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LEARNING FROM PIPELINE FAILURES

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ABSTRACT

All engineering structures can fail, and oil and gas pipelines can and do fail. What can we learn from these failures, and could they have been avoided?

Pipeline failures continue to occur, as pipelines present a complex mix of problems, in particular deterioration with time, changing conditions, external factors, and - as always – the 'human' factor.

This paper emphasises that learning from pipeline failures can help us reduce these failures, and hence we should never allow a pipeline failure to pass without a thorough and wide ranging 'lessons learnt' exercise that is both used and shared within the pipeline community.

Three major conclusions emerge from this paper:

- Pipelines are a safe form of energy transportation;
- Current trends indicate reducing pipeline failure rates;
- Good training (knowledge transfer), a solid skills base, and strong management are key to preventing failures, but safety always starts with good design.

Of particular note from recent failures is the increase in theft, sabotage and terrorist attacks. It will be difficult to reduce these failures by detection methods; therefore, prevention will be the best approach.

KEYWORDS

Pipeline, Oil, Gas, Failure. Damage, Defects, Theft, Sabotage, Terrorism.

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1. INTRODUCTION

Pipelines are a safe form of energy transportation, and the industry now has many years of operational experience. However, there continues to be frequent and tragic pipeline failures around the world. What lessons can we learn from these failures?

We are experiencing change in the pipeline business [1-3], ranging from the need to continue to transport our oil and gas through ageing assets, to a much stricter regulatory safety regime. As engineers, we use our past experiences to improve our future; for example:

- poor quality materials and a lack of understanding of major risk meant that 30 years ago, and before, we needed standards that ensured we had good quality pipe, careful routeing, etc..
- today, we know that in-service defects (damage, corrosion) fail pipelines and cause casualties, and we now need standards to help us manage existing, ageing, pipelines.

Consequently, the safety of today's pipelines is dependent on not only their design and operation, but also their maintenance, and management. Hence, it needs to be emphasised that pipelines are not dangerous or unsafe, but their design, operation, and maintenance and management can make them unsafe.

Recent failures in the USA [4], Figure 1, have been followed by the publication of regulations and standards that formally require pipeline operators to 'manage' their pipeline's integrity and have in place formal risk management plans that clearly mitigate and control risks [5,6]. The USA is not alone: other countries have similar requirements [for example, 7-8].

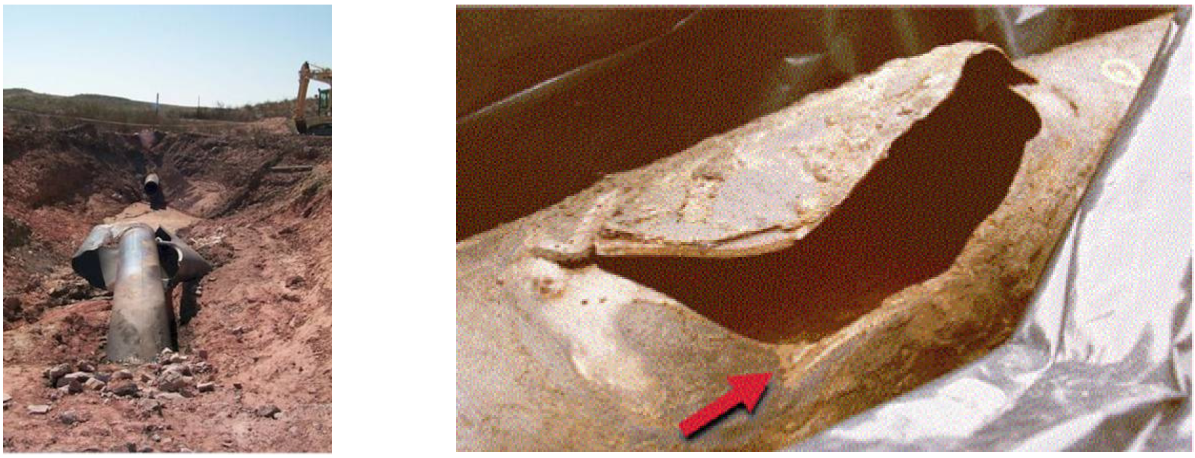

Figure 1. Recent failures of pipelines in the USA [4] (images courtesy of the Office of Pipeline Safety, USA).

Pipelines have, and will, fail, and these types of experiences are used by engineers in developing standards. A key member (Frank Hough) of ASME when the USA gas standard, ASME B31.8, was produced in 1955 said in an article in Gas Magazine in January 1955, *"… a code is not a law… it is… written by engineers, operators and managers… as a result of their experience and their knowledge of the engineering and scientific principles involved, state what they agree is good practice from the standpoint of public safety… a code is merely a statement of what is generally considered good practice"*.

Additionally, safety regulations or government action often follow major pipelines failures [9]; for example, a deadly gas pipeline failure in 1965 in Natchitoches, LA, was the trigger for the USA's Pipeline Safety Program.

What can we learn from pipeline failures? There are many publications on 'lessons learnt' from engineering failures. Many state that most failures could be avoided. An article in the New Scientist (June 1991) by A. Anderson states: *"The relevant information is almost always available: the problem is that it is either not known to the right people or its significance is not appreciated. Far from each failure or disaster being unique, there is usually a past history of similar events that could have resulted in failure but which for some reason didn't"*. This paper will consider some lessons learnt from pipeline failures over the past 20 years.

