Eindhoven University of Technology

MASTER

Cross country defence management
a case study into the management of defences in the pipeline industry

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Cross country defence management

A case study into the managing of defences in the pipeline industry.

Preface

This thesis reports of pipeline incidents and accidents, it evaluates and comments events suddenly happening as the result of the breaching of layers of protection.
The reports reviewed and studied all tell how it could come to this climax of destruction and devastation, how apparent unimportant issues all interacted and became important. The cross case analysis exposes the commons in behavioural patterns. Based on this analysis a defence model is developed.

This thesis concludes the many hours of attending evening courses, preparing for exams and reading and evaluating incident and accident reports, hours I could or perhaps should have spend with my lovely wife Linda.
I hereby wish to express my gratitude for her everlasting support and understanding, thank you my dear.

This thesis is also the result of the professional support of Mr. Wim Wenselaar and Dr. Fred Lambert, my thanks for your patience and your support.
A special word of thanks for Wim who made my graduation possible in his own unselfish manner, thank you,

Thank you all.

Peter Beens
Amstenrade, June 2010

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ACRONYMS AND DEFINITIONS

ARG	Aethylen Rohrleitungs Gesselschaft GmbH& Ko KG (german): Germany based joint venture, pipeline owner
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
Accidents	Unexpected sudden sequences of events, with undesired outcomes inflicting damage to people, property and/or the environment.
Active failures	Failures made by those in the *operational process,* which result into *deviations*.
ALARP	as low as reasonably possible
BRZO	besluit risico zware ongevallen (dutch):dutch Seveso II directive
CEPS	Central European pipeline system
CONCAWE	CONservation of Clean Air and Water in Europe
Deviation	A transformation in all its aspects of an espoused theory and people's perception thereof
DOT	Department of Transportation (US)
EGIG	European Gas pipeline incident data group
EPNG	El Paso Natural Gas company, a pipeline operator
Espoused theory	the prescribed way people should act in an organization.
F&EI	fire & explosion index
GFT	general failure type
HAZOP	hazard and operability
HCA	High consequence area
HRO	high reliability organizations
HSE	Health & Safety Executive
ILI	In line inspection, by means of some kind of intelligent pig
Incidents	The combined set of accidents and near misses
LOC	Loss of containment
LOPA	Layers of protection analysis
MTBE	Methyl Tertiary Butyl Ether, additive in unleaded gasoline that increase its oxygen content
NEB	National Energy Board (Canada)
NTA	Technical Practice (Dutch: Nederlandse Technische Afspraak)
NTSB	National Transport Safety Board (US)
Operational process	The process that combines human factors, organizational factors and technical factors into a desired output
OPS	Office of Pipeline Safety (US)
OSFM	Office of State Fire Marshall
PALL	Pijpleiding Antwerpen Luik Limburg (dutch), pipeline connecting SABIC to the Antwerp harbour
PDCA	Plan Do Check Act; this cycle was originally developed by Walter A. Sheward.
PDM	Pipeline Defence Model
PHMSA	Pipeline and Hazardous Materials Safety Administration

	(US)
PIM (S)	Pipeline integrity management (System)
PLUTO	Pipe line under the ocean
PRB	Pijpleiding Rotterdam Beek (dutch), pipeline connecting SABIC to the Rotterdam harbour
Precursors	Pre-warning signs of accidents, which are defined as re-occurring deviations in an operational process
RCA	Root cause analysis
ROW	Right of way
RSPA	Research and Special Programs Administration
SABIC	Saudi Arabian Basic Industry Corporation
SCADA	Supervisory control and data acquisition
Serious incident	PHMSA defines a serious pipeline safety incident is an event involving a fatality or injury requiring in-patient hospitalization.
TPI	Third party interference or external interference
TSB	Transport Safety Board (Canada)
VROM	Ministry of Housing, Spatial Planning and the Environment

Summary

Pipeline transport is believed to be one of the safest means of transport. The pipelines, many of them transporting toxic or explosive liquids and gasses under high pressures, are buried under ground and are invisible to society's eye, they carry products to and from chemical production sites and are crucial to industry and therefore to society. On the other side the mere existence of these pipelines can pose a risk to their direct surrounding

This thesis addresses the problem of pipelines giving way below their design conditions and the first research question to be answered is how pipeline accidents can still happen, when all pipeline failure types have been identified and all appropriate defences are in place.
These incidents and accidents could only have happened when defences or better layers of protection were breached; even though the knowledge of pipeline failure types is comprehensive, as is shown in the Dutch NTA 8000.
The obvious relation between pipeline failure and layers of protection leads to the second research question how layers of protection can become breached. To support the answering of the two research questions six additional sub questions are formulated. To test the study's validity two hypothesises are posed.

The research focuses on incidents and accidents in the pipeline industry and aims at identifying and clarifying risk management processes in the pipeline industry. This needs a research method that investigates a contemporary phenomenon within its real-life context where the boundaries between phenomenon and context are not clearly evident and where no need of behaviour control is required; Case study research (Yin, 2003). In this study construct validity will be addressed by the use of multiple sources for data collection because any finding or conclusion in a case study is likely to be much more convincing and accurate if it is based on several different sources of information, following a corroboratory mode (Yin, 2003). The complimentary use of grounded theory (Strauss & Corbin, 1990), where emerging patterns of behaviour are theorized is pattern matching in itself. The derived case protocol ensures that all cases are approached in a similar manner so replication logic will take place and the constructed database "Casebase" ensures the reliability of this study.

Theoretical background was found in current risk management models and in incident and accident causation theories. From these theories this thesis' view on the origin of incidents and accidents was developed
To study the pipeline incident and accident backgrounds the databases of PSHMA, NTSB, OSFM and TSB and the reports of CONCAWE and EGIG were consulted.
The databases and reports were studied with emphasis on factors that are believed to be the precursors (defined as re-occurring deviations in an operational process, Körvers, 2004), leading to these pipeline incidents and accidents. For this study a case study protocol was developed.

For this study hundred (100) cases were reviewed of which the fifty six (56) Concawe and EGIG case reports were found not to be conclusive enough, forty three (43) cases, retrieved from the PSHMA, NTSB, OSFM and TSB databases were reviewed based on the case study protocol and one (1) case was reconstructed based on available documentation. The line up of the 100 cases shows that 40% was caused by TPI and 11% was caused by pipeline operation (miss operation). 68% of the TPI cases were reported in Europe.
The 100 cases report of 99 fatalities and 259 injuries.
In the thesis six (6) cases are presented, two (2) to example the accident causation theory developed and four (4) to example the case study protocol.

Cross case analysis shows a lack of data alignment, a lack of clear communication and deviations of organizational procedures that created the opportunities for the accidents to happen. It is the involved parties lack of overview and ability to recognise precursors, their underlying organizational root causes (the latent conditions) and their possible effects on the pipeline's defences.
In case of pipeline operation as cause where clear failures, like causing a rupture or restart pumps after a pipeline was ruptured were identified, one can argue the underlying cause to be lack of data alignment, clear communication and deviation of organizational procedures by the operator. The cases where the operator wrongly anticipated on locally independently developing accidents also showed lack good communication and data alignment.

The case study showed how layers of defence can be breached and the generic pipeline failure route shows how pipeline accidents can still happen. It also showed that without data alignment no defence management is possible and that a pipeline defence management system can control risks at an operational and tactical level.
Based on this analysis a pipeline defence model is developed, adapted from Körvers (Körvers, 2004) reasoning and possibilities model.
This model is tested in a simulation of one of the cases.

This thesis concludes with the evaluation of the single case simulation, some overall conclusions regarding risk management in the business and ends with some suggestions for further research on the PDM (Pipeline Defence Model) concepts.

Bookmaker

Chapter one (1) introduces the pipeline industry as the field of research for this thesis' study. The pipeline industry operates and maintains cross country pipeline systems through which a variety of chemical and petrochemical products are transported. Being buried underground these transports mostly take place without being noticed by societies eye, unless an incident attracts societies attention.

Chapter two (2) presents the research scope and research questions, here the underlying problems leading to the giving way of a pipeline under design conditions or less are focused upon by the construction and posing of research questions. This is what this thesis is about; How can pipeline accidents still happen, when all pipeline failure types have been identified and all appropriate defences are in place and how can layers of protection become breached?

Chapter three (3) elaborates on the research methodology and strategy leading to a multiple case study design complemented by some distinct elements of Grounded Theory. The cases under study are extracted from several international pipeline incident databases.

Chapter four (4) brings the theoretical background to the subject by the presentation of the risk management idea's and techniques and closes with the risk management standards for the pipeline industry. The Standards risk management models, referred to as integrity management systems by the pipeline industry, are worked out based on the consequences in case of an incident.

Chapter five (5) starts off with backgrounds on pipeline incidents and accidents thus enabling the creation of this thesis' view on accident causation illustrated by two (2) accident examples, extracted from this thesis' database Casebase. The Chapter closes off with the presentation of the international databases and some statistics regarding pipeline incidents.

Chapter six (6) opens with the presentation of the case study protocol based on this thesis' view on accident causation and the definition of the operational process. Then four (4) cases around severe pipeline accidents with fatal outcome will be presented. In case breakdowns the net effect of the pipeline operator's defensive actions will be made visible leading to the underlying causes.

Chapter seven (7) again presents the research questions and the hypothesizes, but now, in case of a research question to complete them with the answer or in case of a hypothesis to test it.

Chapter eight (8) introduces the pipeline defence model. The model is adapted from Körvers (Körvers, 2004) reasoning and possibilities model and shows possible defence strategies to arrest the development of an incident. The Chapter closes with the simulation of the defence model on the Bellingham case.

Chapter nine (9) concludes this thesis with the evaluation of the defence model's simulation and some overall conclusions ending with research opportunities.

Chapter 1 Introduction

In this chapter the chemical company SABIC-Europe is introduced, a world class chemical company with production sites in the Netherlands, Germany and Great Britain.
The pipeline department is operating and maintaining the company's pipelines transporting products to and from the production sites
Furthermore will the pipeline business be introduced in order to construct the background and environment where the research will be conducted.

1.1 SABIC-Europe[1]

The Dutch State Mines (later DSM)[2] were founded in 1902 and the first mine, Wilhelmina became productive in 1906 and in 1919 the first cokery, Emma was built to produce cokes and in 1921 a by-product of the cokery, methane gas was transported to the nearby city of Sittard for heating an cooking.
Another by-product, the hydrogen gas was being used to make Ammonium for the production of fertilizer.
This first step in the production of chemicals. was followed by the production of Caprolactam a base material for Nylon in 1952, the starting of the production of Urea in 1956 and the start up of the first high pressure polyethylene plant in 1959. The first steam cracker was built in 1963.
The 1970s and 1980s were times of strategic reorientation for DSM. The company eventually decided to divest its petrochemicals operations.
In 2002, SABIC (Saudi Basic Industries Corporation) acquired DSM Petrochemicals, thus gaining production plants in Geleen (the Netherlands) and Gelsenkirchen (Germany).
This marked the first major acquisition of SABIC outside the Middle East. The head office of SABIC Europe was established in Sittard (the Netherlands) and defines the cutting-edge in flexible workplace design; it offers a perfect illustration of SABIC Europe's ambition to be an innovator, not a follower.
SABIC Europe's new head office building was officially opened in September 2006.

Photo 1: SABIC Europe Head office at Sittard.

In 2006, SABIC acquired Huntsman's European Base Chemicals and Polymers business, with production facilities in North Tees and Wilton (UK).

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[1] http://www.sabic.nl/_en/#
[2] http://www.dsm.com/nl_NL/html/about/unlimited_dsm_2006.htm

The integrated world-scale production facilities are based in Geleen (the Netherlands), Teesside (United Kingdom), and Gelsenkirchen (Germany), with a total yearly production of almost 9 million tons of petrochemicals.

In Europe, apart from polyethylenes and polypropylenes, SABIC also produces chemical products like olefins, benzene, acetylene, and MTBE (Methyl Tertiary Butyl Ether).

Geleen is also the hometown of a state-of-the-art Research & Development centre and the highly qualified Technical Marketing team for expert technical support.

SABIC Europe includes the sales organization for all SABIC products manufactured elsewhere in the world. SABIC sales in Europe amount to almost 11 million tons of polymers, base chemicals, and intermediates. SABIC's sales offices operate from the Netherlands, the United Kingdom, France, Germany, Italy, Spain, Denmark, Poland, the Czech Republic, and Turkey.

SABIC also operate strategically located logistic hubs (warehouses) and storage tanks in key ports in the Netherlands, the United Kingdom, Belgium, Italy, Spain, Sweden, Poland, and Malta. These serve to optimize the supply chain and secure an uninterrupted flow of products produced in Saudi Arabia and marketed in Europe.

1.2 SABIC's pipeline department

SABIC's pipeline department is a Service Provider for cross-country pipelines that carry chemical and petrochemical products. Its service package is focused on the management of pipeline integrity and pipeline transports and comprises design, maintenance, supervision and operational control activities.

SABIC's pipeline department has her office in Urmond (the Netherlands) and operates and maintains four pipelines with a total length of about 925 km in the Netherlands, Belgium and Germany for 4 pipeline companies: ARG, SABIC (PALL and PRB) and LVM. Its services are offered, as independent service provider in an area with a high level of interaction with governments, regulators, landowners, local authorities and first response organizations (e.g. fire brigades). The pipeline networks consist of underground pipelines, as well as above ground pipeline systems and pumping installations.

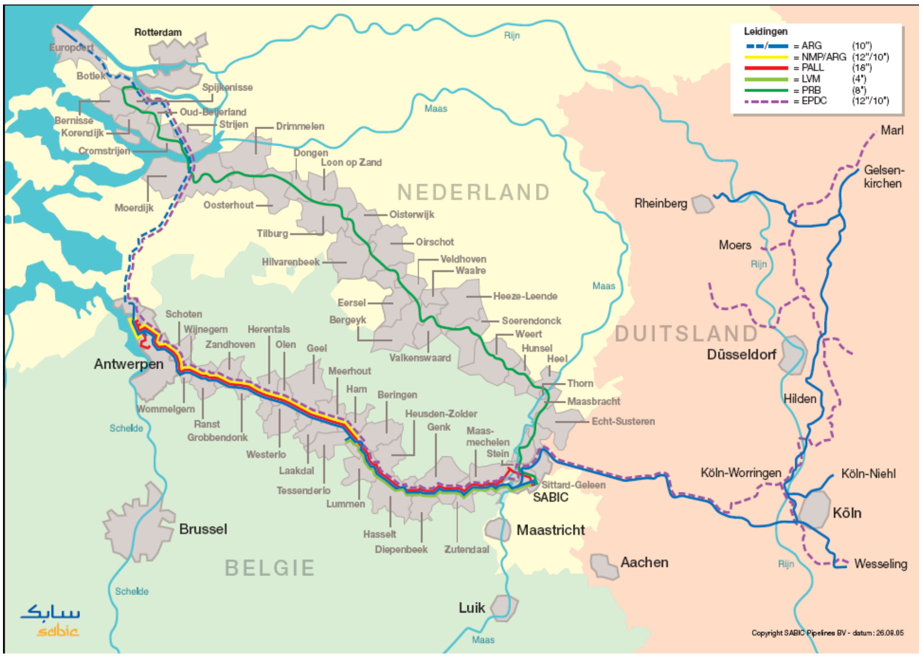

Figure 1: SABIC - pipeline routes

In the context of SABIC regulations, national regulations and demands of the pipeline owners, operation and maintenance of the pipelines are performed.

