RISK AND INTEGRITY MANAGEMENT OF A TRANSMISSION PIPELINE

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Summary

Regulatory authorities in Canada, USA and the UK are moving away from prescriptive approaches to pipeline design and operation, to *'risk management'* as the safest and most cost effective means of maintaining and improving safety levels in pipelines. Risk management is a combination of risk assessment and risk control.

Additionally, operators and regulators are recognising the importance and usefulness of *'management systems'*. A Pipeline Management System is expected to be a requirement in all countries of the European Community in the near future. Therefore, operators should be aware of these new methods and systems.

This paper introduces the reader to risk management methods, and management systems, and combines these two approaches to produce a complete risk management system, including emergency planning and procedures, that can be used on a pipeline system.

1. Introduction

Pipelines must provide a safe method of transporting energy, and pipeline operators must ensure that the public, environment and property are protected from any risks associated with the pipeline.

Most pipeline operators control these risks by complying with their regulatory requirements and national codes, and generally performing additional activities where there is a perceived need, or where analysis or experience has shown there to be a need.

Regulatory regimes are generally 'prescriptive', and will not be adaptable to differing pipelines with differing needs and associated risks. This presents the dual problems of i. potentially 'missing' new risks, and ii. creating an inflexible environment for operators to apply new technologies that can both identify and mitigate the key risks.

1.1 The Move Towards 'Risk Management'.

Regulatory authorities in Canada, USA and the UK (1-5) are moving away from these prescriptive approaches, to 'risk management' as the safest and most cost effective means of maintaining and improving safety levels in pipelines. Risk management is a multi-level programme that allows operators to identify risks, their severity and frequency, and implement the best control measures. The programme includes performance measures for both management and the control measures, and requires constant feedback to test and improve the whole process.

Risk management recognises that it is not possible to eliminate all risk, and it recognises that the best way to control risks is the analytical and cost effective use of available resources, and not by blindly following regulations and codes.

This means that the pipeline industry is changing, from prescriptive (some would say 'restrictive') methods of designing and operating their pipelines, to 'goal setting'. Therefore, operators should be aware of these new management methods.

1.2 The Move Towards 'Management Systems'

Pipeline operators and regulators are recognising the importance and usefulness of formal 'management systems'. A Pipeline Management System(6) is expected to be a requirement in all countries of the European Community in the near future (7).

Management systems bring together company organisation structure, responsibilities, processes, etc., in a single document that is constantly reviewed and audited to quantify its usefulness and effectiveness. A pipeline management system includes the parts of a general management system relating to a pipeline.

Therefore, it is the obvious 'home' for risk management methods and procedures, and allows a company to systematically implement, review and audit a risk management programme (i.e. risk assessment and risk control), Figure 1.

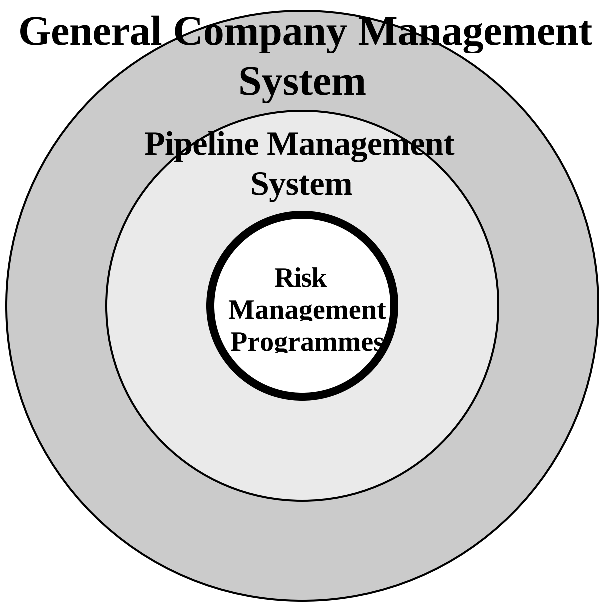

Figure 1. Risk Management Programmes in a Company's Management System.

This paper presents risk management methods, and their background. It also includes simple management systems for pipeline operators to use on their own pipeline systems, which accommodate risk management methods.

2. The Increasing Use of Risk Management Methods

Many countries are actively using, or moving towards, risk management methods. The following are selected examples:

2.1 UK

The Pipelines Safety Regulations 1996 (4) in the UK cover most oil and gas, onshore and offshore, transmission pipelines. These Regulations are not prescriptive, but goal setting. This means that operators of pipelines are not restricted to prescriptive design codes, and can instead base design and operation on 'fitness-for-purpose'. Indeed, the Guidance Notes for the Regulations (5) state that 'A pipeline MAOP (maximum allowable operating pressure) may need to be raised above the original design pressure in some cases. If this is proposed, it will probably have significant implications on the pipeline integrity and risk which must be fully evaluated'.

Pipelines in the UK have to satisfy a number of 'general' regulations but when a pipeline carries a 'dangerous fluid' (e.g. a flammable gas at 8 bar absolute) it is considered a 'major accident hazard pipeline', and attracts additional regulations. Regulation 23 requires the operator of a major accident hazard pipeline to have available a 'Major Accident Prevention Document' (MAPD). A 'major accident' is defined as 'death or serious injury involving a dangerous fluid'.

