Fifty years of European oil pipeline safety and environmental performance statistics

For the past 50 years, Concawe has been committed to the collection and reporting of data on the performance of the European cross-country pipeline network. The results have been published annually in Concawe's oil pipeline performance report which has become a valuable tool for supporting pipeline operators, pipeline designers, regulators and industry actors in the continued management of the safety and integrity of European oil pipelines.

Authors

Members of OPMG/STF-1 annual *Performance of European cross-country oil pipelines* report

At the beginning of the 1970s, Concawe, then a young organisation less than 10 years old, launched a new activity aimed at recording loss-of-containment incidents affecting European cross-country oil pipelines, including their consequences (environmental impact, fires, injuries and/or fatalities) and the underlying causes. Data were collected by way of an annual survey covering Concawe member companies and their affiliates, as well as other European pipeline operators that agreed to participate. The information collected was transferred into a database from which a range of statistics were derived as a means of monitoring the performance of European oil pipelines over time. This activity has now been sustained for the past 50 years with publication of the results in an annual report, from the first one published in 1972 covering incidents recorded in 1971, to the latest edition covering incidents recorded up to 2020. Over the years, the *Performance of European cross-country oil pipelines* report has become one of the most noted Concawe publications, used by pipeline operators, pipeline designers, regulators and industry actors in general to shed light on the risks and potential consequences associated with oil pipeline operations, and to support the learning of lessons from past incidents.

The Concawe pipeline inventory

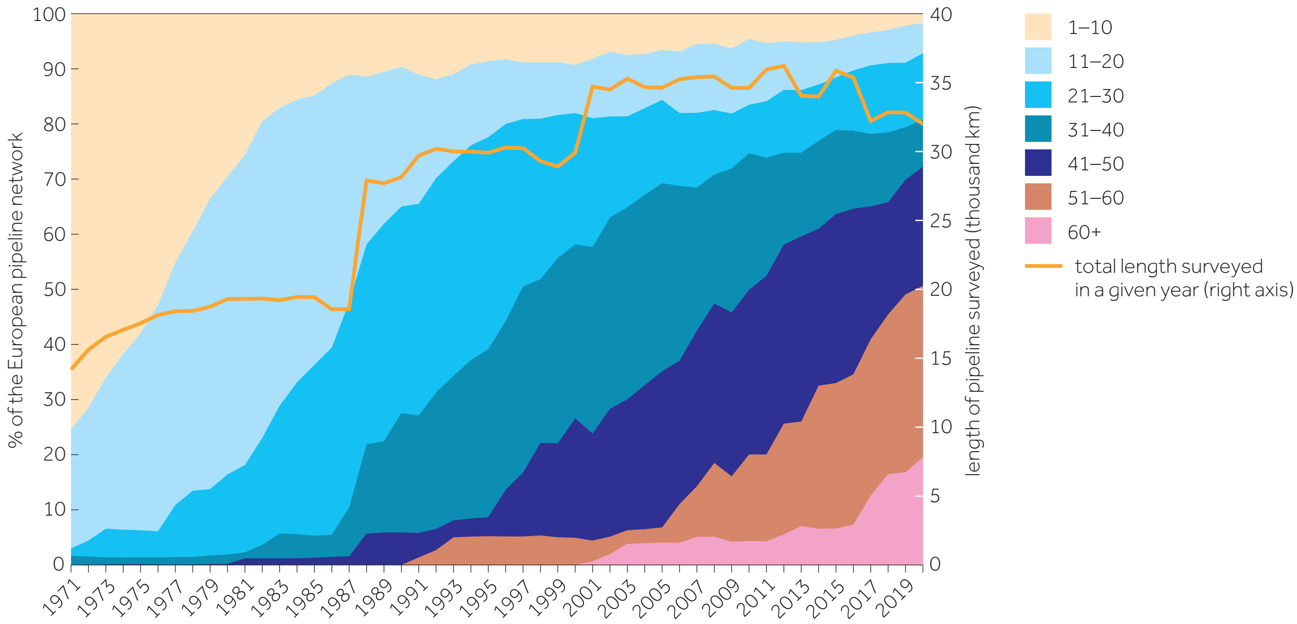
The target inventory includes pipelines used for transporting crude oil or petroleum products, with a length of 2 km or more in the public domain, running cross-country and including short estuary or river crossings but excluding undersea pipeline systems (e.g. for offshore crude oil production). Pump stations, intermediate above-ground installations and intermediate storage facilities are included, but origin and destination terminal facilities and tank farms are excluded. The minimum reportable spillage size has been set at 1 m^3 (1,000 litres) or less where exceptional safety or environmental consequences are reported.