SABIC's pipeline department has a continuously manned control room, dispatchers, engineering department and maintenance organization. Its main mission is to operate the pipelines safely and at a high quality level in an environment of risks introduced by third parties, with a philosophy aimed at minimal environmental impact and risks and maximum availability of the pipelines.

The SABIC control room performs dispatching tasks and is allowed to follow up and contract transports directly or indirectly under (remote) supervision of dispatchers. Its uninterrupted operation, pipeline integrity and volumetric competences are the key factors for success.

1.3 Pipeline industry

Pipeline companies operate and maintain cross country pipelines on behalf of a parent company, Third Party owner(s) or for their own risk and benefit.

Pipeline companies can roughly be divided into two categories:

- A pipeline company can be a specialised department of a chemical company operating this company's pipeline(s), often structured as a daughter company and organisationally mirrored to the parent company. This also means that the parent company rules and culture, e.g. safety rules will be followed; job rotating programs do intensify the company rules and culture embedment process.
- An independent pipeline company owning the pipeline(s) they operate and which do not have a parent company overlooking their activities and therefore all structure in organisation and company safety regulation will have to be developed by the company itself. The culture will grow into the company.

Third Party owned pipelines can be operated by either category of Pipeline Company.

For instance SABIC, has a specialized department that is operating and maintaining SABIC owned pipelines and Third Party owned pipelines.

1.3.1 The pipelines

Since the beginning of civilisation the concept of volume transport was applied to make growth sustainable. The Phoenicians were first in building a volume transport system, stone aqueducts, later the roman engineers built aqueducts and some of them with quite some similarity with pipelines, see Photo 2.

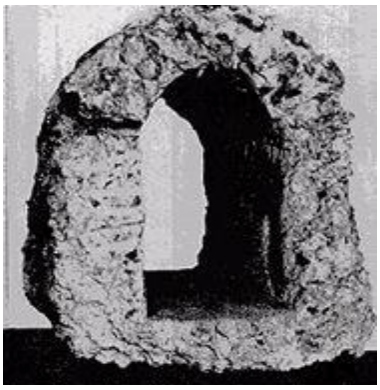

Photo 2: Actual portion of Ancient Roman Aqueduct

Over 359 miles of aqueduct led into ancient Rome, 304 miles of which were underground. It has been reported that around 100 AD the nine aqueducts supplying Rome had a total capacity of 84 million gallons per day. (Abrahams, 1975)

The Roman legislation for the aqueducts, if any, would have been directed towards the protection of their content; the water, the absence of water would have led to death, disease and destruction.

The Industrial Revolution brought cast iron as material for pipelines for the transport of water.

In the Netherlands the first pipeline for the transport of water was constructed in 1852. During World War II fuel was of the utmost importance to the Allied forces A pipeline project called PLUTO (Pipe Line Under The Ocean) would make the invasion fuel logistically possible. In September 1944 the construction of an 8" steel pipeline between Wight en Cherbourg was

completed. The allied forces immediately started the construction of a widespread concealed pipeline network called CEPS (Central European Pipeline System).
The first pipeline for cross country transport of natural gas was constructed in 1951
Before 1951 gas was produced locally by city gas companies, the Dutch State Mines which provided the south of the Netherlands with mine gas, Shell Pernis so there was no need to transport gas cross country over greater distances.

The pipelines, many of them transporting toxic or explosive liquids and gasses under high pressures, are buried under ground and invisible to society's eye, they carry products to and from chemical production sites and are crucial to industry and therefore to society. On the other side the mere existence of these pipelines can pose a risk to their direct surrounding.
It takes considerable effort to construct a pipeline and although many of the existing pipelines once were built in rural surroundings they now are threatened by expanding urbanisation.
The case is, that on many occasions there is a conflict of interest between an existing pipeline and an urban expansion plan, and further does the long life cycle of a pipeline, always make a pipeline become an obstacle somewhere along its existence.

1.3.2 The business behind the business

Although it seems obvious that being a pipeline operator company the business is transporting products from one location to another, but getting it there without losing any or harming anybody along the way that's the real business. Even when you are in a situation where you think you have total control there still is some residual risk; what to think about the great many non-organisationally bound unknown individuals that can have an impact on your installations and perhaps stand at the beginning of what might become a bitter end?
Every pipeline operator knows that nothing compares to the danger to society and environment, the damaged image to both company and business, due to an incident with loss of containment.
That is what the business is really about; preventing the hole in the pipe, with all means, at all costs.

1.3.3 The stakeholders

It is in pipeline operation's nature to introduce risks along the pipeline route, this makes not only the pipeline operator and pipeline owner stakeholder, but also third parties like landowners, land users, local communities and local, national and international governments.
Responsibility towards any risks involving buried pipelines is asked for and expected or perhaps better: should be enforced.

Chapter 2 Research scope

In this chapter the research scope and research questions are presented. The chapter starts with an elaboration on the possible causes for a pipeline to give way under design operating conditions or less and the deriving of the underlying problems for those events The chapter ends with the construction and posing of the research questions, the formulation of two hypothesises and the limitation of this study.

2.1 Observations in the business

In the late eighties, early nineties growing legislatorial and societal pressure lead many pipeline companies into adopting some kind of risk management system, often called a Pipeline Integrity Management System (PIMS). These systems vary from highly sophisticated and deeply detailed computer programs to simple manually made up tables and reports.
What seemed to matter in the end is the result; a perception of the risks involved and a prediction of the installation's reliability and preventing the pipe from structural damage.
Characteristic for pipeline operation are the great many external third party actors, evoking a continuously growing stream of information to and from the company, information regarding intended activities nearby the pipeline route thus introducing risks.
Over the years the amount of data has increased to levels only manageable by computer systems while the outbound response time decreased by two times or more.
Also has the impact of third party systems like railway and power lines heavily increased over the years introducing new risk..
It also should be noticed that in spite of the efforts in risk management, in the pipeline industry every year incidents and accidents happen, not all as catastrophically as the Gislenghien accident, described in § 1.2, but still with some kind of risk for the direct pipeline surrounding.
The potential to cause incidents with catastrophic effects has been recognized by the European Council and Papadakis (Papadakis, 1999), studied the comparison between the severity of pipeline incidents and chemical industry incidents.

2.2 The problem

Pipeline operation comes with a basic problem: a possible pipeline failure or pipeline incident.
The main causes for pipeline incidents are:

- The dynamic external environment accompanied by a growing amount of data, introducing new threads
- Pipe intrinsic causes, threads introduced by the pipe itself, its design, its operation and its knowledge base.

A pipeline incident can be prevented when a leading cause or thread is blocked off. In many investigative safety studies like RCA or Tripod this blocking off is referred to as "defence" against a thread. These defences can be a visible like the pipeline coating or invisible like cathodic protection, both defences against corrosion of the pipeline.
Like in the example above there can be more than one defence against a thread, thus forming virtual layers of protection, as visualised in Figure 2.

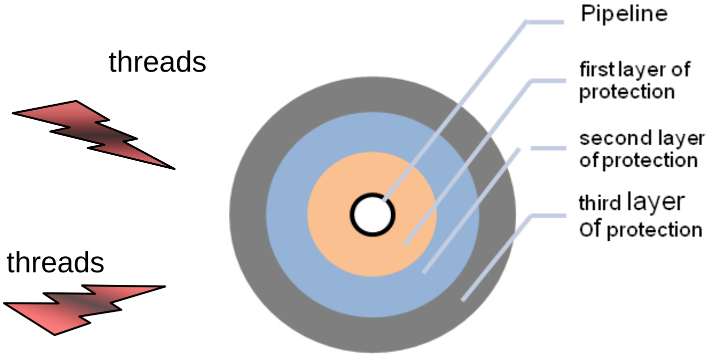

Figure 2: Layers of protection

A solution can best be achieved by a structural approach of the problem described.
This structural approach can be found by formulating research questions, which embody the problem at hand and to answer them.

2.3 Research scope and questions

This research is directed towards the pipeline industry, an industry considered to be one of the safest when transporting large volumes of liquids and gaseous chemicals and hydrocarbons over great distances by large diameter pipelines and high pipeline pressures, both attributing to the consequences of a pipeline failure.
Despite this perceived safety, it is observed, that every year incidents and accidents happen in the pipeline business, thus leading to the first research question formulated as;

How can pipeline accidents still happen, when all pipeline failure types have been identified and all appropriate defences are in place?

These incidents and accidents could only have happened when defences or better layers of protection were breached; even though the knowledge of pipeline failure types is comprehensive, as is shown in the Dutch NTA 8000.
The obvious relation between pipeline failure and layers of protection leads to the second research question formulated as;

How can layers of protection become breached?

To be able to answer these main research questions, sub questions are constructed and if it is assumed that risks emerging from pipeline operation can be assessed and controlled the first sub question can be formulated as;

How can layers of protection be assessed and controlled?

When many parties are involved, like in pipeline operation, it often becomes unclear what and how their interaction is. The success of a risk management process might well be connected to the knowledge of the individual actors involved so the second sub question is formulated as;

How can all the actors involved in the risk management process be identified as well as their influences and interactions?

The presumption that legislation and society have the greatest influence on pipeline operation because all the possible actors together form the society and society is governed by means of legislation leads to the third sub question formulated as;

How can legislatorial and societal influence on pipeline operation be translated into a defence management process?

Assuming that risk management systems and models come in all sorts and varieties, the fourth sub question can be formulated as;

What would be the minimum requirements for a defence management process?

When defence management concepts are defined and known is how to asses, prioritise and control the defences needed for pipeline operation a fifth sub question can be formulated as;

How can these defence management concepts be tested?

The assumption that the risk management concepts can be tested leads to the sixth and final sub question formulated as;

What conclusions can be drawn from the test, with respect to the model's definition and how can these conclusions be translated into the model's definition?

The main purpose of this research is to develop concepts which provide pipeline companies with a better understanding of their possibilities towards defence management and to enable them to further enhance their Defence Management Systems.

2.4 Formulating a hypothesis

The problem is clear and two research questions have been constructed based on this information. Forth going a first hypothesis can be formulated as:

Based on reliable thread assessment and insight in third party activities a pipeline defence management system can control risks at an operational and tactical level.

A second hypothesis can be formulated as:

Without data alignment there is no defence management possible.

2.5 Boundary and limitation

Although the subject is broad, the limitations of this study are given by the industrial branch in which the research takes place: the pipeline industry.
For this industry the societal and legislatorial influences are strong due to the open environment of the businesses' installations; the pipelines are built across the country.
Many of the cases where risk management systems have been breached are documented in European, Canadian and United States' databases.
The boundaries are set on the Canadian and United States' pipeline incident databases to which the reporting of an incident is mandatory and where the conclusive reports are publicly available.
Parallels for the results will be sought in the European pipeline incident databases

Chapter 3 Research methodology

In this Chapter the research methodology used to gain a more complete understanding of risk management models is presented starting by discussing the research process and the research strategy and ending with presenting and elaborating the chosen research model.

3.1 Research process

Research is a logical and systematic search for new and useful information on a particular subject. It is an investigation of finding solutions to scientific and social problems through objective and systematic analysis
Success of a research project is largely achieved through dedication and a steady methodological approach to the work.
Research is broadly classified into two main categories:

1. Fundamental or basic research
2. Applied research.

Basic research is an investigation on basic principles and reasons for occurrence of a particular event or problem. The purpose of basic research is to expand knowledge; where the knowledge is an end in itself. Conducting applied research one solves certain problems using well known and accepted theories and principles (Baarda & de Goede, 2001)
The research described in this thesis is applied research whose purpose is to improve our understanding of the problem with the intent of contributing to the solution of that problem.

3.1.1 Focus of the Research

The outline of the problem in Chapter 2 led to the problem of how to manage risk emerging from pipeline operation and the data accompanying this process, this problem defined the two research questions.
The construction of the research questions and sub questions is very important for the framing of the research. When conducting sound and good research and there must always be a clear linking of the questions to the goal of the research, (Kuijpers, 2008). Furthermore, the research questions should satisfy certain criteria.
According to Punch (Punch, 1998) the research questions must be clear, specific, answerable, and interconnected. If the research questions do not satisfy all of these criteria, problems will occur during the research process. The constructed research questions are then posed, followed by a brief discussion to provide more detail.
In this research two research questions are constructed.

3.2 Research methodology

Given the applied nature of this research, it is methodologically positioned within the design cycle (Roozenburg & Eekels, 1995). Application of the design cycle aims at actively changing an existing reality and creating a new i.e. ‘better’ one by solving a practical problem.
The design cycle is a well-known research model in applied research.
The design cycle is depicted in Figure 3. The basic idea of this research cycle concerns a partial approach and a subsequent integral approach: first the practical problem is analyzed from the parts, and then the integral solution is synthesized for the whole of the parts.

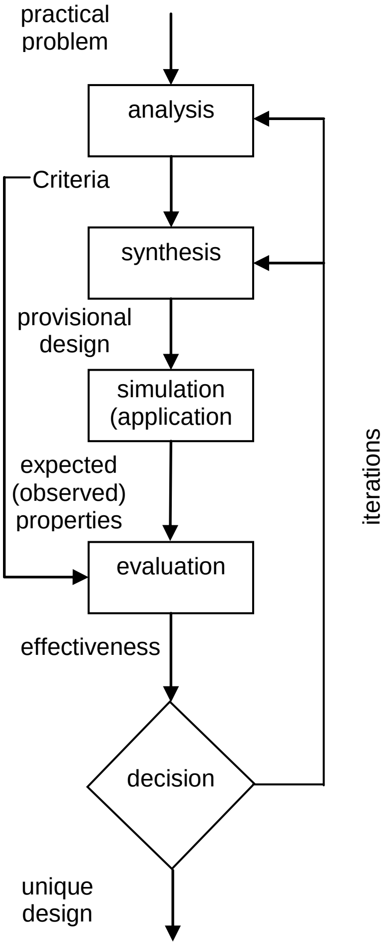

Figure 3: General design cycle (Roozenburg & Eekels, 1995)

Typically, a design process consists of:

- analysis; during the analytical phase the practical problem is decomposed and its parts are analyzed against the concept of the solution in mind,
- synthesis; the diagnosis produces the requirements for the solution, which then are synthesized into a provisional design,
- simulation (application); during the simulation phase, the expected behaviour and properties of the provisionally designed product are judged, using reasoning or model tests
- evaluation;
- decision.