2.1.1 Major Accident Prevention Documents

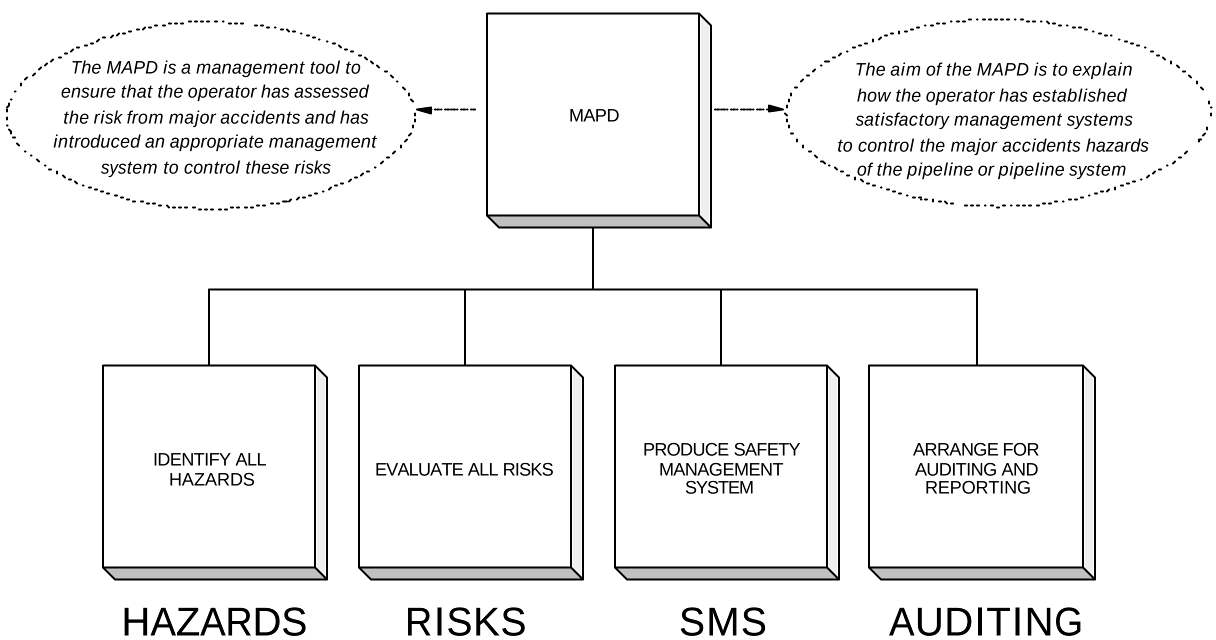

Figure 2. Requirements of a MAPD

The MAPD is a management tool to ensure that the operator has assessed the risk from major accidents and has introduced an appropriate safety management system[1]

[1] In 1993, the UK Royal Society defined ‘safety’ as 'the freedom from unacceptable risks of personal harm', and ‘safety management’ as 'the application of organisational and management principles to

to control these risks, Figure 2. The aim is that the document will explain how the operator has established Satisfactory Management Systems (see below) to control the major accident hazards of the pipeline or pipeline system.'

2.1.2 Safety Management System

The pipeline MAPD must be supported by a Safety Management System (8) which is in place for the control of the safety of the pipeline throughout its lifecycle. The safety management system should cover the organisation and arrangements for preventing, controlling and mitigating the consequences of major accidents. These include specific attention to management competencies and procedures necessary to minimise the possibility of these events.

This combination of MAPD and Safety Management System, is consistent with the overall approach outlined in Figure 1, and equivalent to (but not as comprehensive as) the ‘risk programmes’ and ‘pipeline management system’ described later.

2.2 Canada

In Canada, risk assessment and management is being promoted by the Pipeline Risk Assessment Steering Committee, which has developed a Canada-wide database of reportable pipeline incidents and characteristics.

A non-manadatory appendix ‘Guidelines for Risk Analysis of Pipelines’ was included in the Canadian Standards Association Standard Z662 in 1996. For 1998, risk concepts are being strengthened to include risk evaluation (3).

2.3 USA

In 1998, the USA Office of Pipeline Safety signed a ‘risk management demonstration project order’ approving Shell as the first participant in their risk management demonstration programme (1). This programme was the outcome of a public conference in November 1995, where a partnership of industry and regulators recommended risk management as a potential method of producing equal or greater levels of pipeline safety in a more cost effective manner than the current regulatory regime (2).

The approach is the USA is to implement a complete risk management programme on a pipeline system, which includes a risk assessment, control, performance monitoring and feedback. It also requires operators to ensure that risk management is integrated with the company’s business practices, and therefore it is fully described by Figure 1.

2.4 Europe

The European Commission is reviewing the control of ‘major accident[2]’ pipelines (7) with the aim of controlling major accidents involving pipelines carrying dangerous substances[3].

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achieve optimum safety with high confidence’. This encompasses planning, organising, controlling, co-ordinating all contributory, development and operational activities (14).

[2] A ‘major accident’ is an occurrence such as a major emission, fire, or explosion resulting from uncontrolled development in the course of the operation of the pipeline, and leading to serious danger to human health and/or the environment, immediate or delayed, and involving a ‘dangerous substance’.

[3] A ‘dangerous substance’ is defined in the Regulatory Benchmark. These substances are graded from ‘1’ (very toxic) through ‘5’ (‘highly inflammabe’) to 8 (classes including those that react with water).

This will entail requirements on all member states to draw up a Major Accident Prevention Policy (MAPP) that establishes the overall aims and principles of action with respect to the control of major accident pipelines. There will be another requirement for a Pipeline Management System that ensures the MAPP is properly implemented.

Clearly the European Commission's review (with a MAPP within, and supported by, a Pipeline Management System) is similar to the UK approach of an MAPD (Figure 2) containing a Safety Management System (see Section 4), and is consistent with the approach detailed in Figure 1.

3. Risk and Integrity Management

3.1 What is 'Risk'?

All operators want a pipeline that is safe[4] (does not pose a major risk to the population and environment), and secure (does not pose a major risk to supplies). Therefore, they require high 'integrity'. This is usually interpreted as a low probability of the pipeline failing (or failing to deliver), and is very much a legacy of the 'old' approach of refusing to admit that a pipeline may fail, with significant consequences.

Risk is calculated by combining the likelihood of a hazardous even, with its consequences:

RISK = f(Probability of Failure, Probability of a Consequence)

Failure probability and consequences vary with the pipeline type, product, environment etc.. Failure probabilities will be a projection forward of all the likely failure modes in the pipeline.

Consequence analysis will depend on: release rate through orifices, toxicity of product, generation and dispersion of vapour clouds and flame jets, thermal radiation hazards, vapour cloud explosions, etc..

3.1.1 How Do We Currently Deal With Risk?

Traditionally, transmission pipelines are designed in accordance with design codes such as the American Pipeline Standards ASME B31.4/8. Most national and international pipeline design codes are based on this ASME code.

They use 'deterministic' limits, e.g. 72% SMYS design stress, based on conservative assumptions such as minimum wall thickness. These limits usually have a safety factor associated with them, e.g. a pre-service hydrotest to 100% SMYS means that a 72% SMYS pipeline has a safety factor of 100/72 on pressure at the outset of its design life.

Therefore, by limiting stress, we will ensure a low probability of failure - this is one half of the above Risk Equation. The 'probability of a consequence' is mitigated by ensuring

[4] USA Office of Pipeline Safety (2) considers:
Safety is 'the protection of the public, the environment and property'.
'Risk' is 'any threat to achieving these (above) goals'.

that we have a low failure probabilty in the case of liquid lines, but in gas lines we limit consequences by limiting the number of people (buildings) in the vicinity of the pipeline.