The geographical region covered was originally consistent with Concawe's terms of reference at the time, i.e. OECD Western Europe, which then included 19 member countries, although Turkey was never covered. From 1971 to 1987, only pipelines owned by oil industry companies were included, but from 1988 non-commercially-owned pipeline systems (essentially some of the military/NATO systems) were brought into the inventory. Following the reunification of Germany, the pipelines in former East Germany (DDR) were added to the database from 1991. This was followed by Czech and Hungarian crude and product lines in 2001, Slovakian crude and product lines in 2003 and some of the Croatian crude lines in 2007. From 2013 additional Croatian crude lines were included. The larger pipeline systems that are not included in the current inventory are NATO pipelines in Denmark, Italy, Greece, Norway and Portugal, as well as all crude and product pipelines in Poland.

In 2020, the survey was targeted at 72 operators, and information was received from 68 of these. They cover a total length of nearly 35,000 km, slightly less than a third of which transport refined products, with the balance transporting crude oil. Historically, a small proportion of insulated pipelines transported hot products (mostly heavy fuel oil) but these have gradually been taken out of service as (external) corrosion under insulation was responsible for a number of pipeline failures. Today only about 50 km remain in service.

When the Concawe survey was first performed in 1971, some 70% of the pipelines in the inventory were 10 years old or less. Although the age distribution was quite wide, the oldest pipelines were in the 26–30 years age bracket and represented only a tiny fraction of the total. Over the years, new pipelines were commissioned, some were taken out of service, and existing pipelines were added to the inventory. Although some short sections may have been renewed, there has been no large-scale replacement of existing pipelines. The evolution of the overall age profile (Figure 1) shows that the network has been ageing progressively. By 2020, only 1.5% of the total was 10 years old or less while 72.3% was more than 40 years old. This has presented specific challenges for operators, which are discussed later in this article.

Figure 1: European oil pipeline historical age distribution (1971–2020)



General evolution of performance over time

The annual Concawe survey tracks a number of parameters related to events that have led to loss of containment, including fires, injuries and fatalities. Over the 50-year period, 14 fatalities have been recorded in 5 separate incidents, the latest in 1999. A total of 13 fatalities resulted from a fire in 4 of these incidents, and 1 fatality in 1999 resulted from drowning in a pit filled with product during a theft attempt. Another five incidents involved a fire but without fatalities or injuries. Only three non-fatal injuries (of which two separate events resulted from inhalation/ingestion of oil spray/aerosol) have been recorded, the latest in 2006 (third party injured).

Three single events resulted in multiple fatalities (four in 1975, five in 1979 and three in 1989) caused by delayed ignition of hydrocarbon vapours. This highlights the criticality of securing a spillage area promptly as part of the emergency response and repair procedures (including avoidance of potential ignition sources where volatile products are involved). Similar incidents have been recorded in other world regions, some with much more dramatic consequences.

The bulk of the information collected annually concerns oil spillages and includes the following:

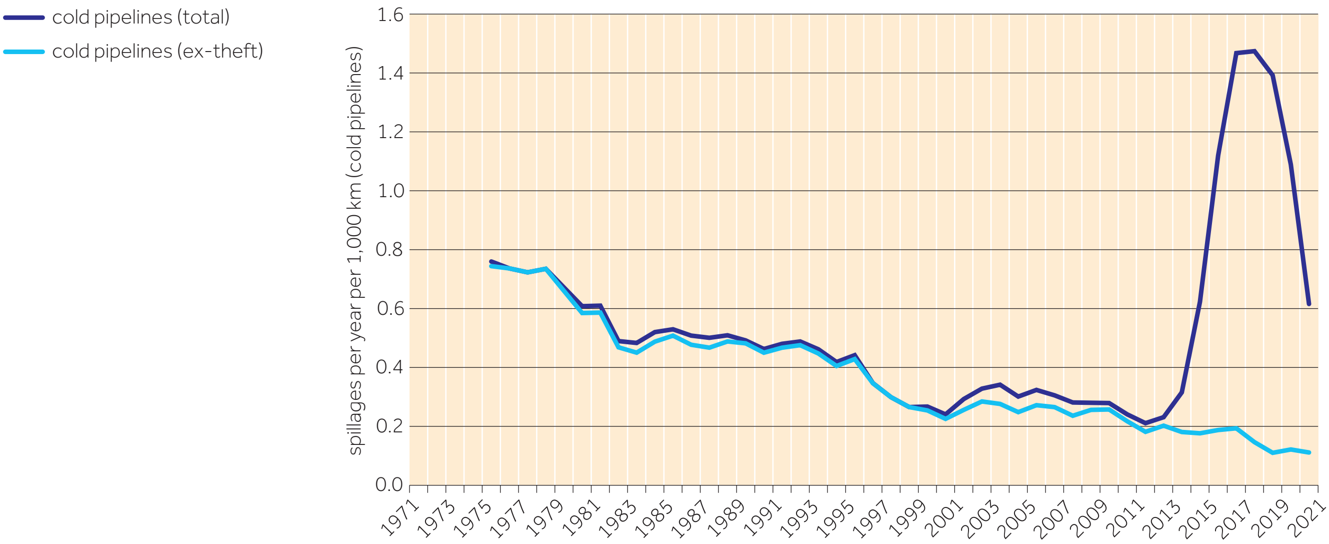
- Data related to the impact and consequences, such as the type of facility (under/overground pipe, pump station), type of area (e.g. residential, industrial, agricultural), volume spilled and recovered, ground area and contamination of water bodies.
- Information on how the leakage was discovered and dealt with.
- The cause of the spillage: causes are split into five main cause categories, namely 'Mechanical', 'Operational', 'Corrosion', 'Natural hazards' and 'Third party'. Each main cause is then divided into a number of subcategories.

Because of the changes in the inventory covered by Concawe over the years, statistical data expressed in terms of frequency (per 1,000 km of pipeline) are more informative than absolute numbers.

Number and frequency of spillages

Over the whole 50-year period 780 spillages have been reported. Two hundred and seventy-two of these were related to theft attempts, a phenomenon that, although recognised previously, has become a major issue in the past 10 years (see discussion later in the article). Another 68 events occurred in the 'hot' pipelines (54 of which were due to external corrosion). Figure 2 shows the five-year moving average of the spillage frequency for cold pipelines (i.e. not 'hot' pipelines), both including and excluding theft events.

Figure 2: 45-year trend in spillage frequency (cold pipelines, moving average)



For cold pipelines, excluding theft, spillages have followed a long-term downward trend from more than 0.7 spillages per 1,000 km in the early 1970s to 0.12 in 2020. To avoid the obvious distortion of the long-term statistics created by the recent spike in theft-related incidents, figures are presented with and without theft-related events where appropriate. Table 1 summarises the key data for cold pipelines per decade and over the full period.

Table 1: Cold pipelines exposure, number of incidents and incident frequencies (including and excluding theft)