Based on the design cycle (Roozenburg & Eekels, 1995) an adapted research cycle is developed for this research, see figure 4.
This adapted research cycle shows a learning loop in defining the case study protocol, refining the protocol based on the theoretical analysis of the practical problem thus leading to a provisional design.

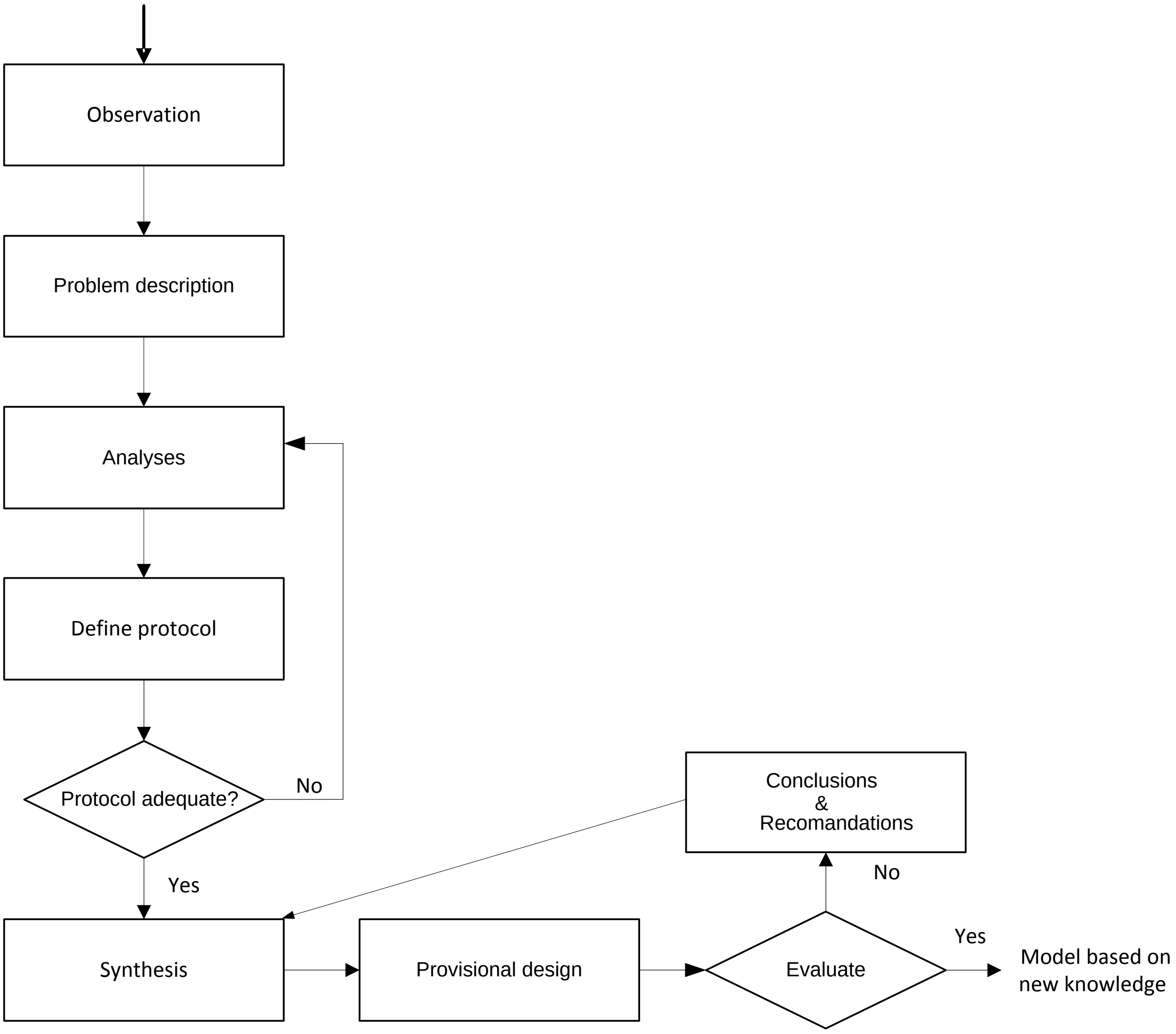

Figure 4: Adapted research cycle

3.2.1 Research strategy

The choice of the most appropriate strategy for the research topic under investigation
is one of the most important choices when designing research. Different methods of collecting and analysing empirical evidence have their own advantages and disadvantages.
Yin (Yin, 2003) discusses for five major research strategies the three different conditions that distinguish which research strategy will be most suitable:
The three conditions consist of (a) the type of research question posed, (b) the extent of control an investigator has over actual behavioural events and (c) the degree of focus on contemporary as opposed to historical events.
Table 1 displays these three conditions and shows how each condition is related to the five major research strategies.

This research aims at identifying and clarifying risk management processes in the pipeline industry, which needs a research method that investigates a contemporary phenomenon within its real-life context where the boundaries between phenomenon and context are not clearly evident (Yin, 2003).

Strategy	Form of Research Question	Requires Control of Behavioural Events?	Focuses on Contemporary Events?
Experiment	how, why?	Yes	Yes
Survey	who, what, where, how many, how much?	No	Yes
Archival analysis	who, what, where, how many, how much?	No	Yes/no
History	how, why?	No	No
Case study	how, why?	No	Yes

Table 1: Relevant situations for Research Strategies (Yin, 2003)

For this research no control of behavioural events is necessary because the processes under study cannot be manipulated but only observed and evaluated.
The research questions constructed in this research are posed in the “how” form.
According to Yin (Yin, 2003) considering these conditions only one strategy remains acceptable; the case study.
With respect to pipeline safety, case histories of pipeline incident and accidents are very important in gaining insight in the risks emerging from pipeline operation and theorise about a risk management systematic to follow.
The case histories are retrieved from the PHMSA[3], TSB[4], CONCAWE[5] and EGIG[6] databases, which are the largest oil and gas pipeline incident databases in the world and together they store more than 13,500 reports concerning incidents with pipelines.

The use of case histories to found principles of risk management processes and theories in the pipeline industry, leads to a complementary strategy called grounded theory ((Strauss & Corbin, 1990).
The three basic elements of grounded theory are concepts, categories and propositions. Concepts are the basic units of analysis since it is from conceptualisation of data, not the actual data per se, that theory is developed. Theories can't be built with actual incidents or activities as observed or reported; that is, from "raw data". The incidents, events, happenings are taken as, or analysed as, potential indicators of phenomena, which are thereby given conceptual labels. Categories are higher in level and more abstract than the concepts they represent. They are generated through the same analytic process of making comparisons to highlight similarities and differences that is used to produce lower level concepts. Categories are the "cornerstones" of developing theory. They provide the means by which the theory can be integrated.
The third element of grounded theory is the proposition which indicate generalised relationships between a category and its concepts and between discrete categories. (Strauss & Corbin, 1990). The grounded theory method aims at generating theory that describes patterns of

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[3] http://primis.phmsa.dot.gov/comm/reports/safety/PSI.html?nocache=4828
[4] http://www.tsb.gc.ca/en/
[5] http://www.concawe.be/Content/Default.asp?PageID=7
[6] http://www.egig.nl/

behaviour, which are relevant and problematic for those involved. The researcher must constantly look for these patterns.
The generation and development of concepts, categories and propositions is an iterative process.

Grounded theory is not generated *a priori* and then subsequently tested. Rather, it is, inductively derived from the study of the phenomenon it represents. That is, discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory should stand in reciprocal relationship with each other. One does not begin with a theory and then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge, as depicted in Figure 5.

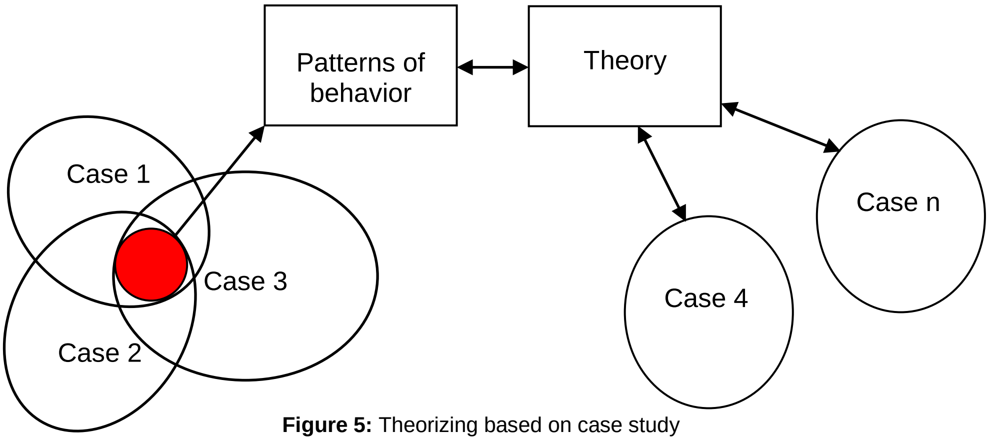

Figure 5: Theorizing based on case study

Case study is argued to be doubtful when it comes to the ability to generalize from it and to cover these doubts you can judge the quality of any given design according to certain logical tests, because a research design is supposed to represent a logical set of statements, (Yin, 2003). These tests are:

- *Construct validity;* establishing correct operational measures for the concepts being studied.
- *Internal validity (for explanatory or causal studies only and not for descriptive or exploratory studies);* establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships.
- *External validity;* establishing the domain to which a study's findings can be generalized.
- *Reliability*; demonstrating that the operations of a study-such as the data collection procedures-can be repeated, with the same results.

Yin, (Yin, 2003) further argues that for case studies, an important revelation is that the several tactics to be used in dealing with these tests should be applied throughout the subsequent conduct of the case study and not just at the beginning. These four widely used tests and the recommended case study tactics, as well as a cross reference to the phase of research when the tactic is to be used are summarized in table 2.
The research design applied in this thesis consists of an embedded multiple case study design.

Tests	Case study tactic	Phase of research in which tactic occurs
Construct validity	▪ Use multiple sources of evidence ▪ Establish chain of evidence ▪ Have key informants review draft case study report	data collection data collection composition
Internal validity	▪ Do pattern matching ▪ Do explanation building ▪ Address rival explanations ▪ Use logic models	data analysis data analysis data analysis data analysis
External validity	▪ Use theory in single case studies ▪ Use replication logic in multiple case studies	research design research design
Reliability	▪ Use case study protocol ▪ Develop case study database	data collection data collection

Table 2: Case study tactics for four design tests (Yin, 2003)

This means that there are multiple units of analysis and multiple case studies performed for collecting data. In this research, distinct sub-units identified in the risk management processes as stated in Chapter 4 will be studied.

3.2.1.1 Construct validity

According to Yin, (Yin, 2003) an investigator must in order to meet the test of construct validity be sure to cover two steps:

1. Select the specific types of changes that are to be studied (and relate them to the original objectives of the study) and
2. Demonstrate that the selected measures of these changes do indeed reflect the specific types of change that have been selected.

In this study construct validity will be addressed by the use of multiple sources for data collection because any finding or conclusion in a case study is likely to be much more convincing and accurate if it is based on several different sources of information, following a corroboratory mode (Yin, 2003) Case histories, documentation, archival records, interviews, surveys and observations provide findings converging in the same line of inquiry, which is called data triangulation, Patton (Patton,1987) see figure 6. In this way the retrieved operational measures are validated.

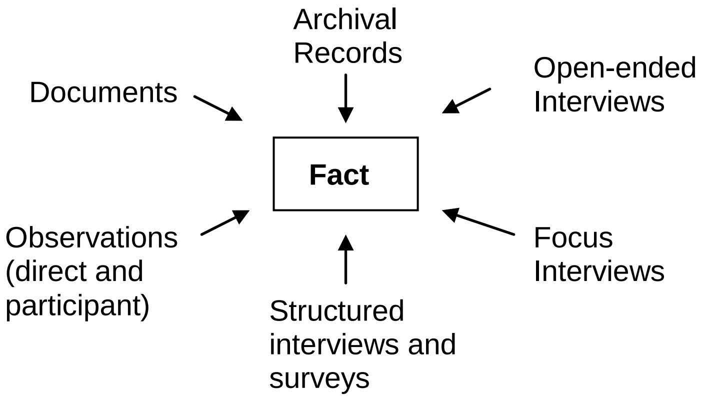

Figure 6: convergence of evidence (adapted and generalised from Yin (Yin, 2003))

3.2.1.2 Internal validity

According to Trochim (Trochim, 1989) pattern matching logic is one of the most desirable techniques to use for case study analysis; such logic compares an empirically based pattern with a predicted one. A complimentary use of grounded theory (Strauss & Corbin, 1990), where emerging patterns of behaviour are theorized is pattern matching in itself.

3.2.1.3 External validity

The cases are selected based on the risk concept as discussed in Chapter 5, in this way all cases are approached in a similar manner. If the results are similar, replication logic will take place. Replication logic is analogous to the logic used in multiple experiments according to Hersen (Hersen & Barlow, 1976). Replication logic increases the extent to which findings can be generalized.
The replication approach to multiple-case studies is illustrated in Figure 7. The figure indicates three stages and that the initial step in designing the study must consist of theory development.