Table 1. Classification Scheme in ASME B31.8

CLASSIFICATION	AREA	Design Factor (hoop stress/SMYS)
Class 1 (Div 1)		0.80
Class 1 (Div 2)	0-10 buildings (rural)	0.72
Class 2	11-45 buildings (areas around towns)	0.60
Class 3	46+ dwellings (e.g. suburban)	0.50
Class 4	Multi-storey-type buildings	0.40

We can see that existing pipeline codes actually address (albeit implicitly), both probability of failure, and consequences of failure. Therefore, when we apply risk management methods we need to address both failure probability and consequences, and this is consistent with good (historical) practices in pipeline codes.

3.1.2 How can we Link 'Risk' and 'Integrity' Management?

Traditionally, operators have considered pipeline integrity as dealing with failure probability, and pipeline safety as dealing with failure consequences. Therefore, operators will often have 'pipeline integrity management systems' and 'safety management systems' dealing with these two separate aspects. However, we will combine these two aspects into one approach in this paper - 'risk management'.

3.2 What is Risk (and Integrity) Management?

Risk management is a combination of the two above aspects (failure analysis and consequence analysis) where we bring together risk assessment and risk control. It has been defined by the USA Office of Pipeline Safety as (2):

'a comprehensive management decision support process, implemented as a program, integrated through defined roles and responsibilities into the day-to-day operations, maintenance, engineering management, and regulatory decisions of the operator'.

Therefore, we will now consider 'risk management' as including both risk (assessment and control) and integrity management aspects (see also Section 5.2 and Table 2, later). It covers three key areas (2):

i. Risk Assessment (Analysis)

What types of risks will be addressed? What adverse events can happen? How likely are these events? How severe would the consequences be? What risk has been increased?

ii. Risk Control and Decision Support

What could be done to control risks? What are the relative merits and options? What set of activities bests achieves the risk management goals?

iii. Performance Monitoring and Feedback

What improvements are expected from the risk control decisions? What measures best capture these expected outcomes? Are the selected risk control activities having the intended effects? How can the overall risk management process be improved?

Figure 3 summarises the above.

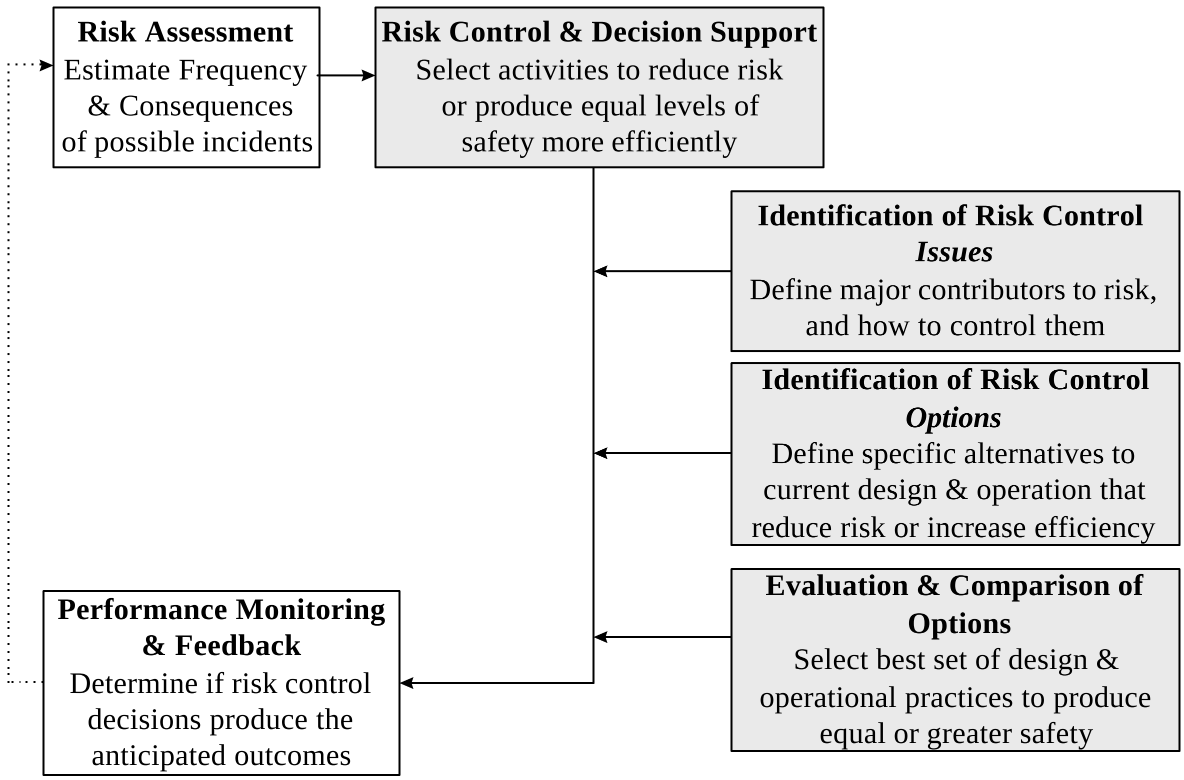


Figure 3. Risk Management - The Approach Adopted in the USA (2)

Clearly, risk assessment is the key starting point. Risk assessments will require expert skills, and should be carefully managed. Figure 4 summarises the full risk assessment process.