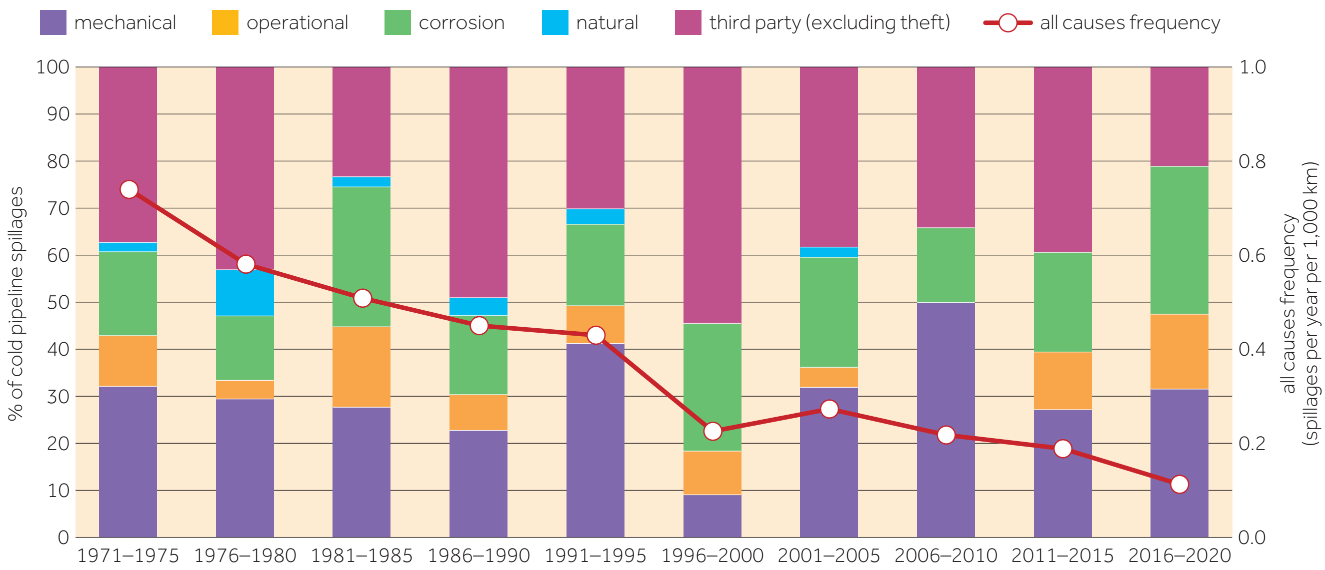
Period	Exposure (1,000 km/year)	Incidents (excluding theft)	Thefts (with spill)	Fatalities	Injuries	Failure frequency per 1,000 km/year (excluding theft)	Failure frequency per 1,000 km/year (including theft)
1971–1980	163	107	3	9		0.66	0.67
1981–1990	210	100	3	3	2	0.48	0.49
1991–2000	293	96	4	2		0.33	0.34
2001–2010	347	85	13		1	0.24	0.28
2011–2020	345	52	249			0.15	0.87
Full period 1971–2020	**1,359**	**440**	**272**	**14**	**3**	**0.32**	**0.52**

The failure frequency for hot pipelines is an order of magnitude higher as a consequence of widespread external corrosion issues. As mentioned above, the issue was recognised by the industry, and the bulk of these lines have now been closed down (or converted to cold service) and the problem has been substantially alleviated.

Causes of spillages

Figure 3 shows the evolution, in five-year periods from 1971 to 2020, of the non-theft-related spillage frequency for cold pipelines, broken down according to the five main causes listed on page 52 (440 spillages in total). The overall decreasing trend shown in Figure 3 is again apparent, albeit a more complex picture when looking at the individual cause categories.

Figure 3: Cold pipelines spillage frequencies by cause (1971–2020)



Third-party activities (excluding theft)

Third-party activities (excluding theft) have caused the largest number of spillages. There have been fewer cases in recent years, and hence the cause structure has become more balanced.

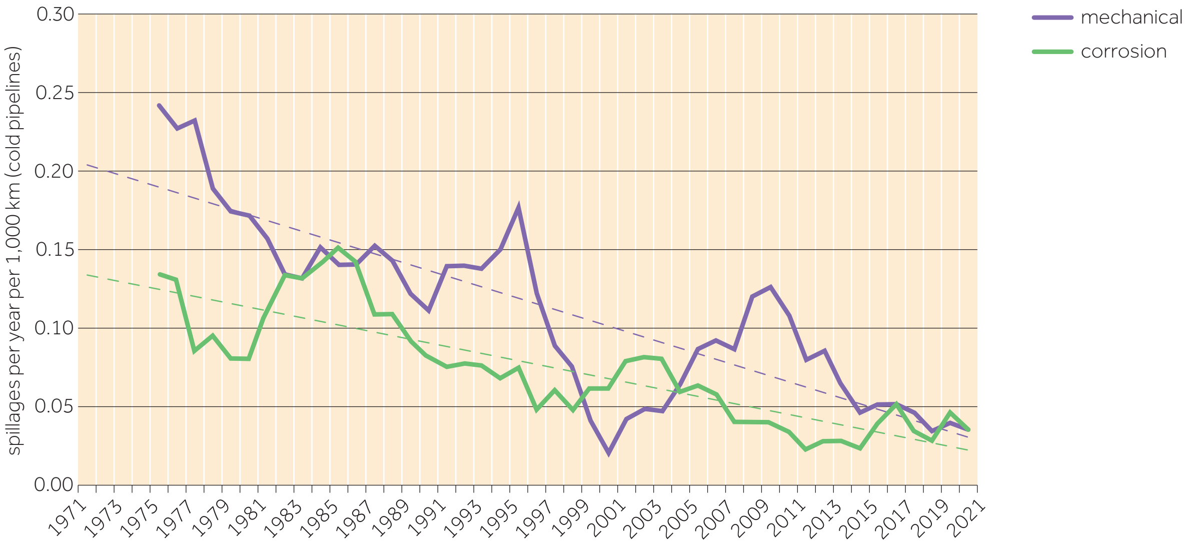
Pipelines run over long distances, predominantly below ground, and through diverse areas. As such, they are vulnerable to accidental damage caused by parties involved in digging and other earth-moving activities. This has been an issue since buried pipelines were first laid. A variety of measures have been put in place over the years, including: marking; physical protection; enhanced surveillance; regular contacts with landowners, utility organisations and civil contractors; and, in some countries, the development of so-called 'one-call systems'. The latter are specifically designed to encourage (or, in some countries, obligate) potential 'excavators' to declare their intentions in advance. These measures, although partly successful, require continual review and adaptation and, although the frequency of related incidents has followed a downward trend, accidental third-party interference remains one of the major causes of spillage for oil pipelines.

