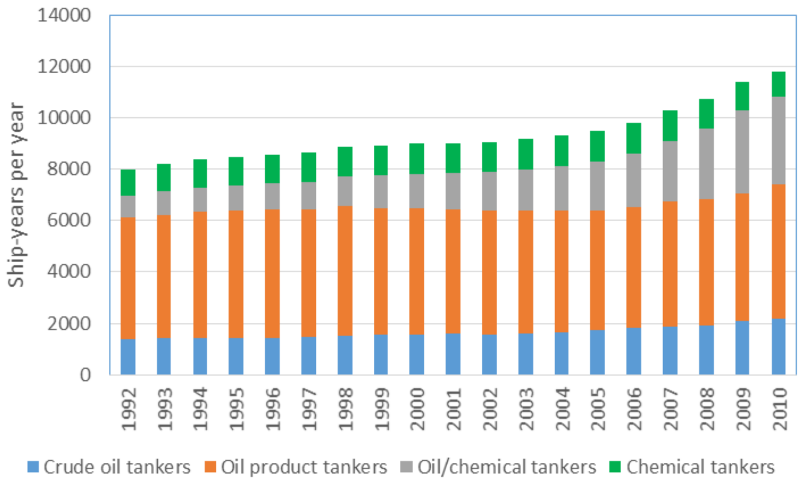
Spill Frequency Estimate

Activity Data

Each loading or unloading of an oil cargo has the potential to cause a transfer spill. To set the number of spills in context, they should therefore be compared to the number of transfers carried out.

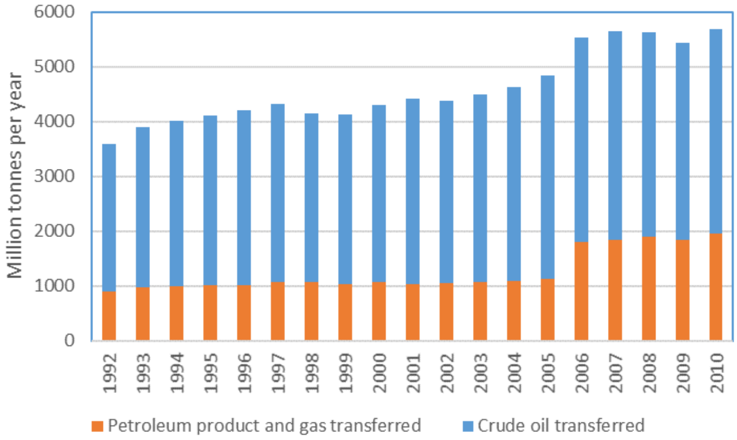
According to the IHS Fleet Database, there were on average 6600 oil tankers in the world-wide fleet during 1992-2010, plus a further 2800 chemical and oil/chemical tankers, which sometimes carry oil cargoes. The fleet increased by almost 50% during the period, although most of the increase was in oil/chemical tankers (see Figure 1) and the crude oil and oil product tanker fleet grew by only 20%. The contribution of chemical and oil/chemical tankers is omitted below to simplify the analysis.

Figure 1 Oil Tanker Fleet Growth



The United Nations Conference on Trade and Development (UNCTAD 2017) gives the world total annual tonnage of crude oil and petroleum products loaded and unloaded for seaborne trade. Figure 2 combines the cargo loaded and unloaded to estimate the total quantity transferred. The average during 1992-2010 was 4.6 billion tonnes per year, and the annual quantity grew 59% during this period. The increase in 2006 followed a change in the UNCTAD methodology, so these results may not be fully reliable.

Figure 2 Word Oil Cargo Growth



To estimate the number of cargoes transferred, two possible ways are considered:

- Assuming an average number of transfers per ship year and multiplying by the tanker fleet in Figure 1. This is difficult because tanker activity is not well documented, and there is uncertainty about the proportion of the world fleet that is active or laid up.
- Assuming an average cargo size and dividing into the world oil cargo in Figure 2. This is difficult because, although tanker sizes are documented, there is uncertainty about the average proportion of vessel cargo that is transferred.

Table 3 makes some simple assumptions about the tanker activity and average cargo size, which allow consistent estimates of the number of transfers by both approaches. This table excludes approximately 0.3 billion tonnes per year of liquefied gas and oil carried in other ship types, which was included in the UNCTAD data above.