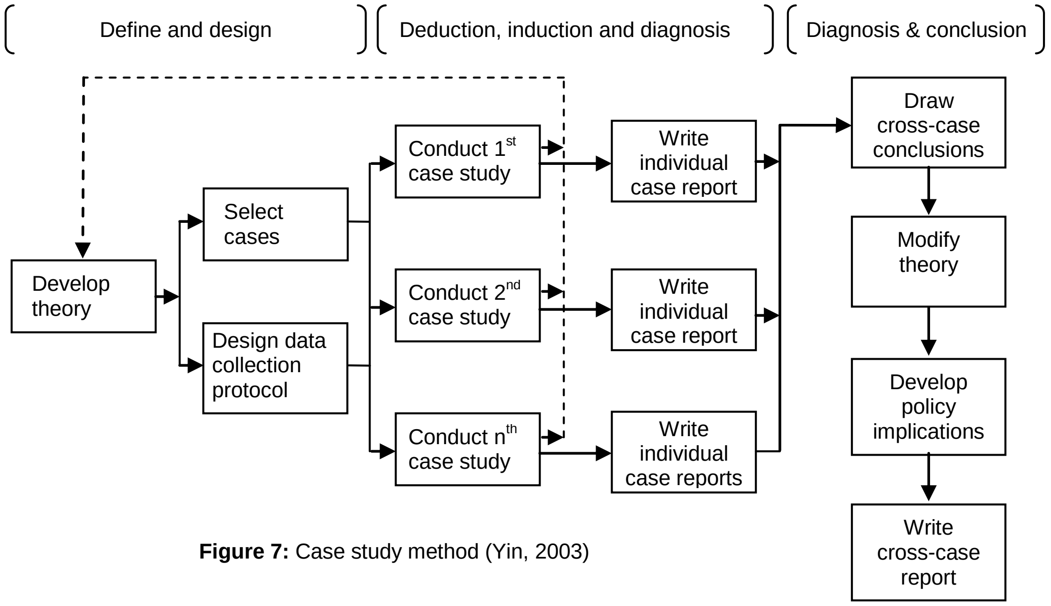

Figure 7: Case study method (Yin, 2003)

3.2.1.4 Reliability

Reliability analysis shows that tasks performed to construct the research can be replicated by other researchers and will result in “identical” findings.
To ensure this a study database named “Casebase” is constructed

3.3 Research design

Because a research design is supposed to represent a logical set of statements, you also can judge the quality of any given design according to certain logical tests. Concepts that have been offered for these tests include trustworthiness, credibility, conformability, and data dependability (GAO Program Evaluation and Methodology Division, 1990)

Figure 8 shows the translation of the adapted research cycle into the research design to be used in this study.
The research design is reflected in this thesis' Chapters, by introducing the relevant industry in Chapter 1 and defining the research scope in Chapter 2.
In this Chapter (Ch. 3) the research methodology is presented leading to this research design.
Chapter 4 will address the current state of risk management processes in the pipeline industry
Chapter 5 will elaborate on the deviations of those processes; the incidents and accidents in the pipeline industry, leading to the defining of the case study protocol and the case study in Chapter 6.
In Chapter 7 the research questions will be answered and the hypothesises tested.
Chapter 8 introduces Körvers reasoning and possibilities model (Körvers, 2004) leading to new concepts for Defence Management and the test of this concept in a single case
This thesis closes off with Chapter 9, the conclusions of the test and its effect on the derived concepts, recommendations and further research opportunities.

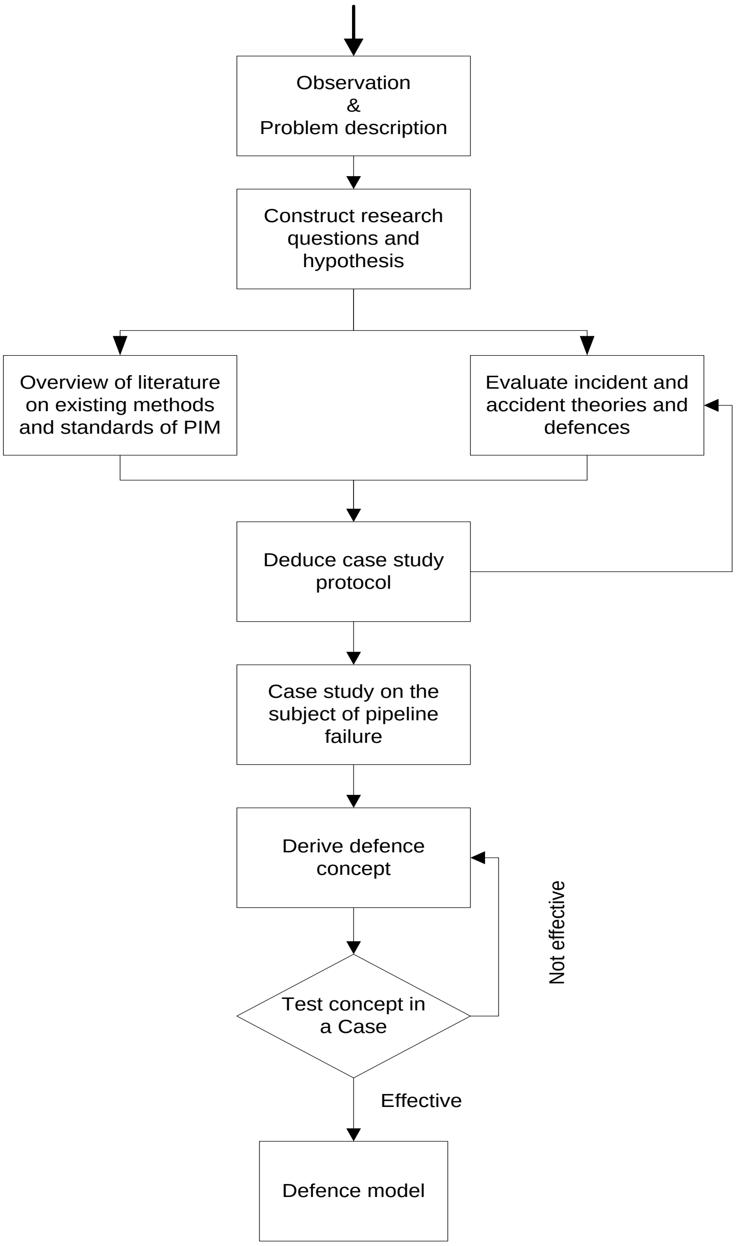

Figure 8: Research design for this study

Chapter 4 Risk management, ideas and techniques

Risk management is practiced in one or other way in practically every business, from hospitals to aircraft carriers, all based on the same desire; to be able to identify and mitigate risks as much as possible. In one of Horace's odes, ode 11 first bundle, it is said "Carpe diem quam minimum credula postero", meaning seize the day, tomorrow we die.
It was Niels Bohr, one of the founding fathers of quantum mechanics, who coined the truism "Prediction is difficult, especially about the future".

4.1 Introduction

In literature risk management is described in many ways, J. Michaels describes risk management as an executive driven process, commitment to excellence, entailing doing things right the first time they are undertaken and ensuring that the technical and financial goals of supplier and customer will be realized to the benefit of both (Michaels, 2005).
ALARM describes risk management as a central part of any organisation's strategic management. It is the process whereby organisations methodically address the risks attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities (AIRMIC, ALARM, IRM, 2002).
Risk management aims to protect the property, income and activities of a company so that the total costs are the lowest possible (Suokas & Rouhiainen, 1993).
My favourite description is by Kearny; although the future is uncertain, it is possible for a business to influence it to a certain extent so as to favour beneficial outcomes and limit the consequences of unfavourable ones.
This is what the field of risk management is about — manipulating an uncertain future, (Kearney, 2007)
This description reflects the needed pro active attitude towards the ongoing process of risk management and it also gives hope by making a promise to the pro-active ones: you can succeed.

4.1.1 Risk management

According to Cox, (Cox & Tait, 1998), (Michaels, 2003), (Suokas & Rouhiainen, 1993), risk management is the term normally applied to the whole process of risk identification, estimation, evaluation, reduction and control.
By ALARM, (ALARM, AIRMIC, IRM, 2002) risk management protects and adds value to the organisation and its stakeholders through supporting the organisation's objectives by:

- *providing a framework for an organisation that enables future activity to take place in a consistent and controlled manner*
- *improving decision making, planning and prioritisation by comprehensive and structured understanding of business activity, volatility and project opportunity/threat*
- *contributing to more efficient use/allocation of capital and resources within the organisation*
- *reducing volatility in the non essential areas of the business*
- *protecting and enhancing assets and company image*
- *developing and supporting people and the organisation's knowledge base*
- *optimising operational efficiency*

4.2 Risk management in the pipeline industry

All the descriptions above fit the principles of the managerial quality systems according to ISO 9001 or ISO 14001,
With respect to risk management or PIMS as it is referred to in the pipeline industry, in some codes, a difference has been made between pipelines transporting gases and pipelines transporting liquids as shown in the Figures 9 and 10.

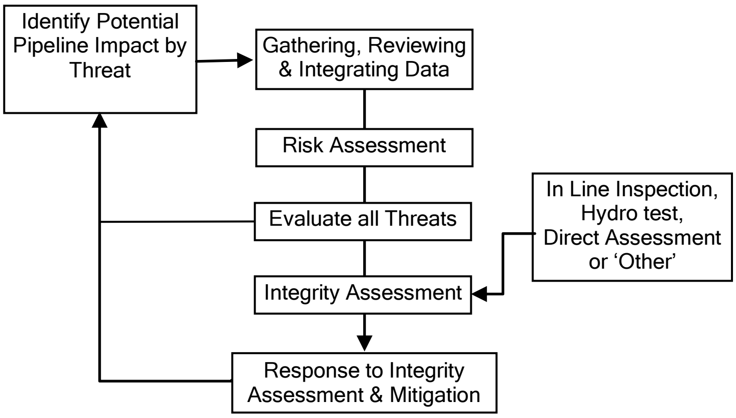

Figure 9: Integrity management process according to ASME B31.8s -2010 for gas pipelines

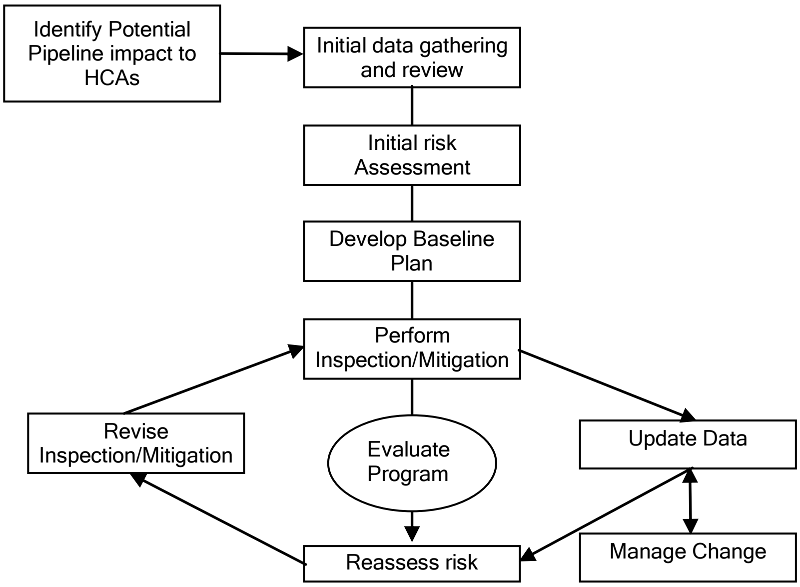

Figure 10: Integrity management process according to API 1160 for liquids pipelines

The ASME 31s' PIMS is focussed on the possible impact of a thread on a gas pipeline this with the gravity of the possible consequences of an accident in mind.
In the integrity management process according to API 1160 for the liquids pipelines a possible environmental impact of an accident is implicitly incorporated in the process by reviewing pipeline's impact on its surrounding, the HCA (High Consequences Area) .
Both codes identify possible consequences for the pipelines' direct environment.

In the Dutch practice NTA 8000 risk management is described as a process based on a continuous PDCA[7] (plan-do-check-act)cycle of risk mitigating activities, as shown in Fig 11.

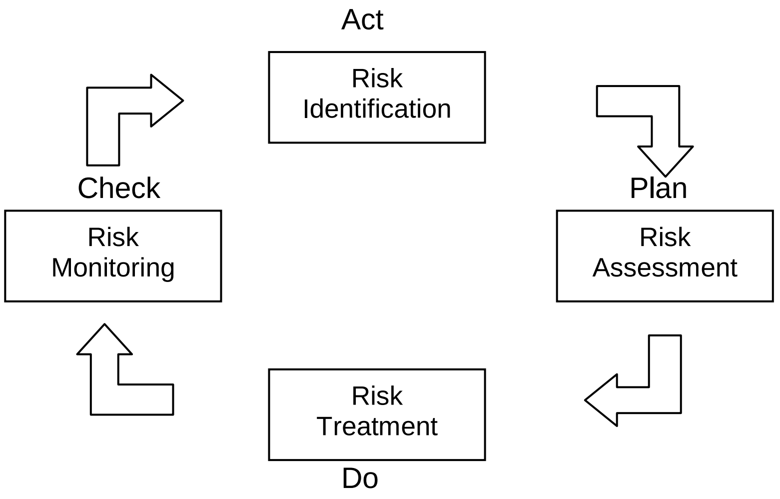

Figure 11: PDCA cycle of risk management activities

In this practice risks mitigation is depicted in so called “Bow-tie” arrangements.
A Bow-tie shows not only the activities (left) leading to a LOC (loss of containment) and the corresponding consequences (right), but also possible lines of defence

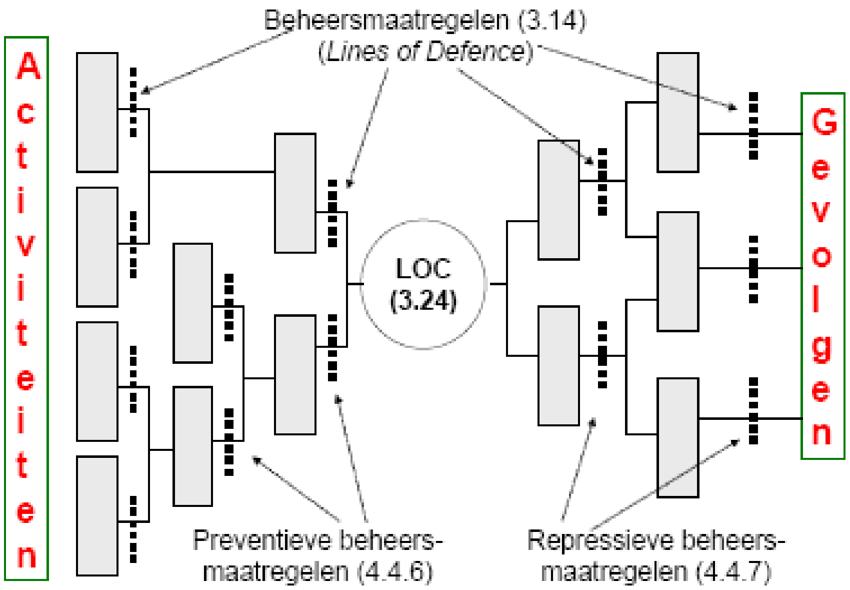

Figure 12: Bow-tie arrangement (Source: NTA 8000 :2008 nl)

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[7] The ‘plan do check act’ (PDCA) cycle was originally developed by Walter A Shewhart, a Bell Laboratories scientist who was a friend and mentor of Deming and the developer of statistical process control (SPC) in the late 1920's.