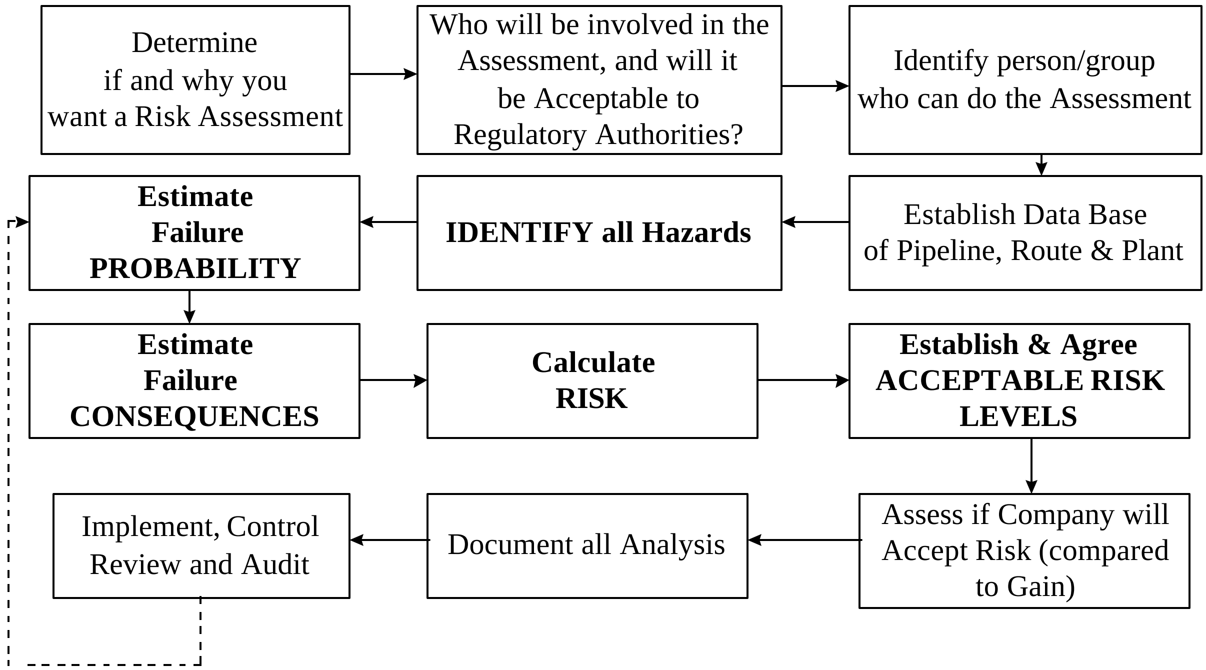


Figure 4. Key Elements of a Pipeline Risk Assessment

We can now see that the conventional view of risk management is a process centred on risk assessment (Figure 4), but containing risk control and decision support, and performance monitoring and feedback (Figure 3).

<u>3.3 What Does Risk Management Do? (2)</u>

Risk management:

i. produces, structures and presents the best available risk information to support and facilitate better management decisions,
ii. allows management decisions and their bases to be more easily communicated,
iii. identifies all risks to the pipeline, selects suitable controls, and appropriate performance measures,
iv. does not replace pipeline company managers or regulators with computer models. Corporate managers and regulators make decisions, aided, but not dictated by, technical and quantitative analyses,
v. is a continuous process, with updates and refinements continually fed back into the process,
vi. requires corporate leadership, commitment, and accountability.

<u>3.4 What are the Tangible Benefits of Adopting Risk Management?</u>

Regulatory Authorities recognise the usefulness of risk management, and operators should be aware of its many advantages:

i. Improvements to pipeline efficiency, safety and security .
ii. Compliance with regulators, legislation and code (moving from prescriptive to goal-based design).
iii. Control of the hazards associated with pipelines (cost of a failure is made up of direct costs (e.g. repairs), and indirect costs (loss of business & goodwill, compensation claims, etc.). Indirects can be the largest.
iv. Control of Insurance Cost .

3.5 How Can I Develop a Full Risk Management Programme?

This paper is going to outline a full risk management programme in the form of a system. It will use the elements of the USA risk management programme detailed in Figure 3, and adopt the risk assessment approach of Figure 4. Additionally, it will include Emergency Procedures and Emergency Planning. All these elements of the risk management programme will be contained in the Pipeline Management System (Figure 1), whose task is to ensure that the whole programme is implemented, measured, reviewed, audited and improved.

It should be emphasised that we are only dealing with the risk management system in this paper. The risk assessment element is key to its success and the safety of the pipeline. Risk assessment will require specialist skills and methods, and will entail detailed discussions with all stakeholders, particularly the Regulatory Authorities. Guidance can be found in the literature (e.g. 9,10).

The risk management model we will use is detailed in Figure 5. It brings together all safety aspects of our pipeline system.

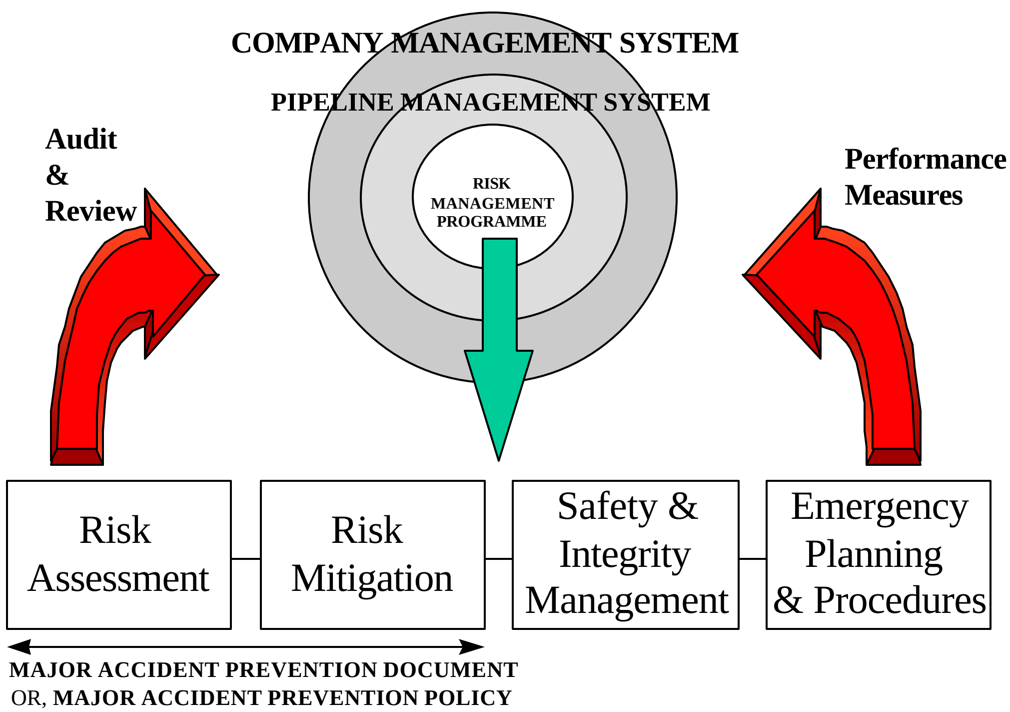


Figure 5. An Overview of a Complete Risk Management 'Programme', Contained within a Pipeline Management System.

3.5. How do I Incorporate Risk Management into my Company?

We can see that risk management relies on the following:

1. Identification of all risks to our pipeline (e.g. corrosion), Figures 3 and 4.
2. An overall procedure for quantifying the above (e.g. risk analysis).
3. Identification of measures to mitigate these risks (e.g. intelligent pigging).
4. Emergency Plans & Procedures to support '3' and provide consequence cover (Figure 5).