Table 3 World Oil Transfer Estimate, 1992-2010

SHIP TYPE	WORLD FLEET (ships)	AVERAGE TRANSFERS (per ship year)	TOTAL TRANSFERS (per year)	AVERAGE CARGO (tonnes)	TOTAL CARGO (million tonnes of oil per year)
Crude oil tankers	1,640	20	32,800	100,000	3,280
Oil product tankers	4,884	40	195,380	5,000	977
Total	6,524	35	228,180	18,700	4,257

This indicates an average number of oil cargo transfers during 1992-2010 of approximately 228,000 per year. If this activity followed the fleet growth, it would have increased by approximately 20% during the period.

Transfer Spill Frequency – Historical Average

Table 4 estimates the average transfer spill frequency over the 19-year period, combining the numbers of spills and transfers from above, for the two oil tanker types. It also shows the average (mean) spill size.

Table 4 Oil Tanker Transfer Spill Frequencies, World-wide, 1992-2010

SHIP TYPE	TRANSFERS (per year)	SPILLS 1992-2010	SPILL FREQUENCY (per transfer)	AVERAGE SPILL (tonnes)
Crude oil tankers	31,160	49	7.9E-05	111
Oil product tankers	195,380	61	1.6E-05	30
Total	228,180	110	2.5E-05	66

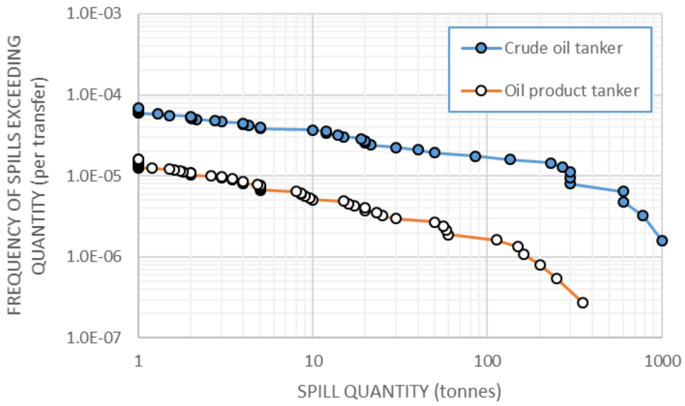
The spill frequency and average spill size are both much larger for crude oil tankers than for oil product tankers. The difference is almost a factor of 5 for frequency and a factor of 4 for spill size. A possible reason for this is that crude oil tankers are in general much larger and transfer larger cargoes. This raises the question of whether the spill frequency should be normalised by tonnes transferred instead of transfer operations. This could be addressed in future work.

Spill Size Distributions

Figure 3 shows the spill frequency-quantity (FQ) distributions for crude oil and oil product tankers. This shows the frequencies of spills exceeding the stated quantity. Exceedance distributions are able to obtain smooth distributions from scattered data. The data points have been joined by straight lines, which provides a way of estimating the frequency of spill sizes that are not recorded in the data. The left-hand end of each curve corresponds to the frequency of spills exceeding 1 tonne, as shown in Table 4.

These distributions show no significant convexity over most of the spill size range (1-100 tonnes). This is interesting because it is a typical feature of comprehensively reported datasets.

Figure 3 Oil Tanker Transfer Spill Frequency-Quantity Distributions, 1992-2010

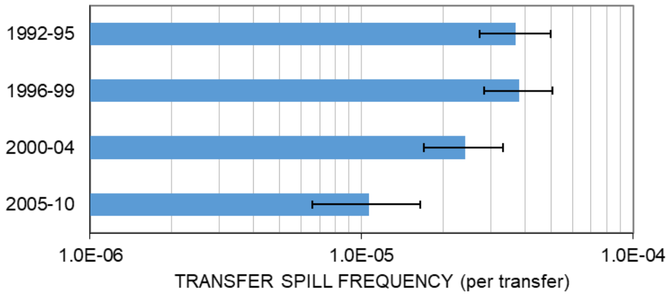


Frequency Trend

Most of the spills occurred before 2000. The oil tanker fleet has grown somewhat since then. Hence a downward trend in frequency is expected.