4.3 Risk and reliability

Indeed a close association between safety and reliability has existed since the early days of mankind where the early hunter gatherers communities used spears and other weapons to protect themselves against wild animals and other hostiles (Cox & Tait, 1998).
A broken shaft or blade could cost a life, so they had to learn which woods and which metals they could rely on and which not, in order to ensure safety (Cox & Tait, 1998).
Through history, the significance of the reliability of weapon design has remained and much of the pioneering work on technical reliability has indeed been carried out by the military.
Until the advent of modern scientific theory, technical progress was made by a sophisticated process of trial and error. Engineers and designers learned not only by their own mistakes but also from other people's misfortunes (Cox & Tait, 1998).
In the pipeline business integrity is used to state the reliability of the pipeline's pressure containing function.

4.4 Likelihood and consequence

Risk is defined by the product of its likelihood and its consequence, for pipelines the former is a relation between defences and pipeline failure mechanisms (or failure types) and the latter has the potential of a major hazard.
With respect to the failing of a pipeline, this can be attributed to several causes but the fact remains that the pipe wall must have been penetrated or heavily damaged in order to have a pipeline failure.
Depending on the failure mechanism more than one defence mechanism must have been breached, in the end the first line or better primary defence being the pipe wall itself.
The generic pipeline failure process is depicted in figure 13, showing pipeline failure types breaching pipelines' defences until the pipeline fails.

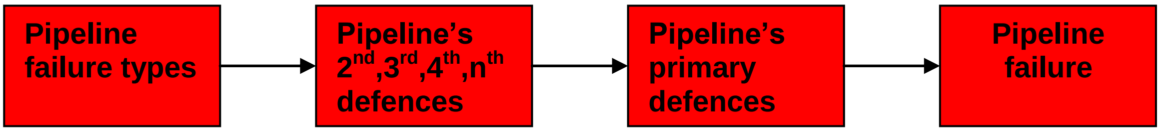


Figure 13: Generic pipeline failure route

At this point it is good to make and introduce the definition of a primary and a secondary, tertiary, etc, level of defence:

- A primary defence is the system's feature or a quality, generically enabling that system or part of it to withstand the effects evoked on it by failure types.
- A secondary defence is the system's feature or a quality, which conjointly with a primary defence enables that system or part of it to withstand the effects evoked on it by failure types.
- A tertiary defence is the system's feature or a quality, which conjointly with a secondary and/or a primary defence enables that system or part of it to withstand the effects evoked on it by failure types and so on

These definitions will prove to be of value in the process of understanding the occurrence of pipeline failure and the analysis thereof.

The more layers of defence against a pipeline failure type the more unlikely the appearance of that particular pipeline failure type becomes.

Chapter 5 Incidents and accidents in the pipeline industry

A single pipeline accident has the potential to cause a catastrophic disaster that can injure hundreds of persons, affect thousands more, and cost millions of dollars in terms of property damage, loss of work opportunity, community disruption, ecological damage, and insurance liability (Papadakis, 1999).

5.1 Introduction

In the wake of the ISO 9000 and ISO 9001 quality performance systems (small) pipeline operator companies started to focus on PIMS.
In 1992, with the introduction of NEN 3650, a base for PIMS was laid down in chapter 13.
According to Papadakis (Papadakis,1999), in the course of the discussions on the Seveso II Directive 96/82//EC (Council Directive, 1997), in both the Council and the European Parliament, three areas were identified as having major accident potential, but were not included within the scope of the Directive because of some inherent differences to chemical installations, namely:

- pipelines,
- ports, and
- Marshalling yards.

In the case of pipelines, both the Council and the European Parliament recognized that accidents had occurred in Europe and worldwide, which clearly indicated the ‘major accident hazard’ potential of pipelines and called for a special study of their case. In this respect, Recital 13 in the Directive 96/82/EC states:
Whereas the transmission of dangerous substances through pipelines also has a potential to produce major accidents; whereas the Commission should, after collecting and evaluating information about existing mechanisms within the community for regulating such activities and the occurrence of relevant accidents, prepare a communication setting out the case, and most appropriate instrument, for action in this area if necessary.

Papadakis (Papadakis, 1999) shows by comparing 67 gas pipeline incidents and 97 oil pipeline accidents against 253 incidents in the “Seveso sites” incident reporting database MARS that pipelines indeed should be considered as a source of industrial ‘major accident hazard’ and that this should be kept in mind when developing a policy on pipelines which should be demonstrably consistent with the overall EU policy on similar industrial risks based on the ‘precautionary principle’. The comparison was made by means of the logarithmic ‘gravity scale’ for accidents (Papadakis & Porter, 1996) and the outcome is shown in figure 14.

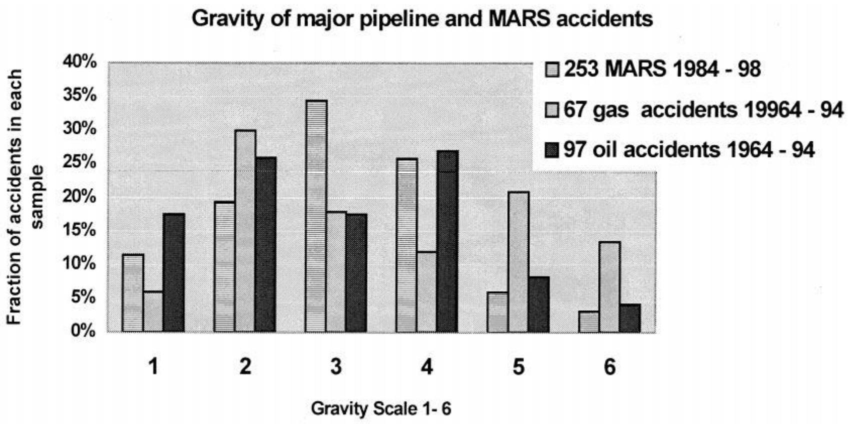


Figure 14: Gravity of major incidents (Papadakis et al., 1999)

Having entered the inter-organisational era, see Figure 15, where incidents and accidents are believed to be originating from flaws in organisational and societal safety culture combined with what best can be described as a lack of understanding the systems and technical interfaces worked with, leading to poor communication and misperceptions, (Körvers, 2004)

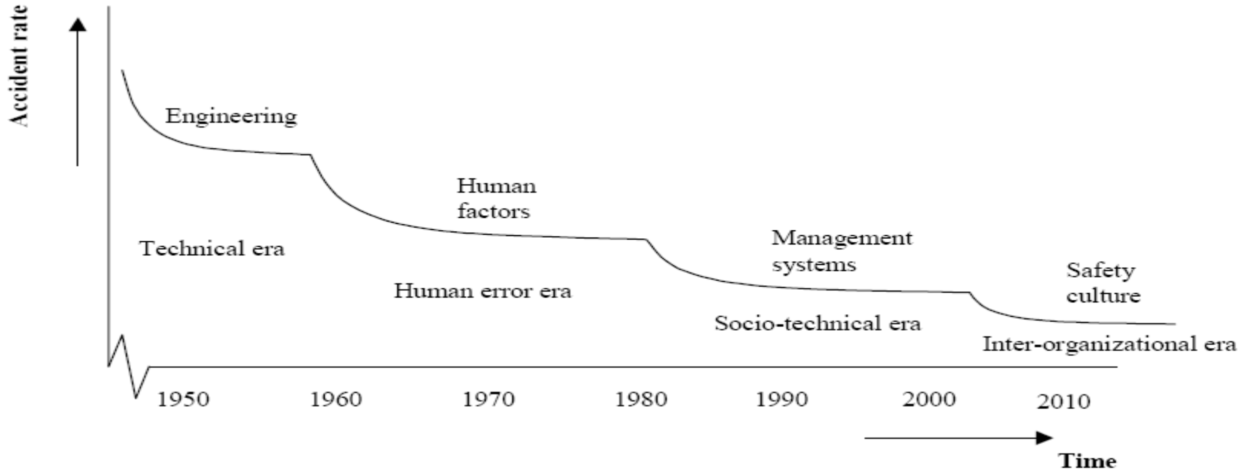


Figure 15: Accident development over time (source: Körvers, 2004)

5.2 Incidents and accidents

Like every other industry incidents and accidents happen in pipeline industry, Figure 16 depicts this thesis' view on the origin of incidents and accidents, all originating from running business, no running business, no pipeline industry, no incidents and no accidents.

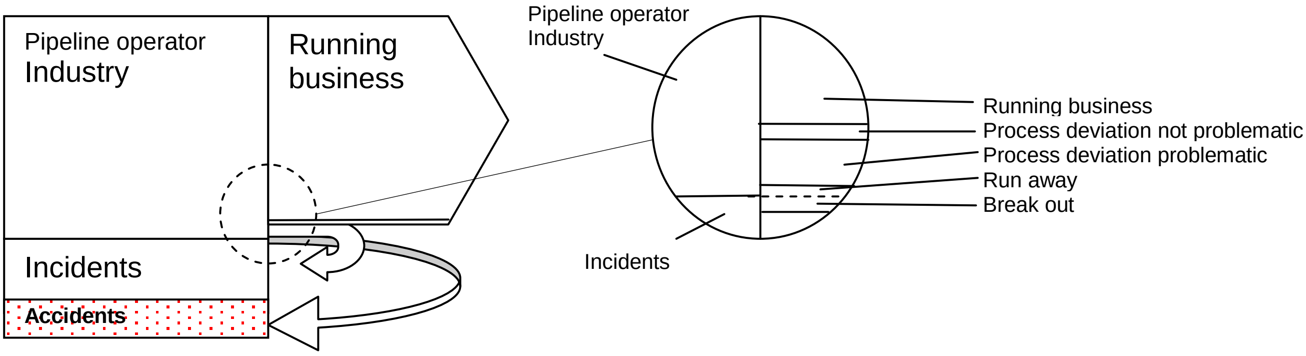


Figure 16: Accidents and incidents

There are two kinds of process deviations; the ones which will not become problematic and the ones that will become problematic and will lead to incidents.
A small fraction of the process deviations which became problematic can become uncontrollable and lead to accidents, a runaway process.

Examples extracted from this study's database Casebase show how a problematic process deviation, the installation of a diversion of the pipeline route can get out of control.

Casebase: Concawe Rpt_03-1-2003-01418-01-E/cs01
Incident description
A 20" crude oil pipeline had been exposed and prepared to install a diversion of its route. To allow the installation to be completed within the available outage time, frozen water plugs were chosen as the method to seal the pipeline for cutting, and a temporary water connection point had been installed for the water filling. Some problems were experienced with the frozen plugs delaying the construction schedule and it was decided to re-supply the refinery with crude oil before commencing with the cutting of the pipeline. As the new water connection was not designed for the pipeline working pressure, a strengthening dome was welded over the connection. When the re-supply pumping was in progress, there was a major failure of the new welds and an 800 m3 spillage occurred. The national authorities are conducting an inquiry to decide on follow-up proceedings. The spillage temporarily affected an area of 10,000 m2. A major clean-up effort has removed all but some 8 m3 of oil at a total repair and clean-up cost of 2.2 MEUR.

Then there are the incidents that although they are identified and being brought under control, will lead to an accident, a break out process. An example extracted from this study's database Casebase shows a situation where many incidents lead to a punctured pipeline although the pipeline operator inspector had regular contact and seemed to have the situation under control.

Casebase: TSB P07H0040
Incident description
At 1231 Pacific daylight time on 24 July 2007, the 610-millimetre (24-inch) Westridge Dock Transfer Line, owned by Trans Mountain Pipeline L.P. and operated by Kinder Morgan Canada Inc.(KMC), was struck and punctured by a contractor's excavator bucket while the contractor was excavating a trench for a new storm sewer line along Inlet Drive in Burnaby, British Columbia. KMC was partly involved in the engineering process, but in the construction package not all KMC's data was correctly drawn up. During construction KMC's inspectors came on site on several occasions to locate their pipeline. The contractor did not come clear when the crossing of the ROW zone would start. Due to miscommunication the pipeline was struck and punctured. When the pipeline was punctured, approximately 234 cubic metres of crude oil was released, approximately 210 cubic metres of which was recovered. Crude oil flowed into Burrard Inlet Bay via the Burnaby storm sewer system. Eleven houses were sprayed with crude oil; many other residential properties required restoration and approximately 250 residents voluntarily left their homes. There were no explosions, fires, or injuries resulting from this occurrence; however, emergency workers and two fire fighters responding to the incident were sprayed with crude oil. Two members of the public were also sprayed.

Casebase: TSB P07H0040

Photos

Figure 17: Incident photos of TSB case P07H0040

The above described incidents luckily only lead to environmental and property damage.

The reason for becoming problematic is argued by James Reason, (Reason, 2000) as flaws and active failures in latent conditions of successive layers of defence, temporally in singular congruence subsequently opening a pathway leading to an incident opportunity, also depicted as the “Swiss cheese model”, see Figure 18.

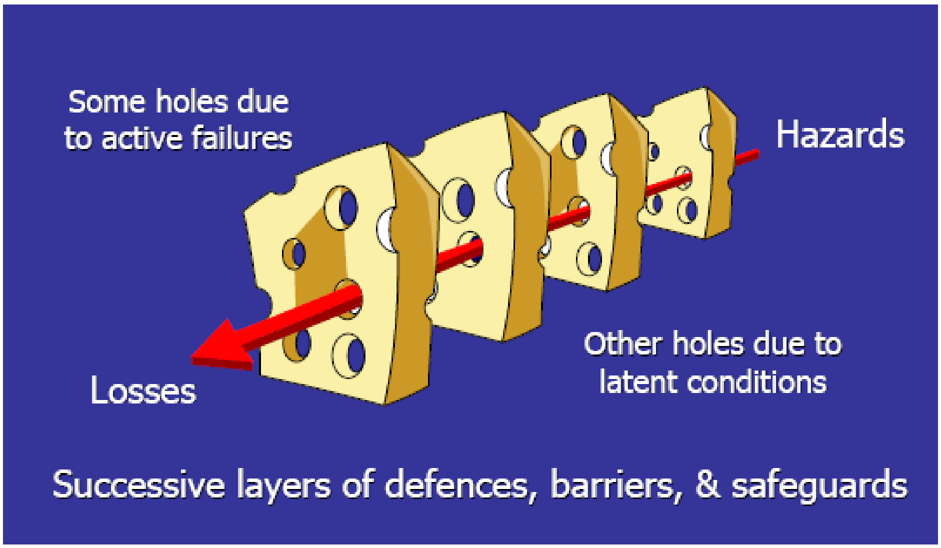


Figure 18: Swiss cheese model by J. Reason (Reason, 2000)

5.3 The statistics

5.3.1 Europe

In Europe the reporting of an incident to EGIG or CONCAWE is on a voluntary base, these databases collect statistical information about failure frequencies and causes of incidents
The creation of the EGIG database (1982) for gas pipeline operators and the CONCAWE database (1971) for liquid pipeline operators has helped pipeline operators to demonstrate the safety performances of Europe's gas and liquid pipelines and to improve safety in their pipeline transmission systems.
Both organizations, EGIG and CONCAWE, report a decline in pipeline incidents over the years as shown in Figures 19 and 20.