The paper is an extension to a previous paper on lessons learnt from pipeline failures, by the same author [10].

2. WHY DO FAILURES OCCUR?

GENERAL

We can learn from pipeline failures. The National Transportation Safety Board of the Department of Transportation in the USA publishes pipeline failure reports that offer significant lessons for pipeline managers, and the reader is encouraged to visit the NTSB website to read failure reports.

But what is the overall reason for failures? We know that nothing is perfect. Failures of all structures occur. But it is reasonable to ask… '*why*'?

A failure, or 'incident', usually occurs when a 'system' breaks down; for example:

- we will be injured in an automobile accident if: we are involved in an incident; the automobile does not protect us; no seat belt, no air bags, the force of impact damages us; etc..
- for a pipeline to fail from corrosion: the coating must be faulty; the CP insufficient; inspections fail to detect the corrosion; etc..

We can now see that most systems have multiple 'barriers' that prevent a threat (e.g. corrosion) from causing an incident (e.g. a leak in a pipeline), Figure 2. All these 'barriers' will have faults (nothing is perfect), but the incident will only occur if all these faults 'line up', Figure 2.

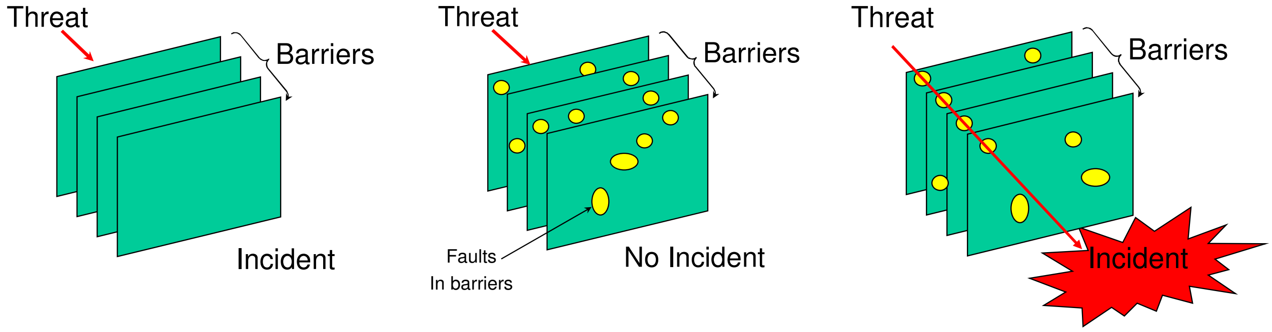

Figure 2. Barriers in a system that help prevent incidents [11]

This 'Swiss Cheese' model of failures was put forward by James Reason in 2000 in the British Medical Journal [11]. The basic model's hypothesis is that 'accidents' can be traced to one or more levels of failure. These are typically quoted as:

- organisational influences;
- unsafe supervision;
- preconditions for unsafe acts; and
- the unsafe acts themselves.

In the Swiss Cheese model, an organisation's defences against failure are modelled as a series of barriers, represented as slices of Swiss cheese. The holes in the cheese slices represent individual weaknesses in individual parts of the system, and are continually varying in size and position in all slices. For example, for a pipeline to fail and cause injury due to impact from a third party:

- the third party must be working around a pipeline, unsupervised (failure in surveillance, awareness, etc.);
- the third party will not be aware of the pipeline and hit it (poor communication, marking, knowledge, etc.);
- the third party will hit the pipeline with sufficient force to cause an incident (pipeline may not be protected);
- the pipeline fails and the product harms people (people are too close to pipeline);
- etc..

The system as a whole produces failures when all of the holes in each of the slices momentarily align, permitting (in Reason's words) *"a trajectory of accident opportunity"*, so that a hazard passes through all of the holes in all of the defences, leading to a failure. These holes may be continually opening, shutting, and shifting their location!

Therefore, when we look at any pipeline failure we must look for a system breakdown, and similarly, we can reduce failures by ensuring a robust, mullti-level, safety system is in place, for all threats.

PIPELINES

We can consider threats (corrosion, external interference, etc.) to our pipelines, and barriers (corrosion protection coatings, surveillance, etc.). We can then simply construct a series of barriers to ensure the threat never causes an incident. We can view barriers as either:

- Barriers that prevent an incident (e.g. coatings on pipelines);
- Barriers that detect a possible incident, before it occurs (e.g. inspection).

Prevention methods are superior to detection: it should always be noted that any ‘detection’ means a ‘prevention’ methods has failed [12].

In the pipeline business ‘management systems’ are being introduced [e.g. 6]. These management systems have a risk assessment at the heart of the process: this allows` threats within the system to be identified, and mitigated by introducing barriers. Figure 3 illustrates how these systems work in the pipeline business. They have been covered in many previous papers [e.g. 3], so they will not be covered here; however, their use should reduce failures.

MANAGEMENT AND STAFF

It should be noted that these ‘systems’ are no substitute for good management. The driving force of these systems is management. Management is critical as incidents, and the resulting crises, are sometimes attributed to a combination of:

- an accumulation of flaws in an organisation that provide the process for an incident (e.g. the ‘Swiss cheese’ model);
- the development of managerial ignorance or unawareness that leaves managers blind to this accumulation.