5. A Management System that will help a company achieve 1 - 4 (Figures 1 and 5).

Therefore, we will first describe these (management) systems that can contain and implement our risk management programme and methods (see Figure 1). Then we will outline risk management techniques.

4. What Is A Management System?

Pipeline companies are going through major changes, ranging from ‘downsizing’, to franchising maintenance and operation activities. These changes, and increasing pressure from regulatory authorities to have auditable management processes in place, mean that pipeline operators are now producing, and working to, management systems.

First of all, we need to know what a management system is, and what it can do. Unfortunately, management systems are often confused with management structures; they are different, although the latter is contained in the former. A Management System is a management plan, in the form of a document, that explains to company staff, customers, regulatory authorities, etc., how the company and its assets are managed, by stating:

- who is responsible for each aspect of the asset and its management,
- what policies and processes are in place to achieve targets and goals,
- how they are implemented,
- how performance is measured, and finally ,
- how the whole system is regularly reviewed and audited.

The document is agreed at board level, constantly and systematically reviewed and updated, and all levels of management comply with its contents. Many companies operate such a system in a piecemeal, or unstructured manner. It is the production of a single, detailed document that encompasses all the above aspects that creates the ‘system’.

Examples of why a company needs management systems, and the need to constantly review all management procedures, can be found in the literature (e.g. (11)). As stated above, recent pipeline regulations (4,5) and future regulations (7) will require pipeline operators to have in place pipeline/safety management systems.

4.1 Simple Management Systems

A simple management system is shown in Figure 6 (8). It shows that we are considering a management policy (e.g. safety), and we want to ensure that this policy is robust, well managed (with clear responsibilities and lines of responsibilities) and that it is implemented effectively, and in line with stated performance measures. The management system crucially contains both review and audit. It should be emphasised that if any of the components in Figure 6 are missing, it is not a complete system.

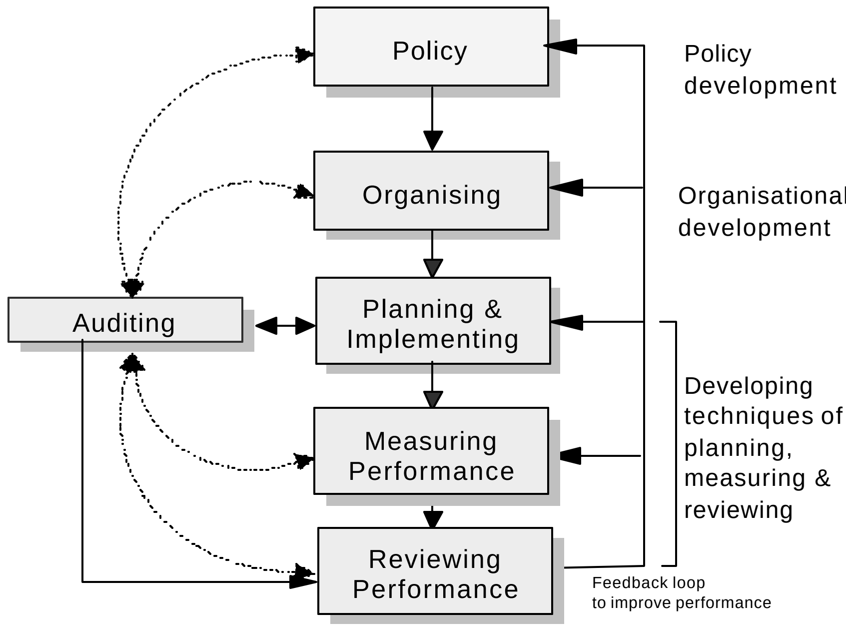


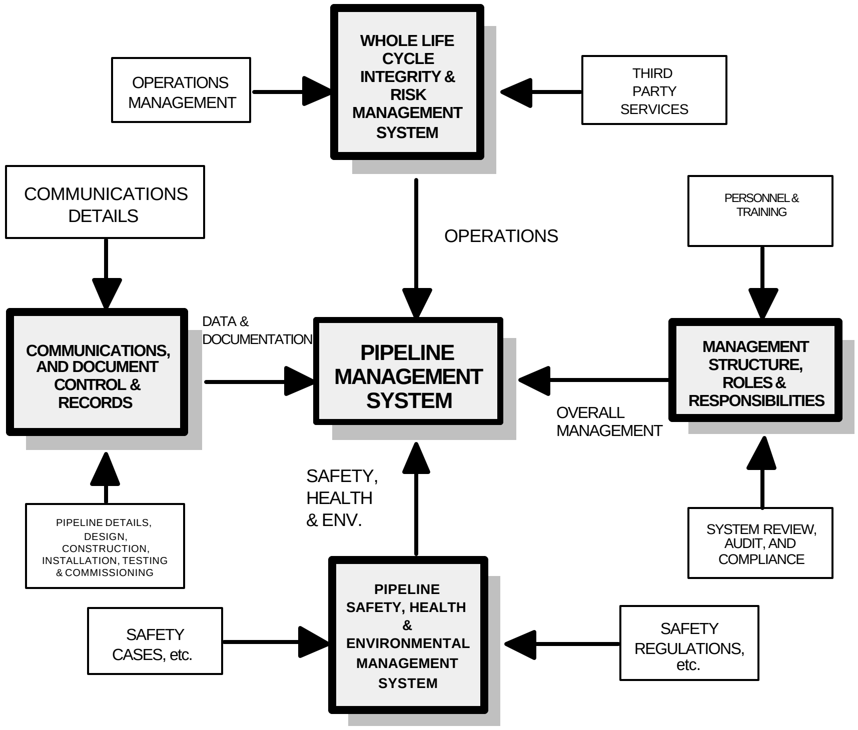
Figure 6. Key Elements of a Management system (8)

4.2 Pipeline Management System

A Pipeline Management System is shown in Figure 7 (6, 12, 13). This is a suggested format; different companies require different formats, and different priorities. However, this overall format should satisfy the needs of most companies, and also satisfy requirements of Regulatory Authorities.

Each arm of the system in Figure 7, should contain all the elements of Figure 6. Therefore, it is not sufficient to have in place a risk and integrity monitoring programme (however good); this programme must be constantly reviewed, and audited to test its adequacy, and checked that it is applied correctly and completely.