Figure 4 shows the breakdown of spill frequency by half-decade, including 90% confidence ranges that reflect uncertainty due to the small numbers of events.

Figure 4 Oil Tanker Transfer Spill Frequency Trend



There is a significant downward trend, as expected. The frequency in the most recent available period, the late 2000s, is less than half the average value in Table 4. Perhaps more surprising is the fact that no trend was apparent during the 1990s, and all the reduction has occurred since then. This calls for some explanation.

One possibility might be that spill reporting became less comprehensive during the period. If reporting is incomplete, small spills are most likely to be omitted, simply because large spills are more likely to be noticed by reporting organisations. Therefore a higher average spill size may indicate under-reporting.

Table 5 shows the average (mean) spill sizes in each period. It is evident that the highest average spill size was in the late 1990s, so that is the period when under-reporting might be suspected.

Table 5 Oil Tanker Transfer Spill Frequency Trend

PERIOD	TRANSFERS	SPILLS	SPILL FREQUENCY (per transfer)	AVERAGE SPILL (tonnes)
1992-95	890,353	33	3.7E-05	63
1996-99	917,353	35	3.8E-05	85
2000-04	1,121,776	27	2.4E-05	49
2005-10	1,405,920	15	1.1E-05	55
Total	4,335,402	110	2.5E-05	66

While these results cannot exclude the possibility of under-reporting in the data, they do suggest that this was not the cause of the recent trend.

Other possible causes, which might be investigated in future work, include:

- Tanker and port operators might have become more proactive in developing procedures and training to avoid oil spills.
- The introduction of double-hulled tankers, which reduced the frequency of major oil spills due to collision and grounding, might have redirected spill prevention efforts onto remaining causes, such as transfer spills.
- Port authorities might have adopted a more aggressive attitude to reporting and prosecuting oil spills.

Regional Distribution

Another way of exploring the data is to break it down by geographical region.

UNCTAD (2017) has published a regional breakdown of crude oil and oil products shipments since 2006. It distinguishes the following regions:

- America (developed economies), principally USA and Canada.
- America (developing economies), principally Latin America and the Caribbean.
- Europe (developed economies).
- Transition economies, principally countries of the former Soviet Union (FSU).

- Africa (all developing economies)
- Asia (developing and developed economies).
- Oceania (developing and developed economies), principally Australia and New Zealand.

In the following analysis, the values from 2006 are used, being most representative of the period 1992-2010. The tonnage shipped is converted into numbers of transfers using the average cargo sizes assumed in Table 3.

Table 6 compares the resulting distribution of cargoes with the distribution of transfer spills. Dividing the percentage of spills by the percentage of transfers gives a relative spill frequency. A relative frequency of 1 is equal to world average. Higher values indicate higher frequencies, and lower values indicate lower frequencies. The average spill size in each region is also included, together with the fraction of spills that occurred in the first half of the data period (Jan 1992 to Jun 2001). The latter is used to indicate trends in the absence of transfer data for the full period.

Table 6 Regional Breakdown of Transfer Spill Frequencies

REGION	SPILLS 1992-2010	SPILLS 1992-2010 (%)	TRANSFER OPERATIONS 2006 (%)	RELATIVE SPILL FREQUENCY	AVERAGE SPILL (tonnes)	% BY JUNE 2001
USA/Canada	14	13%	13%	0.95	40	71%
Latin America	20	18%	8%	2.14	120	80%
Europe	24	22%	28%	0.79	34	54%
FSU	11	10%	3%	3.92	8	45%
Africa	10	9%	7%	1.25	130	70%
Asia	20	18%	39%	0.46	74	75%
Oceania	11	10%	1.3%	7.56	53	91%
World total	110	100%	100%	1.00	66	69%

These results are interpreted as follows:

- For USA/Canada and Europe, the numbers of spills are broadly in proportion to the number of transfer operations, as expected. The average spill size is relatively small (40 and 34 tonnes respectively). Unusually, Europe has reported almost the same number of spills in the two halves of the data period, suggesting less of an improving trend there than elsewhere, or possibly a trend towards more complete reporting.
- Asia had 39% of transfer operations (since much of the world's oil is produced there) but only reported 18% of the spills in the dataset. This could be because the risks are lower there. However, the relatively high average spill size (74 tonnes) suggests that small spills are not as comprehensively reported there as in USA/Canada and Europe. Its relative spill frequency may therefore be under-estimated.
- Latin America and Africa also had high average spill sizes (120 and 130 tonnes), suggesting that small spills are significantly under-reported there. Their relative spill frequencies are therefore likely to be under-estimated.
- FSU had 3% of transfer operations but reported 10% of the spills in the dataset. The low average spill size (8 tonnes) suggests that small spills have been more comprehensively reported there than in any other region. This region is unique in reporting more spills in the second half of the data period, suggesting that reporting has improved relatively recently.
- Oceania, by contrast, had 1% of transfer operations but reported 10% of the spills in the dataset. This region is unusual in that 91% of the spills occurred in the first half of the data period, and it has had no spills over 1 tonne since 2001. This suggests that its reporting was more comprehensive than other regions in the 1990s, when the overall spill frequency was higher, and this is the reason why it has a high relative spill frequency.

In summary, the regional breakdown reveals more about regional reporting patterns than it does about relative risks of transfer spills. The regions that appear most affected by under-reporting (Latin America and Africa) make relatively small contributions to the world total of transfers, as do the regions that appear to have the most complete reporting (Oceania and latterly the FSU). The larger regions (Asia, Europe and USA/Canada) may suffer from under-reporting but it is less pronounced than elsewhere. Overall, the regional breakdown improves confidence that the data above gives a valid estimate of spill frequency in these regions.

Transfer Spill Frequency – Current Estimates

Table 7 presents the best-estimates of the current transfer spill frequency for the two oil tanker types. It is based on the period 2005-10. The number of spills is rather small, but this provides the best available estimate of the more recent experience. The frequencies of spills larger than 1 tonne may be estimated by combining these frequencies with the size distributions in Figure 3.

Table 7 Oil Tanker Transfer Spill Frequencies, World-wide, 2005-10

SHIP TYPE	TRANSFERS (per year)	SPILLS 2006-10	SPILL FREQUENCY (per transfer)	AVERAGE SPILL (tonnes)
Crude oil tankers	38,750	6	2.6E-05	85
Oil product tankers	195,570	9	7.7E-06	36
Total	234,320	15	1.1E-05	55

The spill frequency and average spill size are both larger for crude oil tankers than for oil product tankers, although the difference is less than it was in the overall data in Table 4. The difference is almost a factor of 3 for frequency and a factor of 2 for spill size. The decline in these factors raises the question of whether there was previously more under-reporting for crude oil tankers. This could be investigated in future work. Meanwhile, the values in Table 7 are considered the best available estimates of transfer spill frequencies.

Comparison with Previous Estimates

ACDS

Within DNV, the previous standard transfer spill frequencies were 7.6×10^{-5} per transfer in arms and 1.8×10^{-4} per transfer in hoses. These frequencies were published by ACDS (1991) and have been widely used.

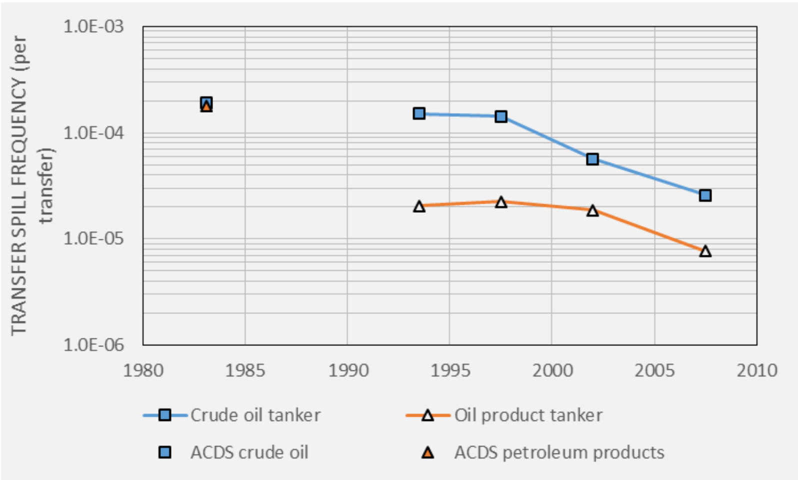
Table 8 shows the source of these values. They were estimated from transfers to/from tankers in British ports between January 1981 and March 1986. The frequencies referred to spills over 1 tonne. The cargoes transferred were estimated by a survey of all British ports. At the time it was assumed that liquefied gases were mainly transferred in arms and oil products in hoses.