This ‘ignorance’ has been defined as a manager’s (unintentional) inability to notice, and take into consideration, this cumulating effect of an organisation’s imperfections. This is interesting: we often hear senior managers praise an organisation for its emphasis on safety, but does he/she know the facts? Is it based on a wide perspective? Is this view based on heritage rather than contemporary facts? Is it based on strategy rather than reality? Are these views ’wishes’ to support financial targets? And are these same managers, knowingly or unknowingly, directing the company into high risk? For example, the March 2005 report on the Texas City Refinery failure noted that corporate culture and ‘upper’ management standards dictate minimum compliance and [safety] optimisation. A shift to ‘minimum’ compliance can result in a decrease in internal [safety] monitoring, auditing, and continued improvement activity; consequently, this is a ‘downward’ shift.

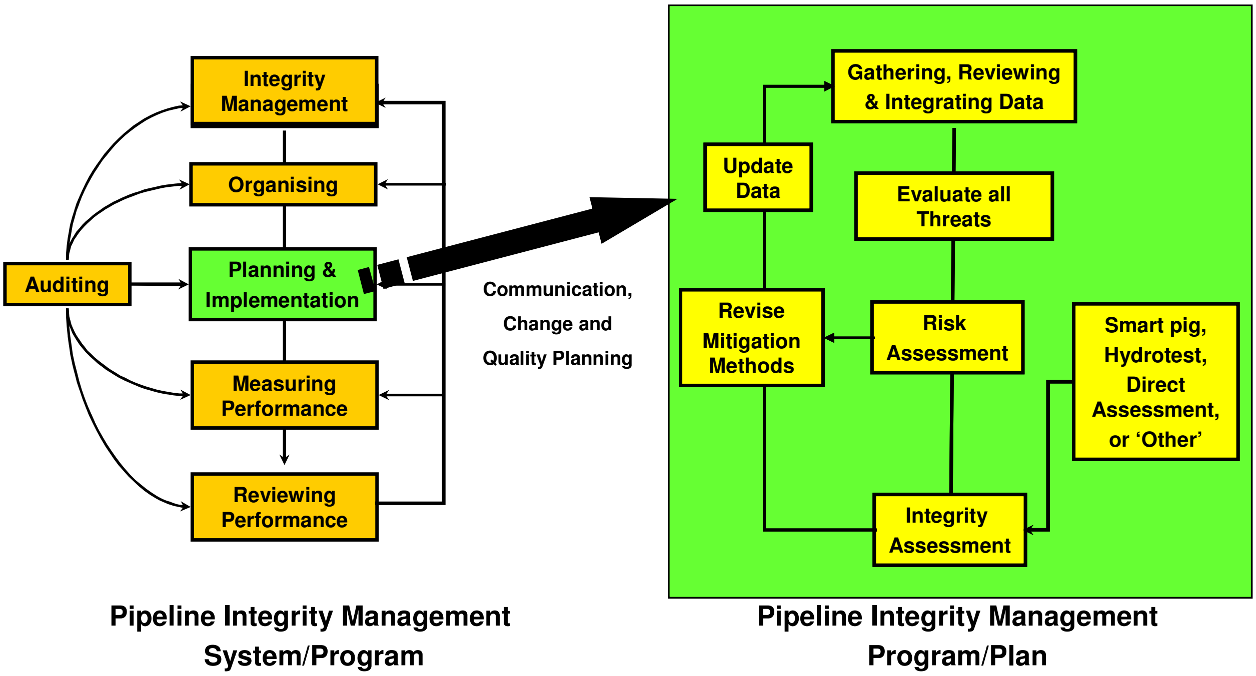

Figure 3. Example of a management system, and its use in a pipeline system.

We can see that system analysis and management can help reduce failures, but what about major causes? Reference 2 reported on a study which analysed many structural failures. When engineers were at fault, the causes of failure were:

Table 1
Causes of Structural Failures

Cause	%
Insufficient knowledge	36
Underestimation of influence	16
Ignorance, carelessness, negligence	14
Forgetfulness, error	13
Relying upon others without sufficient control	9
Objectively unknown situation	7
Imprecise definition of responsibilities	1
Choice of bad quality	1
Other	3

The top three causes suggest a lack of training or knowledge. Reference 2 argued that training may have prevented many of these failures, and recommended improved training and continuous professional development for engineers. Reference 2 went on to show the ageing profile of engineering staff in the pipeline industry, and the alarming loss of skills in recent years [13, 14]: 40 to 60% of skilled staff in the oil and gas industry are approaching retirement, and will do so in the next five years. This latter observations lead to a worrying conclusion: the pipeline industry will lose intellectual capital and this could lead to an increase in failures. More recent publications have again emphasised the loss of skills in the oil and gas industry, and the need to retain skilled staff and train new staff [13, 14].

It is worth noting that talent in no longer a national asset – it is a global commodity [14] that attracts worldwide competition. This can benefit, large, international companies, but lead to a ‘drain’ on national or local talents. This loss of talent can:

- affect operational management; and

- affect a company's ability to understand, and change with, the market.