Mechanical and corrosion

The 'Mechanical' category encompasses failures due to design, material or construction defects (e.g. incorrect material, faulty weld, fatigue). The 'Corrosion' category encompasses failures that have developed from internal or external corrosion. In a small number of cases, cracking due to corrosion under stress has been included as the failure cause.

Data on the frequency of spillages in both categories show a long-term downward trend since the early 1980s, albeit with notable shorter-term peaks and troughs (Figure 4).

Figure 4: Frequency of mechanical and corrosion-related spillages for cold pipelines (five-year moving average)



Over the past two decades, operators and regulators became concerned that ageing pipelines may be increasingly prone to mechanical (e.g. fatigue) or corrosion-related failures. The spike in mechanical failures observed over the decade after the millennium caused particular concern in this respect, but the downward trend has resumed in the past ten years. A relatively high number of corrosion cases was reported in the past decade suggesting that the trend may be flatlining.

A detailed analysis of the data did not reveal any significant correlation between the incident frequency of either mechanical (fatigue-related or otherwise) or corrosion failures and the actual age of the pipeline at the time of failure.

The sophisticated integrity management and maintenance systems developed over the years, including the use of new techniques such as internal inspection with intelligent tools, have doubtless played a key role in maintaining the safe and reliable operation of pipelines and will continue to be an essential tool in the future. Concawe pipeline statistics, in particular those covering the mechanical and corrosion incidents, will continue to be used to monitor performance.

Volume spilled

The volume spilled varies a great deal from event to event, and statistics can be heavily skewed by a few very large spills that occur from time to time. Furthermore, it is not always possible to determine the spillage figures accurately, for instance when small leaks have continued for a period of time before being detected. In the majority of theft cases, the product loss is always a combination of an unknown volume of stolen fuel and product spillage.

The annual spilled volume has decreased steadily over time, mostly as a consequence of the reduced number of spills, with the average volume per spill remaining in the same ball park.

Nearly 50% of above-ground facilities, including pump stations, were detected by pipeline company resources. Underground pipeline leaks were often first detected by a third party (nearly 50%), sometimes by those who caused the incident in the first place. Dedicated automated leak detection systems were involved in detecting only 15% of those spillages over the full survey period, although this has increased gradually since the 1980s to nearly 30% in recent years as a result of the increased use of such systems and their technological improvements. Routine monitoring by pipeline operators (using pressure and flow data) and leak testing (based on pressure and temperature monitoring) when the pipeline is temporarily shut in have also played their part in detecting leaks (nearly 30% of the spillage cases). It should also be noted that the majority of leaks are small and hence reliable detection is a challenge for leak detection systems.

As a rule, a high proportion of the initially spilled product volume is recovered (on average about 60%) either as liquid or in the soil that is excavated as part of the cleaning process.