Table 8 Transfer Spill Frequencies in Ports in Great Britain, 1981-86

CARGO TYPE	CARGOES TRANSFERRED 1981-86Q1	SPILLS 1981-86Q1	SPILL FREQUENCY (per transfer)
Crude oil	10,500	2	1.9×10^{-4}
Petroleum products (low-flash only)	27,300	5	1.8×10^{-4}
Chemicals (low-flash only)	6,300	1	1.5×10^{-4}
Liquefied gas	13,125	1	7.6×10^{-5}

Figure 5 compares the ACDS values with the new frequencies, each plotted on the mid-point of the data collection periods. While the new frequencies are a factor of 7 lower for crude oil and 23 lower for oil products, it is apparent that their trend is broadly consistent with the ACDS data, bearing in mind how old it is and the fact that it was collected in Britain, whereas the new frequencies are based on world-wide data. In future work, a longer trend and perhaps UK-specific data would be desirable to clarify this.

Figure 5 Comparison of ACDS and New Oil Tanker Transfer Spill Frequencies



HSE FRED

In the UK, the standard source of transfer spill frequencies is the publication "Failure rate and event data" (FRED) published by the HSE (2012). For cases where two hard-arms are used (assumed to be typical for oil tanker transfers), this gives the failure frequencies shown in Table 9. No frequency is given for marine hoses.

Table 9 HSE FRED Failure Frequencies for Transfer through Two Hard Arms

FAILURE TYPE	FAILURE FREQUENCY (per transfer)
Guillotine break of both arms	2.6×10^{-5}
Guillotine break of one arm	2.4×10^{-5}
Leak through hole 10% of the pipe cross sectional area	6.6×10^{-5}
Total	1.2×10^{-4}

The source of these values was a judgemental modification of a model based on the ACDS data above. The model resulted in the frequency for two arms being much higher than for one arm, even though the duration would be much shorter. No additional frequency data was available to justify these assumptions.

The new overall frequency of 1.1×10^{-5} per transfer in Table 7 is a factor of 11 lower than in FRED. This difference is consistent with the historical trend in Figure 5.

RIVM BEVI

In the Netherlands, the standard source of transfer spill frequencies is the publication Reference Manual BEVI (RIVM 2009). This gives the failure frequencies shown in Table 10.

Table 10 RIVM BEVI Failure Frequencies for Loading/Unloading

FAILURE TYPE	FREQUENCY FOR ARMS (per hour)	FREQUENCY FOR HOSES (per hour)
Rupture of arm/hose	3.0×10^{-8}	4.0×10^{-6}
Leak through hole of 10% of the pipe diameter up to 50mm	3.0×10^{-7}	4.0×10^{-5}
Total	3.3×10^{-7}	4.4×10^{-5}

The sources of these values are unclear. No specific dataset has been identified, and it is likely that the rupture frequencies are adopted from other industries in the 1960s or perhaps earlier (Spouge 2015). The frequency of smaller leaks is entirely based on a leak-to-rupture ratio assumed by the Netherlands government. There is no evidence for the factor of 130 difference between arms and hoses, or for the choice to apply the same values to road, rail and marine tankers.

To compare with the new values, it is assumed that a typical oil tanker transfer involves 2 hoses or arms and takes 12 hours. Then the frequency from the BEVI approach would be 7.9 x 10^{-6} per transfer by arms and 1.1 x 10^{-3} per transfer by hoses.

The new overall frequency of 1.1 x 10^{-5} per transfer in Table 7 is a factor of 100 lower than for hoses in the BEVI approach, but a factor of 1.4 higher than for arms. These differences are considered to result from the unsubstantiated judgements in the BEVI values.

Influencing Factors

Numerous factors might affect the likelihood of a spill during transfer in port:

- Transfer environment (e.g. whether a protected dock, a riverside berth or an offshore buoy).
- Transfer procedures.
- Safety management practices, including safety cultures in different regions.
- Operator training and experience.
- Oil type.
- Direction of transfer (whether loading or unloading).
- Quantity rate & duration of transfer.
- Use of hoses or hard arms, and the number of hoses/arms used.
- Emergency shut-down (ESD) systems.
- Ranging alarms and quick release couplings (QRC).