An extra dimension is that both clients (e.g. pipeline operators) and contractors (e.g. engineering design companies) are suffering talent and skill shortages: this could lead to the 'blind leading the blind'! There are solutions; for example [13, 14]:

- Use new sources of talent; for example from developing nations. These nations are producing a greater proportion of engineering and science graduates than the developed world. Indeed, Western Europe is seeing a decline in these graduates (the UK now produces more 'media studies' graduates that physics and chemistry graduates [14]).
- Increase incentives for staff, such as remuneration, flexible working, etc..
- Develop links with universities to develop new talent.
- Manage knowledge by capturing existing knowledge, and sharing it with all generations of engineers.
- Increase productivity using more efficient business and working systems.

3. WHO IS LIABLE FOR FAILURES [15-17]?

In the 1800s and early 1900s, engineers discounted the possibility of being blamed for any accident through negligence, as engineers, by definition, could not be negligent. Also, up to the mid-1900s, courts routinely denied liability of engineers and architects to anyone injured at a construction site by arguing that the engineers had a contract with the owners, not construction crews, nor users of the structures.

Engineers, and their employers, are now liable for their mistakes, and often blamed for accidents, although the term 'accident' implies that even where an engineer is at fault, there is no maliciousness on the part of the engineer. However, many 'accidents' should not be described as 'accidents': if an 'accident' has preventable causes, it may become a criminal case! The fact that the engineers involved in the 'accident' did not intend an accident to occur is not a defence! Was it an 'accident waiting to happen'? It is a question of 'reasonable care': did the engineers exercise 'reasonable care'? The reader is directed to the references for guidance on 'reasonable care' [e.g. 17].

4. ARE PIPELINES DANGEROUS, OR ARE THEY BECOMING MORE DANGEROUS?

It is well-established that pipelines are the safest form of energy transportation, when compared to other transportation methods such as rail or highway. It is a credit to the pipeline industry that in many countries it has been able to reduce pipeline failures, even as the pipeline assets age, Tables 2, 3.

Table 2
Casualties in USA Pipelines [19].

Years	**Pipeline**						
	All Types	**Liquid**		**Gas**			
		Subsea	Onshore	Subsea	Onshore	Gathering	Distribution
Average (2002-6)	44	0	2	0	5	1	36
Average (1997-2006)	51	0	4	0	6	1	41
Average (1987-2006)	61	0	5	0	7	1	48

These Tables show that pipelines in some regions are actually becoming safer with age. These tables are further supported by other, more specific data. For example, failure (product loss) data from the UK for onshore pipelines (various fluids, but mainly natural gas) show that [18]:

- The overall failure frequency over the period 1962 to 2004 is 0.263 incidents per 1000 km.year;
- The failure frequency over the most recent period analysed (1999-2004) is 0.028 incidents per 1000 km.year.

Table 3
Incidents (Product Loss) in European and USA Pipelines [20].

	Period	Incidents/year/1000km	
		Europe	USA
Gas	1970-79	0.76	1.28
	1986-2001	0.30	0.55
	1997-2001	0.21	0.55
Oil	1971-80	0.63	-
	1986-2001	0.30	0.48
	1997-2001	0.21	0.38

We must not become complacent: many of our pipelines are now 40 to 50 years old. It is unlikely that our forefathers, who planned, designed and built these pipelines, anticipated that they would be expected to perform to their limits well into the 21st century.

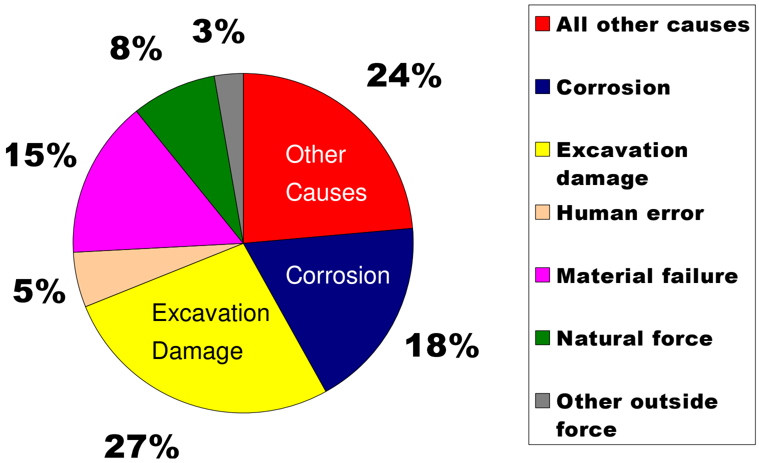

Figure 4. Pipeline failure data from USA. (1987-2006) [21].

5. WHAT CAUSES PIPELINES TO FAIL?

Pipelines can fail, and they fail from a variety of causes ranging from corrosion to land slip. Defects introduced into the pipeline during service can cause failures:

- Corrosion caused by the pipeline's product or environment;
- Pipewall damage, such as dents and gouges, caused by external interference (such as excavation) with the pipeline.

Data on pipeline failure are readily available, and we can quickly learn from these data. For example, pipeline failure data in Figure 4 show defects and damage to be major failure causes; hence, a key aspect of pipeline safety is to prevent or detect these types of defects.