Product theft: a new threat that is being vigorously and successfully addressed

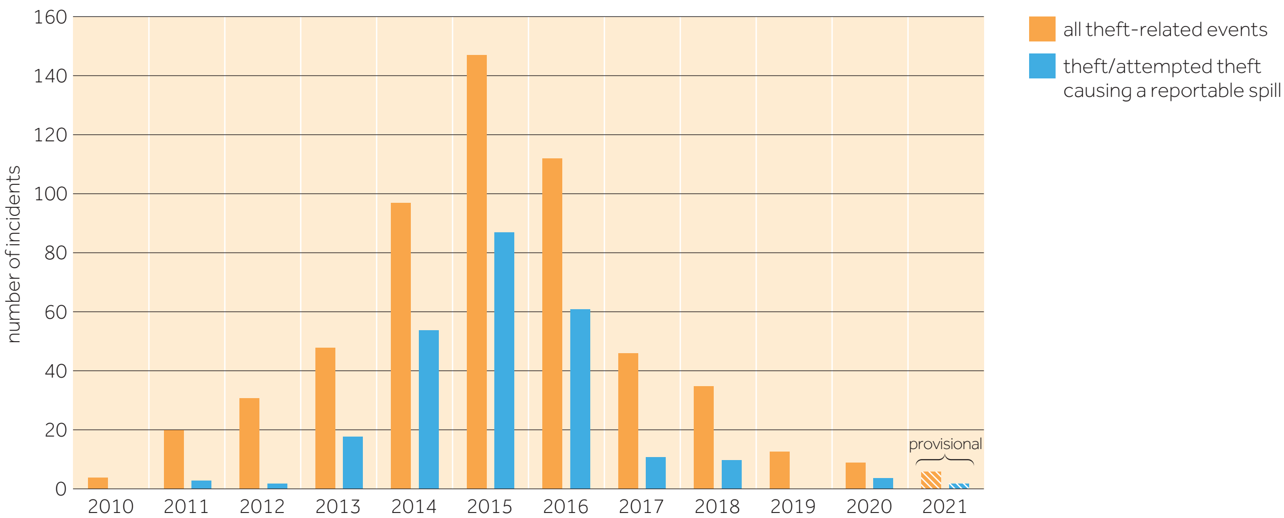
Because of the nature of their location and the fact that they transport valuable commodities, oil pipelines have always been a potential target for criminals, vandals and even terrorists. Up to the beginning of the past decade, only a few incidents involving any of the above were recorded in Europe (less than one incident per year on average), mostly related to theft attempts and geographically concentrated in South-Eastern Europe.

From 2011, there was a sharp increase in the number of theft attempts, culminating at 147 in 2015, 87 of which led to a spill. These occurred in several different countries across the continent, often with evidence of sophisticated criminal operations.

In addition to the potential loss of product and/or disturbance to operations, such interference with pipelines, which can involve drilling through the pipeline to install a small-bore connection, can also lead to serious environmental damage, and potentially injuries or even fatalities.

Faced with this serious new threat, operators reacted promptly, enhancing physical surveillance, improving leak detection system capabilities, increasing awareness of the problem with own staff, contractors and law enforcement authorities, and enhancing capability for a fast response and quick repairs. Relevant information was shared within Concawe, and good practices established and disseminated to pipeline operators. These efforts have paid off, and the trend was reversed with 112 events recorded in 2016, 46 in 2017, 35 in 2018, 13 in 2019 (with no reportable spill) and 9 in 2020 (Figure 5). Indications are that the downward trend continued in 2021 with a provisional total of six incidents and two spills. Nonetheless, the annual rate is still above the 50-year average, requiring continued focus and vigilance.

Figure 5: Theft-related events and the associated number of spills (2010–2021)



Improving pipeline integrity and mitigating failure consequences through technology