As stated above, one of the key components of the management system is measuring performance (see Section 5.2 later), Figure 6. This is important in pipeline engineering, as it can allow early detection of problems, and can also allow relaxations in operational



practices, that can allow reductions in operating costs.
Figure 7. A Pipeline Management System (6)

5. Pipeline Risk Management Systems

It will be difficult to visualise a pipeline risk management system using the above figures. However, it is a relatively easy system to produce, and will take the form of a document, that clearly sets out missions, responsibilities, policies and procedures. The main elements of this management system are summarised below.

<u>5.1 Overall Risk Management System</u>
References 2, 4 and 7 can be used to construct a Pipeline Risk Management System, which is similar to one already proposed (13), Table 2. In this Table, Item 8 is the ‘risk management (programme)’, Item 9 is the ‘integrity management’, Items 10 and 11 are ‘emergency management’, and the addition of all the other Items creates the ‘system’.

Table 2. A Risk Management System

1. Introduction: Purpose, Objectives, Goals, Company Mission Statements, Corporate Administration.
2. Description of Pipeline Systems & Legal and Statutory Duties: Interfaces with Other Operators' Facilities or Pipelines, Description of design, construction, etc., Standards, and Formal Statement of Legal and Code Compliance.
3. Organisation & Control: Structure, Accountabilities and Responsibilities, Organisation, Relationships with Other Groups/Bodies, Integration into Company and Pipeline Management Systems.
4. Key Personnel - Roles, Responsibilities, Qualifications, Training and Updating of Skills
5. Stakeholders: Listing of all Stakeholders, with interests and concerns. Information to be given to all stakeholders (pipeline operator details, system details, nature of the major accident hazards, procedures (including communications) in case of an accident, and information concerning emergency plans and procedures.
6. Documentation and Communication Systems: Type, Methods, Location, Feedback from/to all personnel and Stakeholders.
7. Management of Change: both change of management and engineering detail.
8. Risk Analysis, Evaluation and Control for the Whole Life of the Pipeline: Methodology (with limitations & assumptions), types of hazard/risk, adverse events, likelihood, frequency, consequences, quantification, sensitivity and uncertainty analysis, acceptance levels. Identification of major risks, control of risks, evaluation of control options, prevention and mitigation methods, acceptance levels. Emphasis on identifying all major accident scenarios, and their probability, the events triggering the accident, and the extent, severity and consequences. All hazards should be eliminated or reduced *as is reasonably practicable*[5] Where hazards cannot be eliminated, appropriate measures (protection) should be applied.
9. Integrity Management - control, maintenance, inspection & monitoring- policies, procedures & specifications: i. Internal Erosion, Corrosion and External Damage - Control, Mitigation, and Monitoring, ii. Pipeline Geometry, Leaks, Ground Movement - Control, Mitigation and Monitoring, iii. Pressure and Overpressure Control - Control and Monitoring, iv. Definition of Reportable Incident/Damage, Incident Investigation and Analysis, v. Full Listings Of All Integrity Monitoring Procedures, Intervals, Responsibilities, Agency Carrying Out Duties, Reporting, vi. Repair, Modification and Emergency Procedures and Methods, vii. Emergency Plans, and Liaison with Other Services, viii. Information & Documentation Relating to Pipeline Integrity, ix. Statement of compliance with any Pipeline Safety Regulations and Associated Laws.
10. Emergency Planning: Responsible persons, co-ordination/liaison/interface roles, actions to control/limit consequences of an accident, early warning systems, information/communications, training by/with local emergency services.
11. Emergency Procedures: Detail procedures, roles and responsibilities, testing, updating, links and compatibility with local services and procedures.
12. Performance Measures: i. Stated Performance Measures, ii. Evaluation of Measures, iii. Improvement Process
13. Management System Review - Responsibility and Frequency
14. Management Review - Responsibility and Frequency

[5] **'As low as reasonably practicable' (ALARP).** ALARP is achieved by basing criteria on a robust, consistent methodology contained within an appropriate safety assessment philosophy or management system. Hazards which can be reasonably minimised or eliminated cannot be considered acceptable, however minimal the frequency or consequences appear to be (8).

We can see that this risk management system brings together all aspects of our pipeline safety and integrity methods, Figure 8.

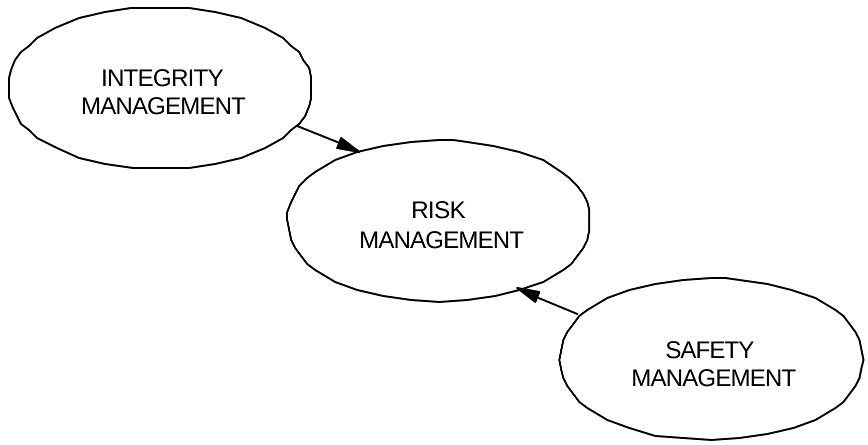


Figure 8. How a Risk Management System Brings Together Integrity and Safety Management Issues (see also Table 2).

5.2 Performance Measures

As stated previously, it is the inclusion of the performance measures, review and audit sections that turn the above into a 'system'. Most of the items in Table 2 will be contained in the Pipeline Management System, and therefore the risk management system need not be a large document.

Performance measures can be difficult to develop and agree with Regulatory Authorities. Reference 2 acknowledges this:

⇒ Performance measures can be difficult to interpret over a short programme
⇒ Performance measures for safety & reliability will mainly be 'outcome-based' (e.g. number of leaks).
⇒ Trends can be useful, e.g. increases in frequencies of events.

In general, three measures can be proposed (2):

i. *Safety & Reliability* - How are incident data changing, are new and previously unrecognised risks being identified, is there better customer/public service (e.g. reduced number of complaints, down time, etc.)?
ii. *Resource Effectiveness* - Are new technologies being used or trialled, are required resourcings being reduced due (directly) to the management programme?
iii. *Communication & Partnership* - Do all stakeholders (operator, regulator, customers, public) appreciate all risks, and agree? Are all stakeholders actively involved in the programme, with a reasonable say in its outcome?