Weld failures are not a major problem in pipelines; for example, only 2% of all failures in USA gas pipelines are due to girth welds. The majority of these failures give leaks not ruptures, and there has been no recorded casualty/fatality caused by them in the USA. This is of interest, as girth welds in older pipelines can contain large defects, and be of poor quality [22], Figure 5. The defects in these photographs did not fail the pipeline, although similar defects in a neighbouring weld did cause a failure during work on the line.

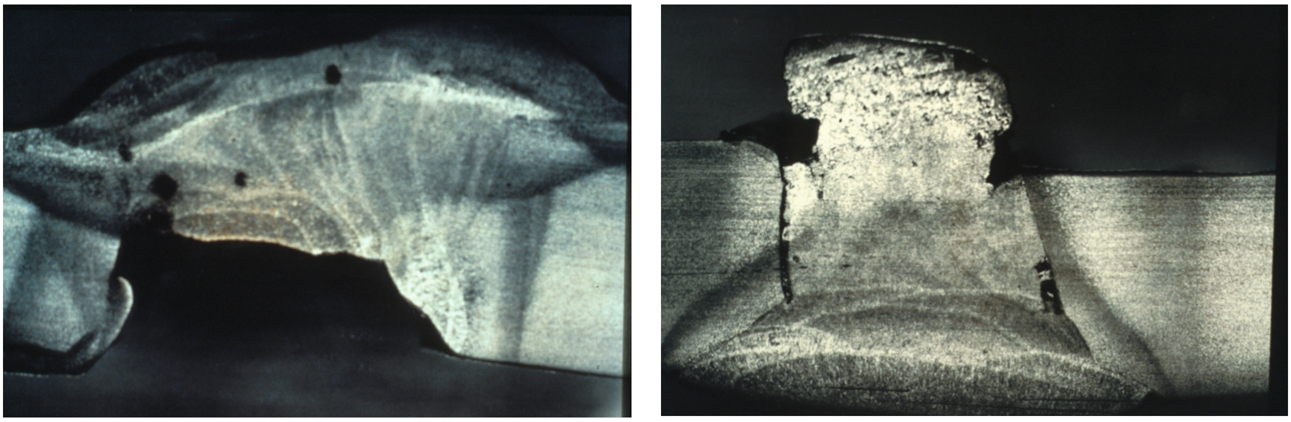

Figure 5. Defects in old pipeline girth welds [22]

Pipeline girth welds are welded using standards that control the procedures and materials, and hence minimize the number and severity of defects. The most common pipeline girth welding standard is API 1104, but it must be remembered that this was not always used on older pipelines; for example, in one review, 70% of all girth welds in a pipeline constructed in the 1960s contained defects that were outside current welding standards. Additionally, radiography to inspect girth welds was not included in API 1104 until 1953, and pipeline standards do not require all girth welds to receive such detailed inspections as radiography. Consequently, girth welds can contain numerous, and large defects. There are two major reasons why these defects do not cause failures:

- pipeline girth welds are highly resistant to defects [23];
- girth welds are usually located in, or on, stable ground, where increases in axial loads are unlikely.

Consequently, provided we do not change the axial loadings on a girth weld, they are unlikely to fail in-service.

Other welds (longitudinal and spiral) in line pipe are now high quality and not a major cause of failures, as they are fabricated in controlled, factory conditions, and receive extensive inspections, and strength testing at the pipe manufacturers, and additionally receiving a field pressure test before going into service. Older line pipe welds may not have received these levels of inspection and testing (for example, some types of older longitudinal welds such as electric resistance welds) and these can be a failure concern (e.g. [24]).

We must be careful to account for local conditions when we investigate pipeline failures. Different regions record differing failure rates and causes. Data from a pipeline system in China shows that the three major causes of pipeline failure are: seam welds; corrosion; and theft. We conclude weld defects are a major problem, but also ‘theft’ is a major failure cause. Theft, sabotage, terrorism, and vandalism are becoming the major cause of pipeline failures involving deaths and injuries; consequently, the next section deals with this worrying development.

6. THE RISE OF VANDALISM, SABOTAGE, TERRORISM, AND THEFT

Pipelines can be attacked by vandals or terrorists, and can be a tempting target for thieves. These attacks are not new: Shell in Nigeria have been dealing with ‘hot tapping’ (drilling into a pressurised pipeline) and ‘bunkering’ (illegally obtaining fuel from pipelines) for 40 years [12]. Other countries are not greatly affected by these acts, although this can quickly change: a terrorist plot to destroy fuel pipelines at John F Kennedy airport in 2007 was foiled by the FBI.

Some of the engineering aftermath of these events can be dealt with by pipelines operators: they will require the same emergency procedures, repairs, environmental clean-up, etc., as other major failures or product loss. The pipeline can be returned to service quickly; however, these attacks on pipelines differ in two significant areas: prevention; and consequences.

It is not easy to prevent hostile, armed groups attacking a pipeline, and the consequences of the attacks, and acts of theft, can be dire: hundred of people die from these acts every year. Another consequence may be a fuel shortage or price rise (a ‘spike’) both locally, nationally, or even internationally, although countries such as the USA, with large ‘redundancy’ in their pipeline systems, and good storage facilities may not suffer from these consequences. This section briefly introduces the growing problem of attacks on pipelines.