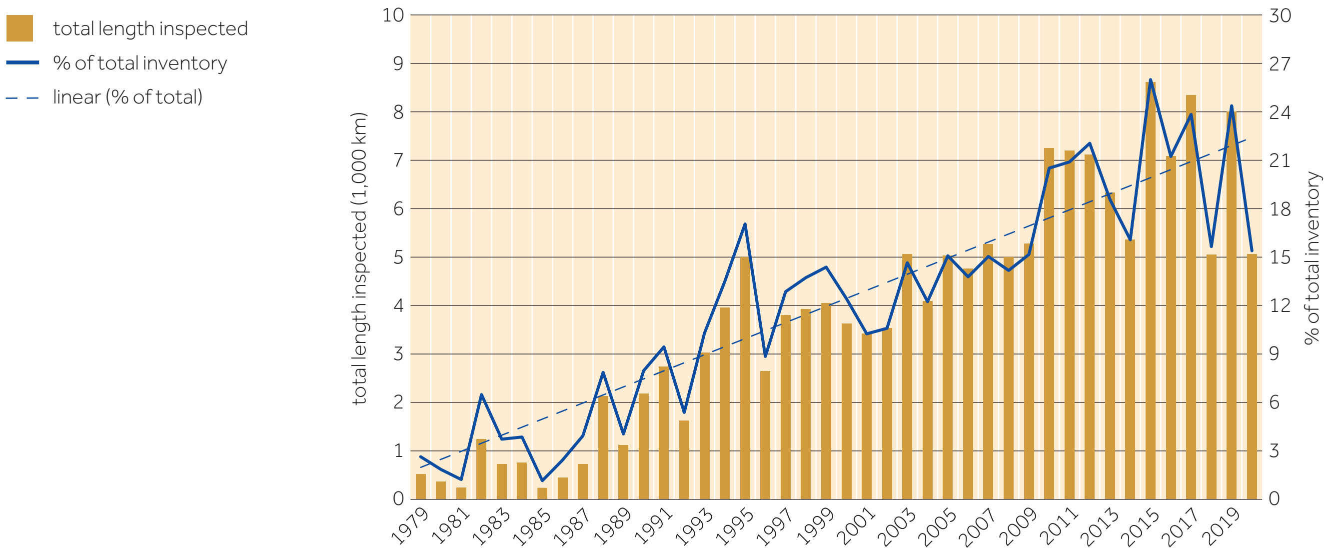
The Concawe annual performance report has supported operators in the implementation of pipeline integrity management systems, to both improve pipeline integrity and mitigate the consequences of integrity failures through technology. Typical elements of these systems include the following:

- Intelligent tools to inspect the pipelines for internal corrosion, external corrosion, cracks and dents, to provide assurance of the integrity of the pipelines and to allow planning of suitable repair strategies, for example to prevent an area of corrosion progressing to a leak and a potential spillage. These tools are referred to as metal loss tools, crack detection tools and geometry tools.
- Various techniques to monitor the pipeline coating and the effectiveness of the cathodic protection systems, e.g. CIPS (close interval potential surveys) and DCVG (direct current voltage gradient). These monitoring processes provide assurance that the protection systems are working effectively, together with information on potential remedial works that may be required to prevent failures.

- Intelligent tools to provide detailed GPS (global positioning system) data for the pipelines that can be overlaid onto geographic information mapping systems (GIS) to support the management of third-party activities close to the pipelines.
- Increased use of more sophisticated dedicated pipeline leak detection systems (metering, pressure wave, etc.) to monitor for pipeline leaks, and also identify and locate pipeline theft events.
- Tools for the detection of pipeline leaks and theft events (inspection 'pigs').
- Photographic and video systems to support the regular aerial inspection of pipelines.
- Innovative repair techniques such as composite materials for pipeline repair in the event of corrosion or damage, and techniques that enable pipeline fittings to be quickly secured following a theft (including temporary encapsulation of the fitting) to ensure the integrity of the pipeline and allow safe operation to be resumed.

Concawe's *Performance of European cross-country oil pipelines* report provides a summary of how the use of intelligent tools for internal inspection has increased over the years (Figure 6). The use of such tools grew steadily up to the mid-1990s, stabilising at around 12% of the inventory every year, and then increased further to around 15% of the inventory in the first decade of the new millennium, and reached more than 20% in the past decade.

Figure 6: Annual length inspected by intelligent tools



The way forward

For the past 50 years, the Concawe's *Performance of European cross-country oil pipelines* report has been a valuable tool for supporting pipeline operators, pipeline designers, regulators and industry actors in the continued management of the safety and integrity of European oil pipelines. Faced with the challenge of an ageing infrastructure and, in recent years, the new threat caused by theft activities, pipeline operators have responded with enhanced integrity management systems, assisted by technological developments in the fields of inline inspections and leak detection systems. As a result, the industry has seen the number and severity of incidents decrease over the past 50 years. Concawe remains committed to providing the framework for the confidential collection and reporting of data, as well as a forum for European pipeline operators to share non-commercially sensitive information, leading to continuous improvements in safety and integrity management.