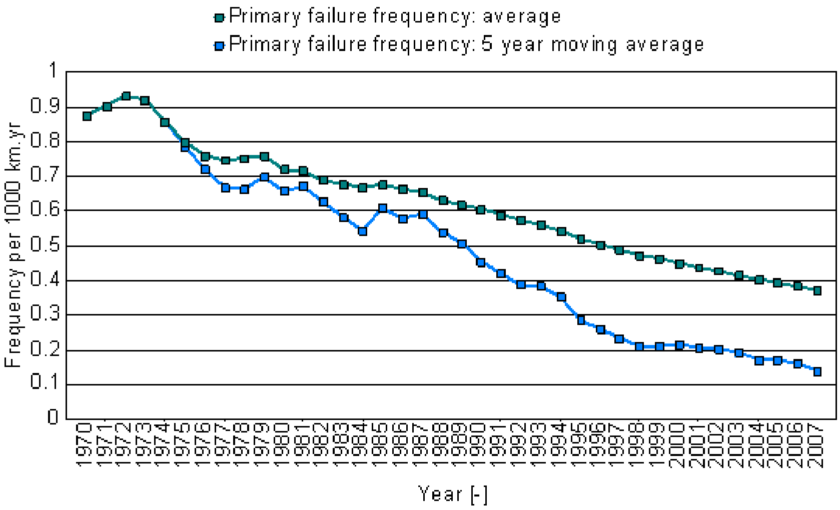


Figure 19: Development safety performance (source: EGIG)

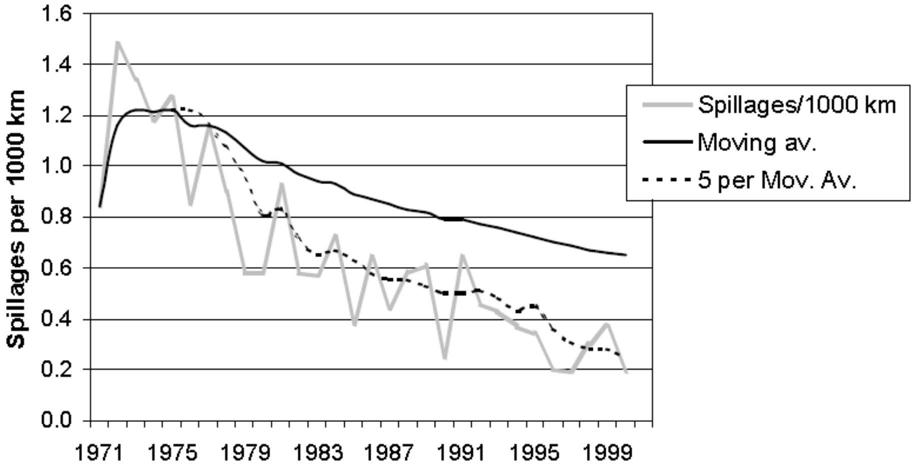


Figure 20: The number of spillages per 1000 km, 30 year trend (source: Report 1/02, CONCAWE)

Their analysis shows the decline being caused by lesser incidents due to corrosion and mechanical failures.
The regulatory incident investigation results if any are not open to the public.

5.3.2 United States

In the United States the reporting of incidents is mandatory, the incidents must to be reported to the Research and Special Programs Administration's (RSPA) Office of Pipeline Safety (OPS) maintains the Hazardous Liquid Pipelines Accident Report database and the Natural Gas Transmission Systems Incident Database, which contains data describing accidents involving hazardous liquid and natural gas transmission pipelines. The databases were established in 1970. The incident investigation is performed by the NTSB

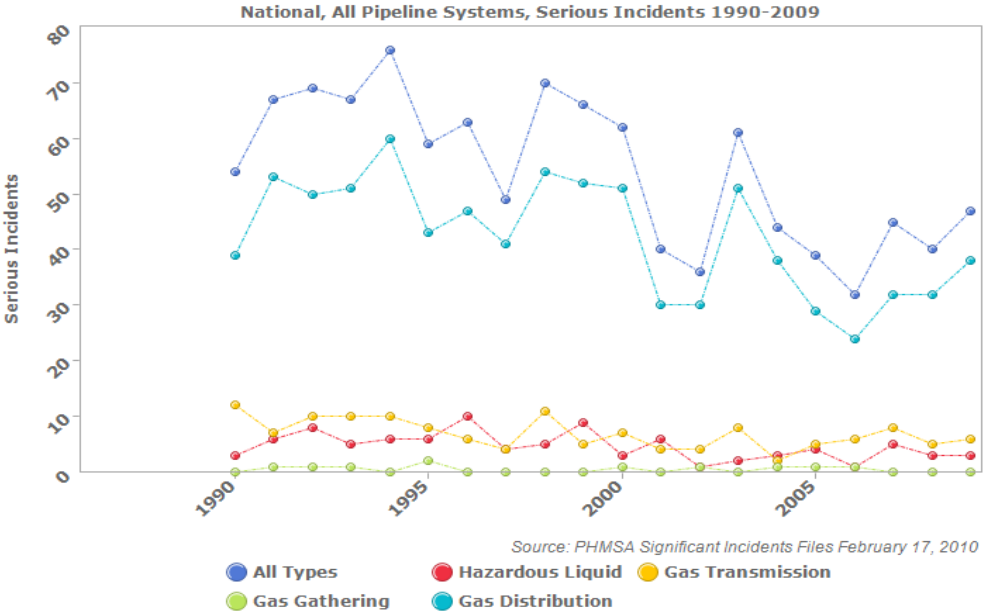


Figure 21: Serious Incidents, 10 year trend (source: PHMSA)

A significant downward trend as the European data shows is not recognizable, the "All types" graph follows the Gas distribution graph in a downward trend, the other graphs show modest decline

5.3.3 Canada

In Canada the reporting of a pipeline incident is mandatory and TSB is responsible for both data collection and incident investigation.

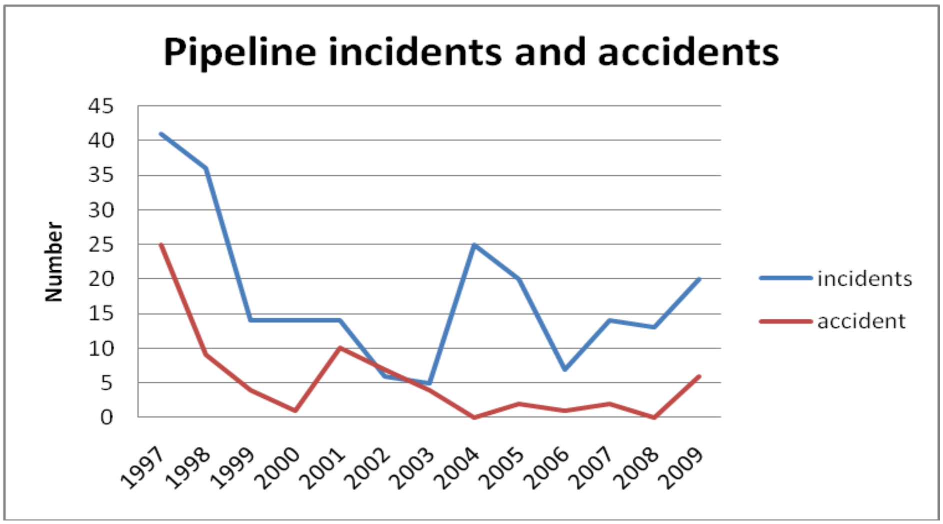


Figure 22: Pipeline incidents and accidents, 10 year trend (source: TSB)

5.3.4 Reporting

The statistics for pipeline incidents are commonly presented by incident cause. The cause categories used in the incident databases are summarized in table 3:

PHMSA	TSB	Concawe	EGIG
Corrosion	Corrosion/ Environmental Cracking	Corrosion	Corrosion
Excavation Damage	3rd Party Damage with release	Third party activity	External interference
Human error		Operational	Hot tap made by error
Material Failure		Mechanical failure	Material failure/ construction defect
Natural Force Damage	Disturbance of Supporting Environment with release	Natural hazard	Ground movement
Other Outside Force Damage			
	Fire/Ignition/Explosion		
All Other Causes	Other Damage with Release		Other and unknown

Table 3: Cause categories used in incident databases

Please notice:

- That per row the categories are perceived to be one and the same category.
- That the Canadian TSB is the only agency not taking human errors and material failures into account.
- That the Canadian TSB is also the only agency taking incident consequences into account.

That Concawe is the only agency who was able to identify all causes, when asked Concawe stated that close contact to the reporting parties had always lead to cause definition, (enclosure Con-001).

Chapter 6 The pipeline accident cases

At his government-required anti-terrorist training session recently, a captain for a major airline said, "The bits of information were so few and far between that people weren't even paying attention. My instructor for the eight-hour course entered the room only to change videotapes. People were talking; they were doing other things, including reading the paper" (Philidelphia Inquirer, 1986).
This is a case instance. It is an effective way of drawing attention to a problem such as training quality. Such anecdotes are remembered and they are convincing. What they are not, however, is generalizable: that is, an anecdote doesn't tell whether it is the only such instance or whether the problem is wide-spread. And anecdotes usually don't show the reasons for a situation, and thus are of limited value in suggesting solutions.

6.1 Case study protocol.

To study the pipeline incident and accident backgrounds the databases of PSHMA, NTSB and TSB and the reports of CONCAWE and EGIG were consulted.
The databases and reports were studied with emphasis on factors that are believed to be the precursors (defined as re-occurring deviations in an operational process, Körvers, 2004), leading to these pipeline incidents and accidents.
For this study the following protocol was developed:

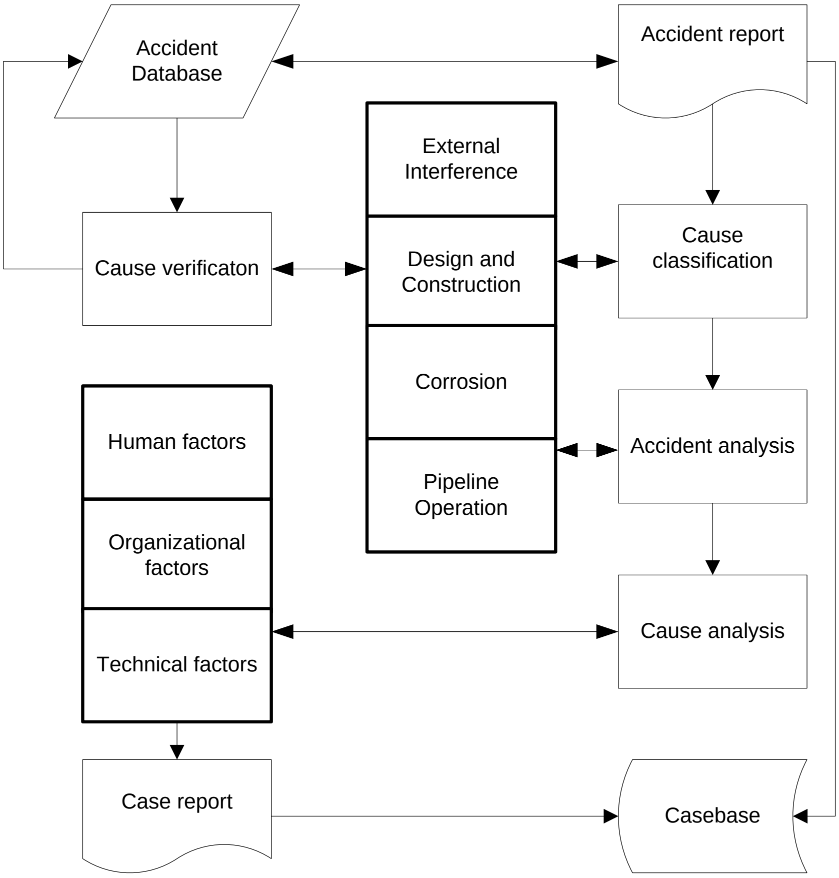


Figure 23: Case study protocol

In the review of the databases and the available reports the reported causes are cross checked and generalized into the four (4) cause categories used in the case study protocol. Table 3 specifies the cause categories used by the agencies
Analysis of the databases revealed some discrepancy between the cause category recorded and the information given by the reporting party. For example the database of significant accidents Hazardous Liquids in the period 1986 - 2002 shows 1781 onshore pipeline incidents. In 254 cases the cause "other" was recorded. After reviewing the actual reporting 103 cases could be re-assigned to the correct cause and for the 151 remaining cases there was not enough conclusive information to re-assign them.

The cause analysis focussed on deviations in the operational processes, as far as factual information was available. Figure 24 depicts the operational process, comprising of:

- Human Factors,
- Organisational Factors,
- Technical Factors.

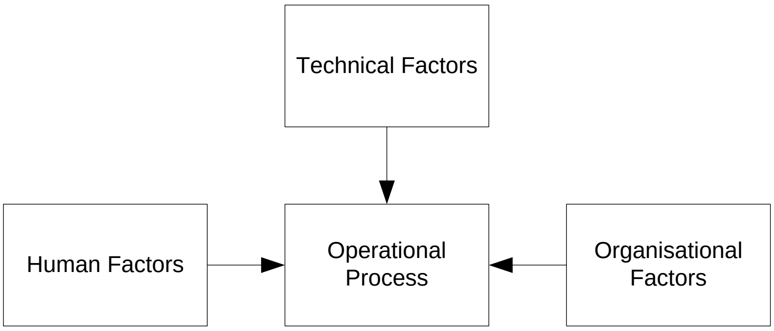


Figure 24: Operational process

The 43 investigative reports of the United States NTSB and Canadian TSB are conclusive enough to analyse according to the protocol.
The 56 EGIG and Concawe reports only show anonymized and generalized cause related information and there for not conclusive enough.