VANDALISM

Pipelines are easy targets for vandals, particularly above ground pipelines. In 2001 an oil pipeline in Alaska was vandalised by a drunken hunter who repeatedly shot at the line until it leaked over 1,000,000 barrels of oil. The result was a $17 million clean up bill, and $8 million lost royalties and taxes. The ‘persistent drunk’ was subsequently caught and imprisoned for 16 years, and fined $17million. He will repay at $1000/year…!

SABOTAGE AND TERRORISM

The oil and gas industry is a target often attacked by terrorists [25, 26]. The terrorists preferred targets are:

- government, diplomatic and security forces;
- transportation;
- property;
- infrastructure, utilities and manufacture;
- retail, hospitality, leisure and entertainment.

Oil and gas production facilities are ‘high value’ targets, and often attacked, but these facilities are relatively easy to secure/protect. They present the same security issues as any other target, and hence can be protected by the same security measures. Unfortunately, pipelines are difficult to protect, and can be easy to damage. They extend over long distances, and their location can be posted in websites or company literature. Additionally, a typical attack may involve 2 or 3 terrorists, three shovels, <5kg explosive, a roll of wire, and a battery.

Pipelines may not be the prime target for terrorists, as they may not produce the publicity the terrorists desire: high casualties, ‘iconic’ locations, heavy media coverage, etc.. Nevertheless, sabotage and terrorism are on the increase around the world, and pipeline systems are prime targets. Governments are acting; for example, the Russian government has allowed its oil major, Gazprom, to form a private army to protect its infrastructure [12]. This is not surprising if we illustrate the scale of the problem:

- Sabotage to an oil pipeline in Colombia in 2001 cost Occidental Petroleum $445 million in lost production. Colombia's Caño limón oil pipeline has been attacked 654 times by the National Liberation Army, or ‘ELN’, since 1986.
- Iraq’s pipeline system is regularly attacked: one attack on the main oil pipeline from the Kirkuk oilfields in northern Iraq to Turkey's Mediterranean port of Ceyhun in 2003 caused losses of $7 million/day. Between 2003 and 2007 there were 449 reported attacks against Iraqi oil infrastructure targets [12]. This infrastructure is protected by the Iraqi Government Facility Protection Service and Coalition which comprises of tens of thousands of military personnel, and 14,000 private security personnel are employed protecting this infrastructure.

THEFT FROM PIPELINES

Theft of products from pipelines is becoming a major cause of ‘failure’ in many pipelines around the world. Theft occurs in poor countries, and reflects social problems and hardships; hence, it is not a problem than can be simply solved by engineering invention. The loss of product and damage to the pipeline is worrying, but far more worrying is the huge loss of life sometimes associated with these thefts.

Theft in poor regions can take several forms:

- Small scale, local opportunist theft. This is usually local, small scale theft, for local consumption, by 'amateurs'. Usually this theft has the highest consequences in terms of casualties.
- Small scale, local compensation claims. Local people will damage the pipeline, to seek compensation gains (food, farming, etc.).
- Larger scale, product pipeline theft, by local organised crime. This scale of theft can fill road tankers.
- Large scale crude oil line theft, by organised criminals. This can be done by international criminals, using valves permanently fitted to the pipeline. This scale of theft can fill ocean tankers.

It is the human cost of theft that is alarming. In Nigeria, this theft, or 'bunkering', is rife, and causes huge loss of life. The BBC (26/12/06) reported examples of the loss of life from this theft in Nigeria:

- December 2006: >260 killed in Lagos
- May 2006: >150 killed in Lagos
- December 2004: >20 killed in Lagos
- September 2004: >60 killed in Lagos
- June 2003: >105 killed in Abia State
- July 2000: >300 killed in Warri
- March 2000: >50 killed in Abia State
- October 1998: >1,000 killed in Jesse

Other countries (e.g. India, China, Mexico) have major problems with theft. Clearly, theft from pipelines is a major issue for the pipeline industry, and needs urgent attention and remedies, but these illegal 'taps' can be sophisticated and difficult to detect; hence theft will not be an easy problem to solve. Most simple solutions come with significant limitations:

- Popular methods such as CCTV, barriers (e.g. fences), motion detectors, etc., may have a role within above ground facilities, but will have little use in remote locations where they are easily disabled;
- On-line leak detection systems are unlikely to have a sensitivity to detect the thefts;
- Ground patrolling of the pipeline can be dangerous, as the theft is sometimes conducted by armed and organised gangs;
- Aerial surveillance can help, but the thefts can occur both in daylight and at night;
- Surveillance for ground disturbances can also help, but it is known that some theft is achieved by mining under the pipeline which avoids any visible ground disturbance;
- Fibre optic cables can be buried along a pipeline to detect disturbances of impact, but these cables would be an easy target for vandalisation once their presence is known;
- Impact monitors that pick up vibrations or excavations may not have the sensitivity as the excavation can be by hand, and the tapping can also be by hand drill. Again, if the thieves know the pipeline is monitored for impacts, they would vandalise the field equipment, or create false signals.

Therefore, it is unlikely that there will be a simple, single technical solution to this problem: the solution may be a collection of technical and social tactics. One approach to reduce theft is:

- Partner with all stakeholders, particularly local communities to determine the issues and problems, and gain 'intelligence';
- Work with local communities to recognise the benefit of the pipelines, and their inherent dangers;
- Educate local communities on pipelines, and their role in the community;
- Patrol pipelines at areas of high risk (e.g. near villages or local criminals);
- Work with police to destroy the 'organised' crime (many of the thefts are for a criminal with an organisation selling to customers). This will require special detective work.
- Review internal staffing (often criminals are working with pipeline staff).