5.3 'Acceptable' Risks and Failure Probability

A difficult aspect of the risk analysis is setting 'acceptable' levels of risk. There is some guidance in the literature; for example the UK works to 'as low as reasonable practicable' (see footnote in Table 2) when considering risks to people, Figure 9.

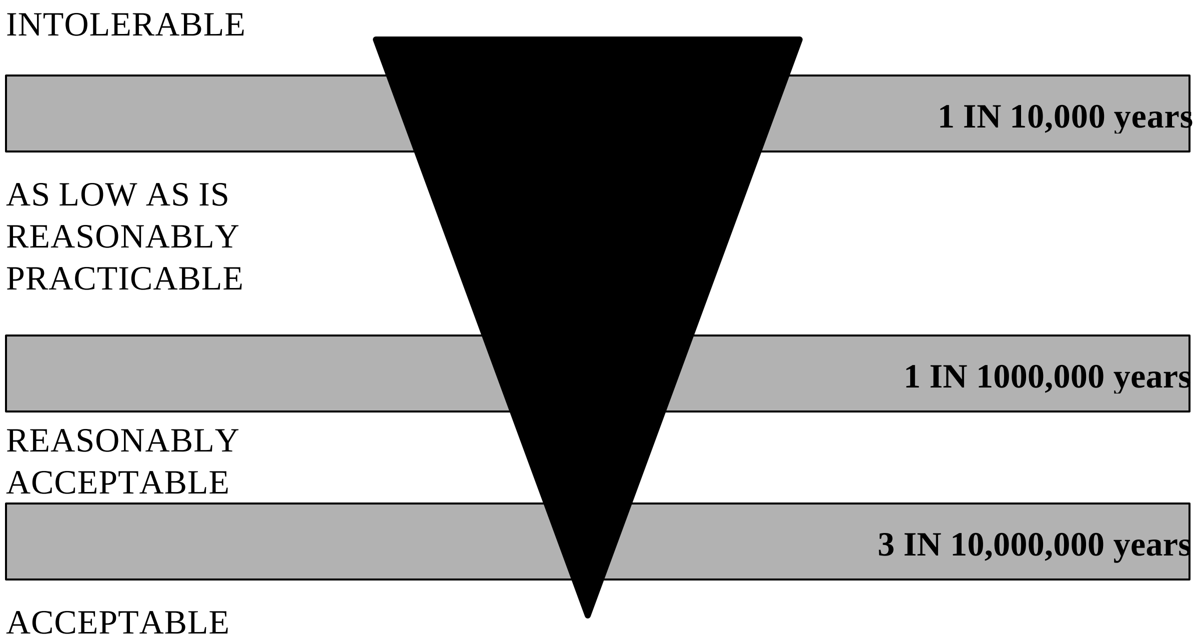


Figure 9. ‘Acceptable’ Risks (of being a casualty) to the UK Population (8,9,14,15)

‘Acceptable’ failure probabilities are also published in the literature (see Reference 10 for a summary), Table 3.

Table 3. ‘Acceptable/Target’ Failure Probabilities (16, 17)

<table>
<tr><td>OFFSHORE</td><td colspan="3">ACCEPTABLE FAILURE PROBABILITIES (per year)</td></tr>
<tr><td>Limit States</td><td colspan="2">SAFETY ZONE</td><td>OPEN WATER</td></tr>
<tr><td>Ultimate</td><td colspan="2">$10^{-5} - 10^{-6}$</td><td>$10^{-3} - 10^{-4}$</td></tr>
<tr><td>Serviceability</td><td colspan="2">$10^{-1} - 10^{-2}$</td><td>$10^{-1} - 10^{-2}$</td></tr>
<tr><td>ONSHORE</td><td colspan="3">TARGET FAILURE PROBABILITIES (per km)</td></tr>
<tr><td>Limit States</td><td>MORE SERIOUS (Urban)</td><td>LESS SERIOUS (Remote)</td><td>SERVICEABILITY</td></tr>
<tr><td>Ultimate</td><td>10^{-7}</td><td>10^{-4}</td><td></td></tr>
<tr><td>Serviceability</td><td></td><td></td><td>10^{-3}</td></tr>
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5.4 Emergency Planning

Figure 5 shows the key role of Emergency Planning in our risk management system. References 4 and 5 give us a good summary of the requirements for emergency planning, Figure 10.