Any of these factors might cause individual operations to differ from the average. There is very little information on the occurrence of these factors in oil transfers world-wide, although the industry has made efforts to standardise some preventive measures. While some models attempt to represent some of the other factors, they are based almost entirely on judgement. Clearly, it would be desirable to collect data that could support a robust model of such factors. Meanwhile, the frequencies presented in this paper represent an average of all the oil transfers that take place in ports world-wide.

Conclusions

Method

Transfer spill frequencies for oil tankers in ports are available in recent government publications (e.g. HSE 2012, RIVM 2009). However, investigation of the source material reveals that they are in fact derived from data collected in the 1980s or even earlier. Since these values were first proposed, transfer equipment and safety management practices have improved. Millions of oil cargoes have been safely transferred, and occasional spills have occurred. This paper attempts to collect this experience and derive up-to-date spill frequencies from it.

The paper presents a collection of 121 transfer spills of 1 tonne or more from oil tankers, world-wide, during 1992-2010, drawn from published sources. By combining data on tanker fleets and oil cargoes, the paper also estimates the number of transfer operations world-wide in the same period. Hence it estimates the frequency of transfer spills, including the historical trend during the data period, and breaks the results down by tanker type, spill size and geographical region.

Data Quality

The use of public-domain sources inevitably raises the question of whether the collection is comprehensive, given that tanker operators have a financial incentive to keep accident reports confidential. The paper has therefore examined the data in detail, searching for characteristic indicators of under-reporting. The results are summarised as follows:

- The shape of the spill size distributions shows no signs of under-reporting, at least for spills of 1 tonne or more.
- The regional breakdown shows that some regions are significantly affected by under-reporting (notably Latin America and Africa), but these make relatively small contributions to the overall spill frequency.
- The trend in average spill size suggests that under-reporting was greatest in the late 1990s, and the downward trend in spill frequency is not due to under-reporting.

In conclusion, the dataset appears to give a valid estimate of spill frequency in the main areas of tanker activity (Asia, Europe and USA/Canada).

Despite these encouraging signs, the possibility of under-reporting is always present in public-domain data. It would therefore be desirable to validate the present results against data from internal company or individual country reports.

Transfer Frequencies

The overall frequency of spilling one tonne or more of oil when loading or unloading an oil tanker in port is estimated to be 1.1×10^{-5} per transfer operation, i.e. about 1 in 100,000 transfers.

The frequency reduced significantly during the 2000s. The frequency above is based on the period 2005-10. It would be desirable to extend the data collection to cover more recent years. At present it is not proposed to extrapolate the trend because its cause is unclear.

The spill frequency and average spill size are both much larger for crude oil tankers than for oil product tankers. The difference has reduced somewhat in more recent data, possibly due to improved reporting on crude oil tankers. Nevertheless, since crude oil tankers are in general much larger and transfer larger cargoes, future work might investigate whether the spill frequency should be normalised by tonnes transferred instead of transfer operations.

The current data provides no evidence of a different spill frequency for hoses and hard arms. Although such a difference is commonly assumed, there was no evidence in previous data for this difference. Showing such an effect would require collection of hose and arm activity.

The new frequency is much lower than most previous estimates. This paper shows that this change is consistent with historical trends, suggesting that previous estimates are simply out of date.

Uncertainties

The main sources of uncertainty in the chosen spill frequency are:

- Incomplete reporting of oil spills in the available sources.
- Inaccurate estimates of the spill quantity in the known spills.
- Inaccurate estimate of the number of transfers due to uncertainty about world-wide tanker activity.
- Uncertainty about the frequency trend during the decade since the data was collected.

In the absence of any recent independent estimate that could be used for validation, the 90% confidence range on the current frequency is judged to be a factor of 3 higher or lower.

Application to Individual Transfer Operations

The frequency presented in this paper represents an average of all the oil transfers that take place in ports world-wide. There are many factors that might cause individual operations to differ from the average. In future work, it would be desirable to collect data that could support a robust model of such factors. Meanwhile they can only be represented by judgement.

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