Consequently, the most sensible, and effective, approach to theft reduction is likely to be 'theft prevention', not 'theft detection'.

The increasing scale of theft from pipelines, and the tragic consequences, require a joint industry solution, and much more analysis and discussion via specialist conferences and workshops. It is rapidly becoming a commercial issue: theft and sabotage is now affecting output of oil in developing countries such as Nigeria, by both disrupting supply of the raw product, and the output of refineries.

Pipeline security is now being openly discussed (e.g. there was an international pipeline security forum in 2007 in Ontario, Canada), and it is appropriate to consider similar meetings on theft.

7. COST OF FAILURES

Failures can be expensive. There are relatively simple costs to estimate (e.g. repair) and difficult costs (loss of life). There are short term losses (loss of production), and long term losses (loss of public image). There is some data published for repairs to pipelines in the USA:

Table 4
Cost of Repairs to USA Onshore Pipelines [27]

Repair	Cost (2004 prices), $million
Repair (non-leaking) to gas pipeline (depends on whether supply is interrupted)	$20,000 to $40,000
Repair (leaking) to gas pipeline	~$200,000 to $400,000
Major failure to gas line	~$5,000,000

The same publication gives costs of injury and fatalities for cost benefit purposes:

Table 5
Cost of Injury (for cost benefit purposes) [27].

Injury	Cost (2004 prices), $million
Fatality	3
Serious injury	0.5

Care should be taken with using these types of figures. Litigation costs and payment of damages following a fatality from a pipeline failure will be above those given in Table 5. Similarly, the cost of a failure will not be a simple sum of the costs associated with that failure. There will be wider costs; for example, the failure of an oil transit line in Alaska in 2006 resulted in BP increasing its annual spending on corrosion by $12 million, to $72 million.

8. LEARNING FROM 'NEAR MISSES'

We often hear in engineering… 'If it ain't broke, don't fix it!' Is this correct? Major accidents are infrequent; hence we often have to base our safety practices on limited information. For example, some companies and regions will have a small database of pipeline failures, from which they will be unable to pick up trends or learn lessons. Using 'near miss' data can increase this database.

'Near misses' in pipelines are defects or damage that has been detected before they can cause a product loss. 'Near misses' and actual failures may have the same causes ('common cause hypothesis'), and it can be valid to use 'near misses' to set safety standards 'Near misses' are often ignored as they are low consequence, but… 'prevention' does not have to wait until an accident happens!

Figure 6 [28] illustrates this point. 1768 incidents were recorded on these pipelines that did not cause a product loss, whereas 239 incidents recorded product loss. We can see that there is not an exact match, but major causes of product loss (e.g. corrosion (23%) and external interference (19%)) were also frequent near misses (corrosion (25%) and external interference (30%)).

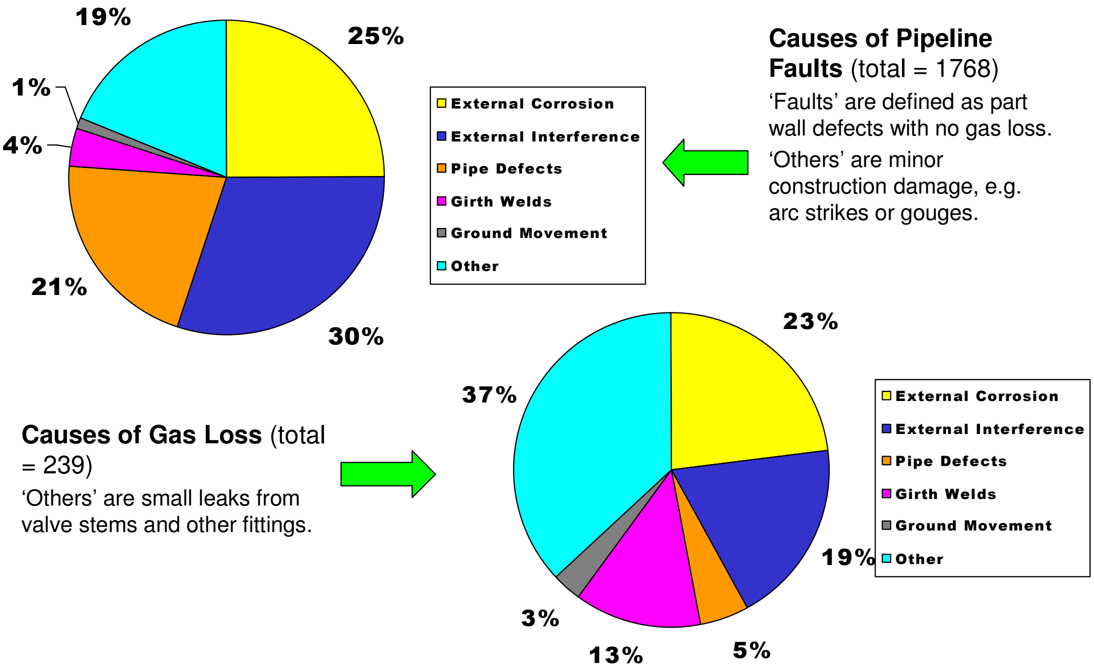

Figure 6. 'Near misses' and failures in onshore UK gas pipelines [28]

We also have other lessons from near misses; for example, we now can obtain detailed information about a pipeline's condition by using internal inspection devices ('pigs') that have sophisticated detection technologies ('smart'). These devices can detect and size cracks, corrosion, dents, etc., before they fail the pipeline. This allows an operator to be able to repair this detected damage, or assess its significance using structural analysis methods.