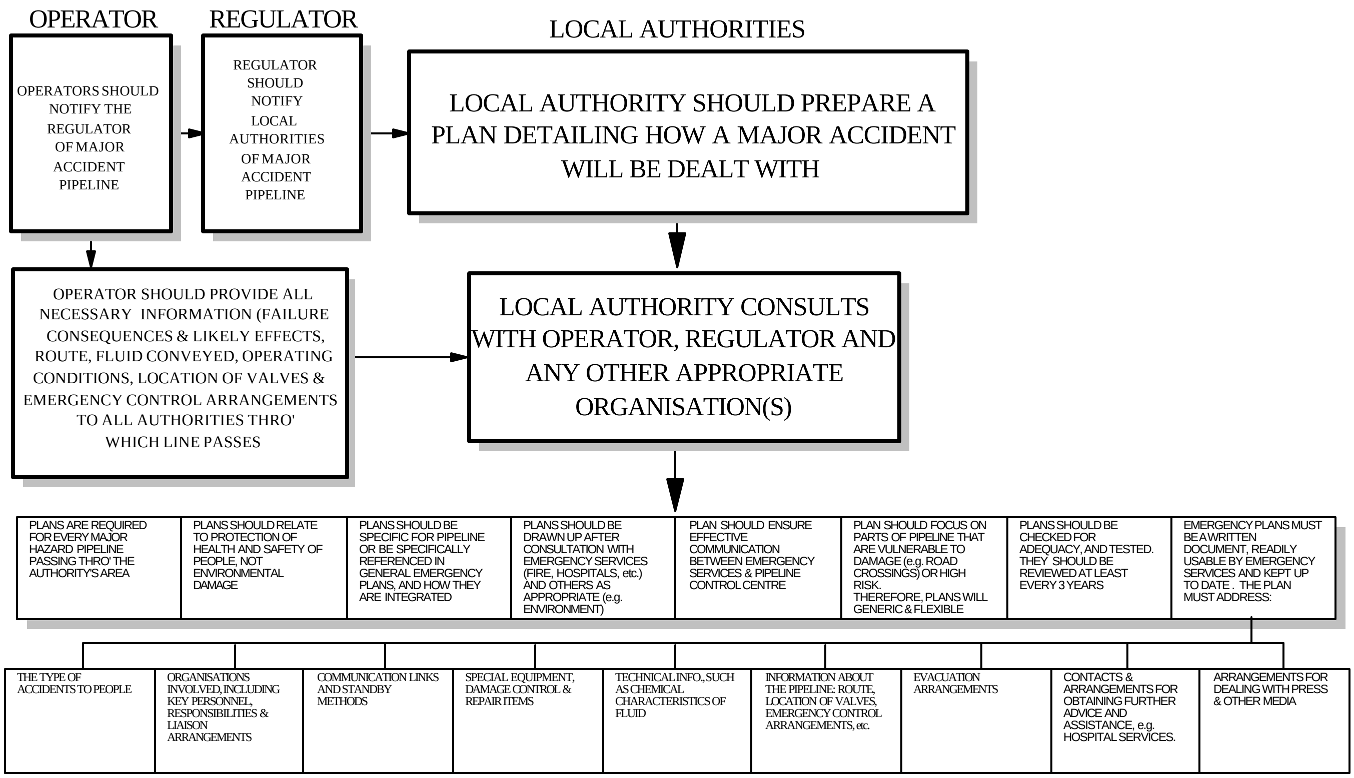

Figure 10. Key Elements of Emergency Planning (4,5)

5.5 Emergency Procedures

Again, References 4 and 5 give us a good summary of the requirements for (in this case) emergency procedures, Figure 11.

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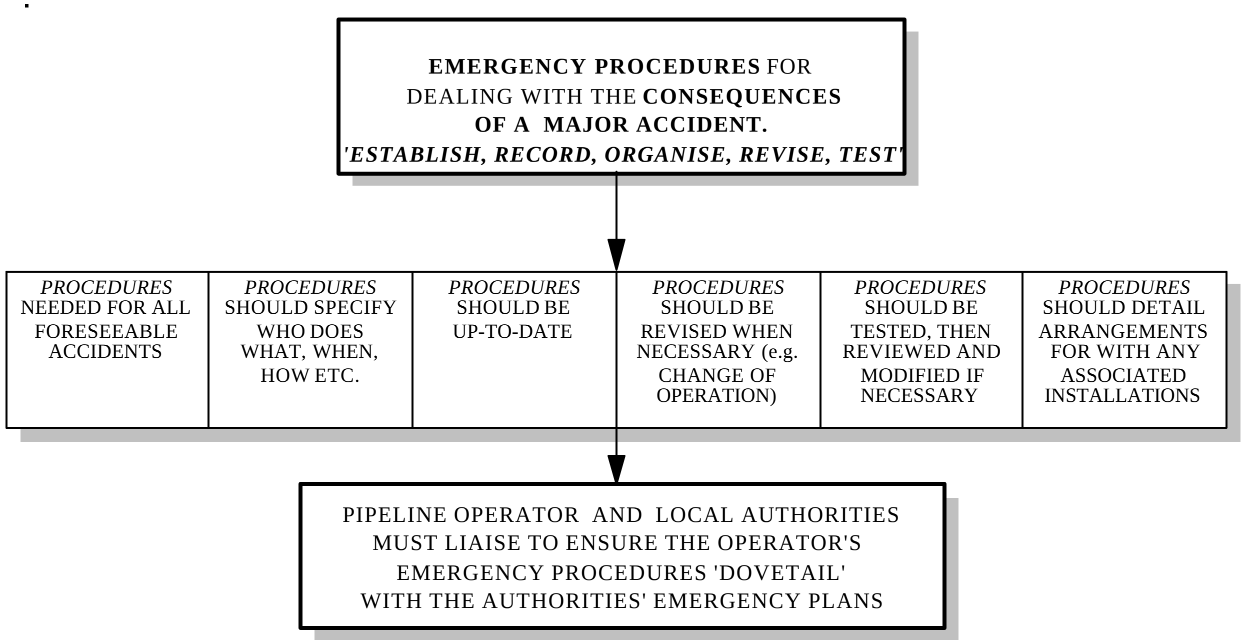

Figure 11. Key Elements of Emergency Procedures for Inclusion into a Risk Management System (4,5).

5.6 Review and Audit of the System (6)

The whole risk management system (organisation, plan, implementation, processes utilised, and performance measures in place) should be regularly **reviewed** against specified criteria. The review must have 'teeth', i.e. where deficiencies are identified, procedures must be in place and implemented to ensure rectification. Indeed, a performance measure for the whole system is the speed of the review and implementation of recommendations and changes.

Finally, the whole system, and all its elements should be subject to regular **audit**. This audit should not be a '*compliance audit'*, that merely checks that the paperwork is in place, and the staff are following all the policies, etc.. The audit should be a *'critical audit'*, that appraises both the system in place, and each element, to ensure it is performing its stated function effectively.

5.7 The Way Ahead

The previous sections have outlined a complete pipeline risk management system. It is now a relatively easy step to include this system into a pipeline company.

The preferable way to do this is to follow the above steps (Table 2), and produce a 'paper-based' system. At the core of this system will be a risk analysis (Item 8, Table 2). This analysis can be either quantitative or qualitative. A qualitative analysis is usually the preferred first step, and this should show an operator the key risks, and they can be quickly addressed. Quantitative analysis can follow this first step, if necessary, but in both cases (quantitative and qualitative) expert judgement and analysis will be required. Later versions of the system could be in the form of software.

Pipeline operators are strongly recommended to adopt these risk management systems for the benefits summarised in Section 3, and their increasing regulatory and industry-wide adoption (Section 2).

6. Conclusions

This paper has covered two major new applications for pipeline operators: risk managment methods, and management systems.

It has shown how the risk management methods and recommendations from North America and Europe can be combined to create a comprehensive 'risk management system'. This system includes all aspects of the integrity and safety management of a pipeline (including emergency plans and procedures), and is positioned within an overall pipeline management system.

A risk management system can be constructed using the guidelines detailed in this paper. It can be a time-consuming exercise, that needs the support of all levels of staff to both compile it, and implement it successfully. Pipeline operators are strongly recommended to produce these risk management systems, as they provide significant benefits, and are increasingly being adopted by the industry and regulatory authorities.

Acknowledgements

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[6] A ‘Benchmark’ serves as a basis for self-assessment performed by Member States to compare their existing legislation.