The case study findings are reported by means of a case report and recorded in this study's database Casebase.

6.2 The Ghislenghien case

July 30 2004 09:01 Ghislenghien, (Belgium); an explosion disrupts the peaceful summer morning when one of two existing 39 inch diameter high pressure gas pipelines ruptures and 250 m. high flames reach into the sky killing 24 people and injuring 132 more. What had happened?

Based on information from the Belgium Ministry of Economic Affairs, the Dutch “Kennistafel” , a publication of Prof.dr. B.J.M. Ale in the Dangerous Goods journal this case can somewhat be reconstructed.
Due to maintenance works on a part of this pipeline system, not in the Gellingen area, the working pressure was reduced from 80 bars to 50 bars as a standard precautionary safety measure.

In that same period of time infrastructural works were carried out at an industrial park in Gellingen these works would cross the pipeline route. In response to that interference with its pipeline route, the pipeline operator had the presence and the location of its pipeline marked in the field. in order to safeguard its pipeline
One of these infrastructural activities was to level the site during which to cover of this pipeline was reduced. After the accident forensics showed intensive marking on the pipe wall, locally reducing the wall thickness to 25%. When the pipeline was pressurised back to 80 bar it ruptured; a full bore rupture!

Photo 3: Gas clouds (Belgium Min. Econ. Aff.)

Photo 4: Gas clouds (Belgium Min. Econ. Aff.)

Photos 3 and 4 show a huge white cloud of escaping gas and were taken at a distance of approx 9 Km with a 1 minute interval. Photo 3 and 4 were just taken before the ignition of the gas cloud.

When ignited the flames burned up to 450 m high.

Photo 5: Gas cloud burning (Belgium Min. Econ. Aff.)

The blast dug a crater of 14 m. x 14 m. wide, with an average depth of 4 m.

Photo 6: Crater from the pipeline rupture, (Belgium Min. Econ. Aff.)

Photo 6 also shows the second 39 inch diameter pipeline, down in the left corner. This pipeline was undamaged and in order to cool this pipeline down it was kept under full flow.

The missing piece of pipe, approx 9 m. was found at 155 m. from the blast zone.

Photo 7: The missing piece of pipe (Belgium Min. Econ. Aff.)

Among the dead were the first ones to arrive at the scene; policemen and fire fighters who responded to investigate a call stating a strong gas smell.
This call came in at 08:45 and the patrols arrived at the scene at 09:00, 1 minute before the gas clouds did ignite; they did not have a chance.

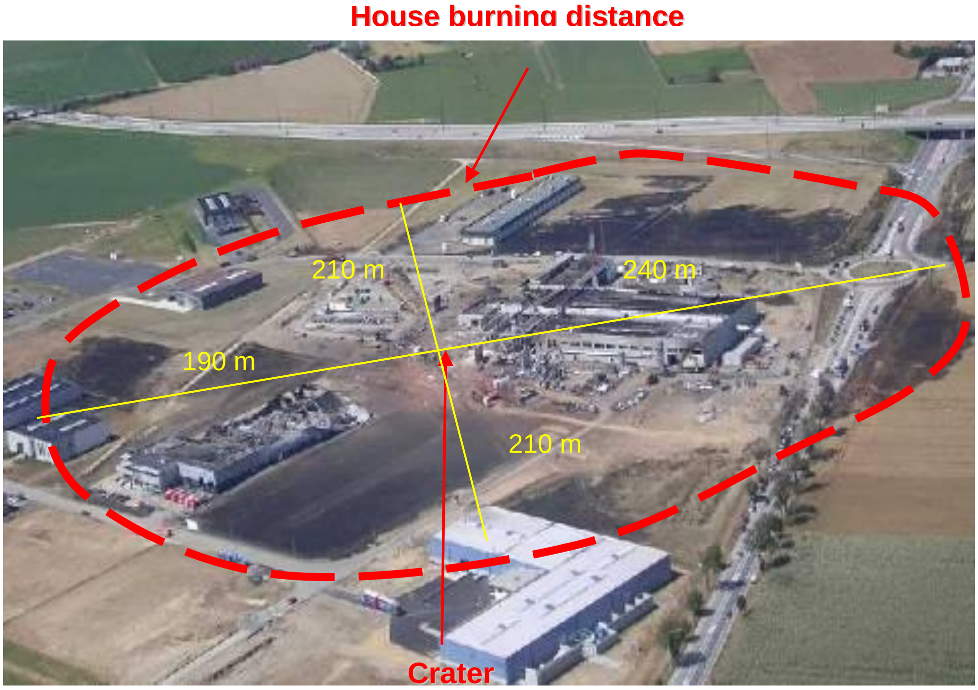


Photo 8: Aerial photo of the affected zone. (Belgium Min. Econ. Aff.)

6.2.1 Case specifics

This pipeline accident was brought to court by the Belgium Justice Department and allegations were made against 14 parties amongst which the mayor of the city of Ath, the town's secretary, the pipeline operator Fluxys and the principal Husqvarna.
On February 22th 2010, the Doornik magistrates' court ruled Fluxys, Diamond Boart, the mayor, the town secretary and 8 other parties not guilty. The contractor Tramo, his supervisor and the Architect were found to be guilty; all were sentenced reprieved of penalty.

The pipeline was struck during excavation works some five (5) weeks before the actual incident, but the pipeline operators was not informed about that. This fact did lead to the acquittal of Fluxys.

The principal having contracted specialized firms, from which he could expect they would have the knowledge that would have prevented this event, was also not to blame.

The mayor and the town's secretary were responsible for providing the information of the presence of the Fluxys gas pipelines to all parties stating their excavation initiatives. It is not clear whether Fluxys provided updated information regarding its pipelines' position to the town's secretary.

The safety coordinator was responsible for coordinating all safety aspects between parties. It is know that the onsite marking of Fluxys' pipeline was replaced inaccurate or completely removed during construction works. It was the Court's believe that this could not be related to the accident.

Both contractor Tramo's supervisor and architect should have known that the depth cover of both Fluxys pipelines was decreased due to ground movement and excavation works and that working with heavy equipment above the pipelines in this condition was not acceptable. This did lead to their conviction.

The investigation is not public and therefore the facts leading to this incident remain undisclosed.

This case shows the result of third party interference, but also clear deviations of operational processes and lack of data alignment.

6.3 The Bellingham, Washington case (source: NTSB report PAR0202)

The Bellingham case shows that in case of a pipeline accident the control room activities are or better should be aimed at consequence repression. In this case however latent conditions and active failures lead to human failure and to loss of lives when about 3:28 p.m., Pacific daylight time, on June 10, 1999, a 16-inch-diameter steel pipeline owned by Olympic Pipe Line Company (Olympic) ruptured and released about 237,000 gallons of gasoline into a creek that flowed through Whatcom Falls Park in Bellingham, Washington.

About 1 1/2 hours after the rupture, the gasoline ignited and burned approximately 1 1/2 miles along the creek.

Two 10-year-old boys and an 18-year old young man died as a result of the accident. Eight additional injuries were documented.

A single-family residence and the city of Bellingham’s water treatment plant were severely damaged.

As of January 2002, Olympic estimated that total property damages were at least $45 million.

A partial aerial view off the accident site is shown by Photo 9.

Photo 9: Post accident aerial view of portion of Whatcom Creek showing fire damage.

6.3.1 Case specifics

The schematic below depict this cases' “breakdown” where Olympics' defences and their temporal implementation are made visible, starting off with a third party desire leading to an activity in the pipelines' ROW.

On the right hand side all Olympics' defensive activities like the management system, SCADA system, operational and maintenance procedures, emergency response procedure, ILI inspections, are lined up.

On the left hand side the net effect of Olympics' defensive activities leading to the chain of events breaking down Olympics' defences

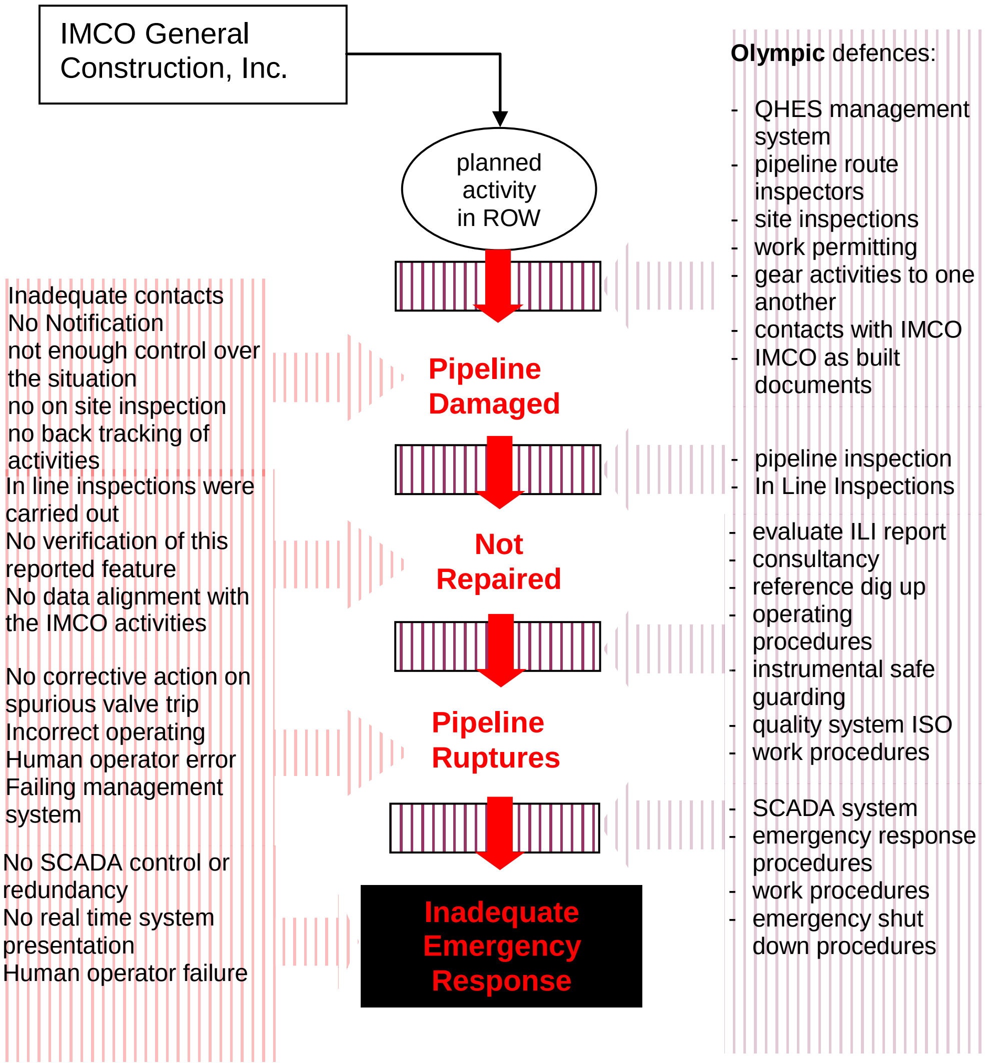


Figure 25: Bellingham case breakdown

6.3.2 Case conclusions

Looking at the left hand side of the case breakdown one can conclude the following:

- The first line of defence against TPI is the ROW. The ROW triggers, or should trigger, third parties to direct their attention toward an existing pipeline, giving the pipeline operator the means of contact and the enforcement of control over the situation.
  This case shows the operator to be unable to enforce control over the situation, leading to the damaging of the pipeline.
- A defence against the results of third party interference is an ILI survey. This inspection shows besides wall thickness changes also dents and ovality, both possible evidence of third party interference. This knowledge gives the pipeline operator the opportunity to inspect and mitigate.
  This case shows the operator unable to profit from the opportunity and no inspection or repair was done.
- A more basic defence regards the management system and procedures these should intrinsically attribute to the defence of a pipeline system.

- This case shows a pipeline operator troubled by a failing management system and lack of data algnment.
- The SCADA system, a defence in the sense of safeguarding the operational parameters, is also one of the most important instruments in times of emergency. It is by SCADA that most pipelines can be shut down thus repressing the consequences of the incident.
- This case shows the operators' SCADA system to malfunction due to improper use and misunderstanding of the basic concepts.
- All factors mentioned above are believed to be the precursors (defined as re-occurring deviations in an operational process), that lead to this pipeline operator's poor performance during his emergency situation.

6.4 The Walnut Creek, California case (source: Walnut Creek final report)

At 1322 hours on 9 November 2004, excavation equipment operated by Mountain Cascade, Inc., struck Kinder Morgan's LS-16 pipeline, a 51.4 mile long intrastate products pipeline that travels from Concord to San Jose.
The excavator was working on a large-diameter water supply expansion project in Walnut Creek, CA for the East Bay Municipal Utility District (EBMUD).
Upon puncture of the Kinder Morgan pipeline, gasoline under high pressure was immediately released into the surrounding area.

Photo 10: Punctured Kinder Morgan pipeline

Kinder Morgan control center operators in Concord immediately noticed the large pressure drop and started to shut the pipeline down.
Several seconds after the line was hit, the gasoline streaming out of the line was ignited by welders employed by Matamoros Pipelines, Inc. who were also working on the new water supply pipeline. The ensuing explosion and fire resulted in the deaths of five workers and significant injury to four others. One nearby two-story structure was burned and other property was damaged.
The direct cause of the accident was the excavator's bucket striking the pipeline and puncturing through the wall of the pipe. However, there were several factors that significantly contributed to this accident. These include inadequate line locating, inadequate project safety oversight and communication, and failure to follow the one-call law.