There is a lesson being learnt from these inspections: the smart pigs are becoming very smart, and finding more defects with greater accuracy and improved sizing. This is good, but it is not without its problems:

- Smart pigs today can detect 'anomalies[1]' that were undetectable by previous (earlier technology) smart pigs. This can lead to a pipeline showing 1000s more anomalies in a contemporary pig run compared to a previous historical run. There may well be more anomalies present, but the increase in level may also be due to a more sensitive technology on the contemporary smart pig.

[1] API 1163 [5] says that an 'anomaly' is a deviation from sound pipe material or weld. An 'imperfection' is an anomaly with characteristics that do not exceed acceptable limits. A 'defect' is an anomaly with dimensions or characteristics that exceed acceptable limits.

- Smart pigs can now detect very small anomalies. These may be within acceptable limits according to line pipe standards or pipeline design standards. They also may not be within these standards but are being detected due to more sophisticated inspection equipment being used in operation that at the pipemill. Clearly, there is a need to understand the anomalies being reported by these smart pigs, and compare them with both existing standards and good engineering judgement.
- Defects in pipelines can be assessed using fracture mechanics or other structural analysis methods. Up to 20 years ago (before the major use of smart pigs), there was a limited need for these methods, but now they are in demand for a wide variety of defects. Unfortunately, the defect assessment methods we use in pipelines have not kept up pace with the advance of pigging technology. The pigs are smarter than the assessors! There is an urgent need to invest in defect assessment methods, otherwise we will be repairing many of the defects reported by these pigs, rather than assessing them, and hopefully avoiding a repair.

Another lesson from near misses' relates to repair. When a pipeline is damaged and needs repair, there is often an urgency placed on the repair and its timescale. Here are some wise words on repair [29]:

- 'Do no harm!' A bad repair can make matters worse. Repairs need careful engineering, at least as much as a new construction. Do not act in haste.
- A repair is often not a good time to try something new. There is less experience with a new procedure, compared to tried and tested designs. Surprises may occur with uncertainty and incompletely planned engineering.
- Preparedness pays off; for example, repairs may need additional pipe and a prudent operator buys more pipe than the project needs (e.g. 1-2% in length).

Another lesson relates to the actual repair methods. Leak clamps, composite wraps, etc., are all available good repair methods. But some pipeline damage requires specialist repairs and significant planning. This is particularly true of offshore pipelines. These pipelines can be damaged by anchors or fishing equipment that can cause extensive deformation (e.g. bending), and damage (e.g. denting and gouging), Figure 7 [30].

Figure 7. Damage to a subsea pipeline [30]

The impact and movement of the pipeline can lead to high 'locked-in' stresses that must be taken into account during: any pressure reduction; work on the pipeline; assessment of the damage; and repair considerations.

The overall effect can be that proprietary repairs such as clamps may not be suitable; consequently, a lesson learnt from near misses in subsea pipelines has been that available repair methods have not been suitable, and specialist repairs are needed. It is prudent to develop and make these specialist repairs before any damage/failure, to allow rapid deployment.

9. CONCLUSIONS

We know that society, ably supported by our lawyers, increasingly expects ‘zero risk’ in engineering structures, but engineers know that zero risk is only a dream. We cannot avoid pipeline failures: they will continue to happen, as pipelines present a complex mix of problems, in particular deterioration with time, changing conditions, external factors, and - as always – the ‘human’ factor. But we must strive to reduce our pipeline failures, both in terms of numbers and consequences. Learning from pipeline failures can help us reduce these failures, and hence we should never allow a pipeline failure to pass without a thorough and wide ranging ‘lessons learnt’ exercise that is both used and shared with the pipeline community.

Three major conclusions emerge from this paper:

- Pipelines are a safe form of energy transportation, and a pipeline failure will be due to a ‘system’ failure, the chances of which can be reduced by adopting formal management systems which include risk assessment.
- Good training (knowledge transfer), a solid skills base, and strong management are key to preventing failures, but safety always starts with good design.
- Current trends indicate reducing pipeline failure rates: in parallel there is evidence of increased inspection and repair spending, which suggests focussed (based on threat/risk assessment) inspection and repair will reduce pipeline failures.

Two major issues are also highlighted:

- There is a major increase in theft, sabotage and terrorist attacks. It will be difficult to reduce these failures by detection methods; therefore, prevention will be the best approach, including an engagement with the local communities to highlight the benefits and dangers of pipelines, and discuss issues and problems.
- The role of skilled staff and management in preventing pipeline failure is noted. It is worth ending this paper by emphasising that pipeline failures will decrease with the employment of good staff and management, but there are increasing indications of shortages in these areas in the pipeline business. Let us hope that loss of skills and lack of investment in both engineers and engineering will not be a future ‘lesson learnt’ in pipeline failures.

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