6.4.1 Case specifics

The schematic below depict this cases' “breakdown” where Kinder Morgan's defences and their temporal implementation are made visible, starting off with a third party desire leading to an activity in the ROW.
On the right hand side all Kinder Morgan's defensive activities like the management system, SCADA system, operational and maintenance procedures, emergency response procedure, ILI inspections, are lined up.
On the left hand side the net effect of Kinder Morgan's defensive activities leading to the chain of events breaking down Kinder Morgan's defences

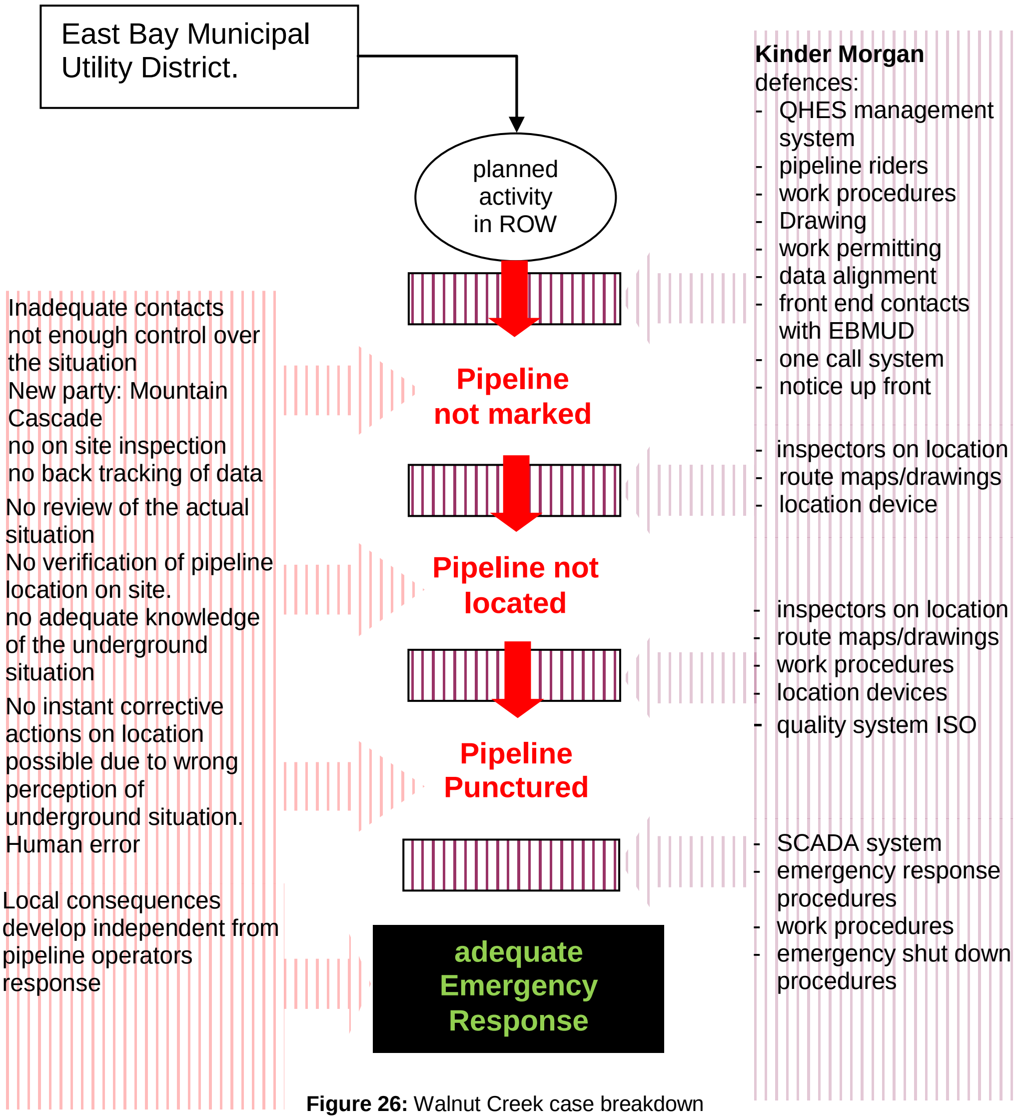


Figure 26: Walnut Creek case breakdown

6.4.2 Case conclusions

Looking at the left hand side of the case breakdown one can conclude the following:

- The first line of defence against TPI is the ROW. The ROW triggers, or should trigger, third parties to direct their attention toward an existing pipeline, giving the pipeline operator the means of contact and the enforcement of control over the situation.

This case shows the operator to be unable to enforce control over the situation, due to a wrong perception of the actual underground situation.

- The data change out with EBMUD took place in the front end phase and did not (fully) reach the contractor Mountain Cascade in the construction phase, this case shows a lack of data alignment
- In violation of the Kinder Morgan safety procedure the pipeline was not located and marked.
- The factors mentioned above are believed to be the precursors (defined as re-occurring deviations in an operational process) that lead to initial puncturing of the pipeline.
- The local consequences developed independent from pipeline operator’s response.

6.5 The Carlsbad, New Mexico case (source: NTSB report PAR 0301)

At 5:26 a.m., mountain daylight time, on Saturday, August 19, 2000, a 30-inchdiameter natural gas transmission pipeline operated by EPNG (El Paso Natural Gas Company) ruptured adjacent to the Pecos River near Carlsbad, New Mexico. The released gas ignited and burned for 55 minutes. Twelve persons who were camping under a concrete-decked steel bridge that supported the pipeline across the river were killed and their three vehicles destroyed. Two nearby steel suspension bridges for gas pipelines crossing the river were extensively damaged. According to EPNG, property and other damages or losses totaled $998,296.

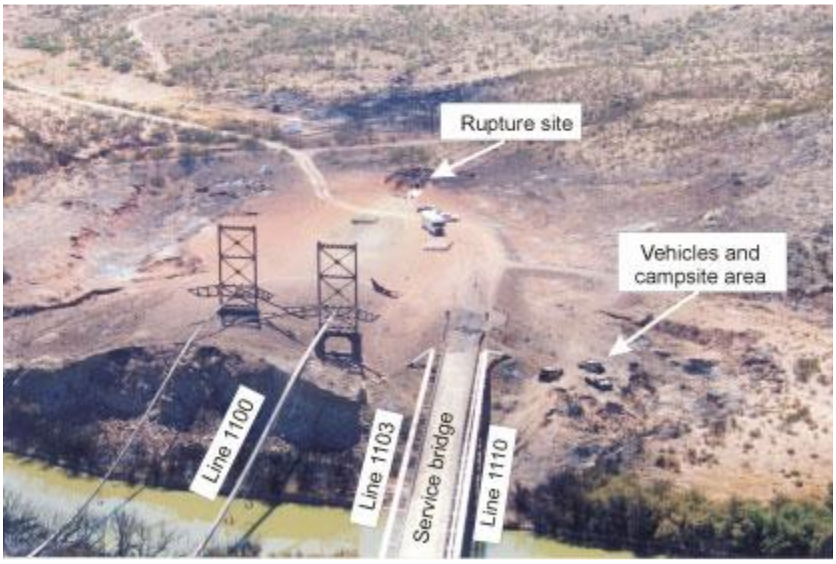


Photo 11: Aerial view of accident site looking east.

At the time of the accident, 12 members of an extended family were camping on the east bank of the Pecos River near the service bridge.1 (See figure 4.) A locked wire rope and a .Private Right of Way□No Trespassing. sign at each entrance to the bridge restricted access to the bridge above the campsite. Two .Caution□High Pressure Gas Line. signs were posted near the east entrance to the service bridge. Also, a sign reading as follows:

Warning - No Trespassing - This road and right of way is private property and is not for public use. This pipeline carries natural gas under high pressure and is dangerous. All persons are warned of the danger to person and property.
KEEP OFF

had been posted alongside the right-of-way road (near the intersection with the county road) leading past the block valves and pig receivers to the service bridge on the east side of the river.

The pipeline system was operated from EPNG's gas control center in El Paso, Texas, as a north system and a south system. The gas control center was equipped with three SCADA system work consoles, each of which was capable of displaying data for both pipeline systems. On the morning of August 19, 2000, three EPNG employees, a coordinator of pipeline control (who was in charge of the shift) and two gas controllers, were nearing the end of their 12-hour shifts at the gas control center. One of the controllers was operating the north system and the other the south, while the coordinator assisted the two controllers.

The south system controller, at 5:26 a.m., received SCADA rate-of-change alarms for the speed of compressor unit No. 3 at the Pecos River compressor station. Less than a minute later, compressor unit No. 1 at the station shut down and the compressor station was automatically isolated from the pipeline. A few seconds later, additional alarms from the station displayed on the controller's monitor, including a rate-of-change alarm for falling suction (inlet) pressure at the station. (Unknown to the controller at the time, pressure on the inlet side of the station dropped because pipeline 1103 had ruptured near the river crossing.)

At approximately 5:30 a.m., the controller telephoned the Pecos River district station lead operations specialist at home and asked him to send people to the Pecos River compressor station. The south controller later stated:

> *I noted that we did have a low suction pressure, and generally when our plants go down, the suction pressure goes up instead of down. I told [the station lead operations specialist], .We need to get somebody out there right away because I think we have a problem.*

Photo 12: Post-rupture fire. At lower left of fireball can be seen the 85-foot-tall support structures for the pipeline suspension bridges.

6.5.1 Case specifics

Pipeline 1103 ruptured as a result of severe internal corrosion that caused a reduction in pipe wall thickness to the point that the remaining metal could no longer contain the pressure within the pipe. The corrosion that was found at the rupture site was likely caused by a combination within the pipeline of microbes and such contaminants as moisture, chlorides, oxygen, carbon dioxide, and hydrogen sulfide.

The accident section was not pigable, so cleaning and ILI was not possible.

The installed drip, upstream of the rupture location, was partly clogged making it possible for liquids and solids to bypass this drip and accumulate somewhere at a low point in the pipeline, in this case the rupture site.

Had EPNG effectively monitored the quality of gas entering the pipeline and the operating conditions in pipeline 1103 and periodically sampled and analyzed the liquids and solids that were removed from the line, it would likely have determined that the potential existed for significant corrosion to occur within the pipeline.

The schematic below depict this cases' “breakdown” where EPNG's defences and their temporal implementation are made visible, starting off with a lack of monitoring both gas quality and pipeline operation leading to massive internal corrosion.
On the right hand side all EPNG's defensive activities like the corrosion control program, SCADA system, operational and maintenance procedures, emergency response procedure, are lined up.
On the left hand side the net effect of EPNG's defensive activities leading to the chain of events breaking down the defences

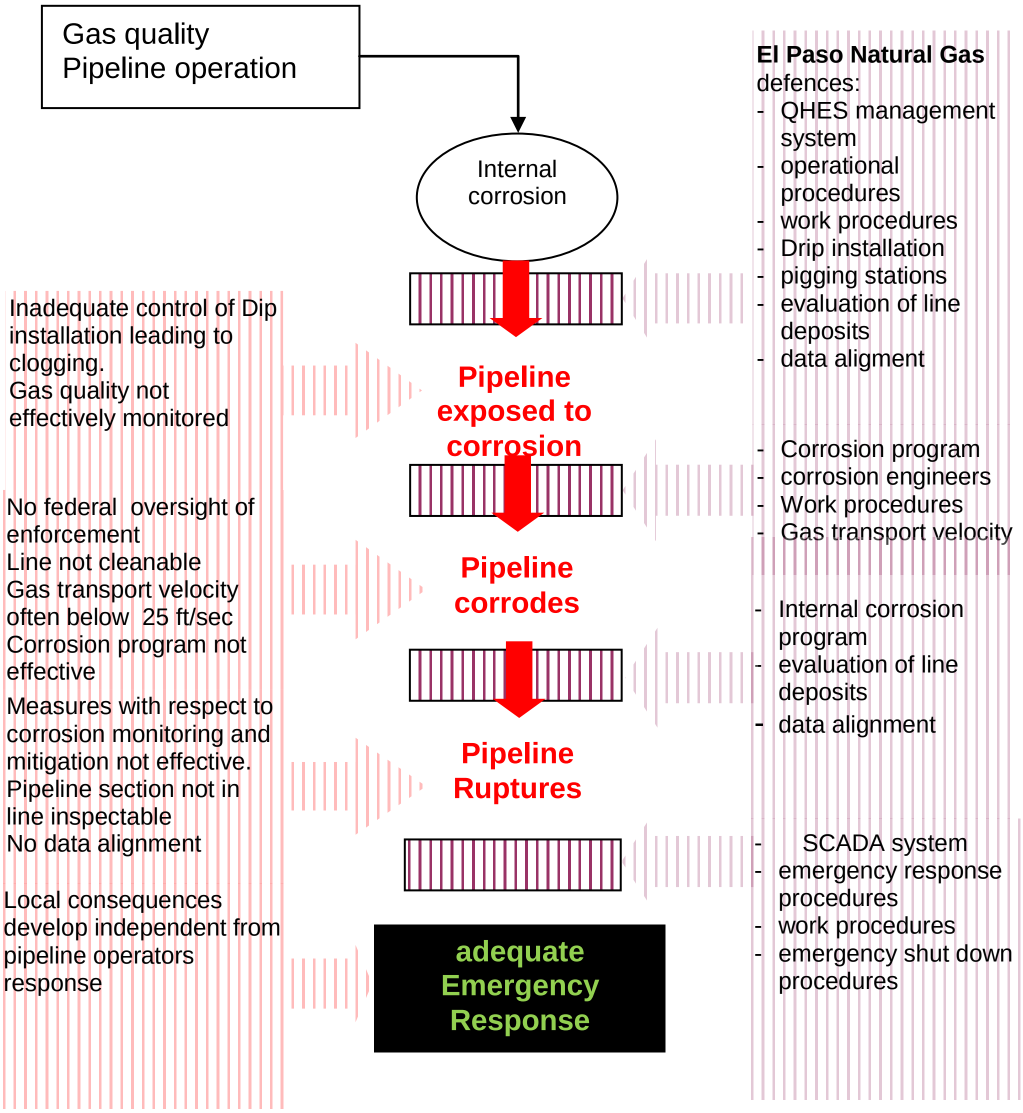


Figure 27: Carlsbad, New Mexico case breakdown

6.5.2 Case conclusions

This case shows an Operator not fully understanding or not acting up to the possible impact of the transported products on their pipeline(s).

- The product's corrosivity is not adequately monitored,

- The product's contamination is not adequately monitored and evaluated. The fact that the Operator has a corrosion monitoring program in place and commercially transports gas from different suppliers tells that at some organizational level knowledge with respect to the gas quality transported is available. The report states that in 1989 the drip installation of the parallel pipeline was cut out, it was found to be completely full of solidified black solids & oil.
- The effectiveness of the corrosion program was not doubted until the pipeline ruptured, the fact that there was not enough Federal oversight in this matter does not clear EPNG's responsibility to enhance the corrosion program based on the knowledge available.
- There was a lack of data alignment which would have given EPNG to possibility to better address the problem at hand and possibly have saved twelve lives.
- The factors mentioned above are believed to be the precursors (defined as re-occurring deviations in an operational process) that lead to the massive internal corrosion resulting in the rupturing of the pipeline
- The local consequences developed independent from pipeline operator’s response.

6.6 Cross case conclusions

Based on the accident reports from NTSB and TBS studied the following conclusions with respect to the four generalized cause categories can be drawn across the cases:

External interference causes:

In cases of external interference causes a lack of data alignment, lack of clear communication and deviations of organizational procedures created the opportunity for safety risks in the operational pipeline process, despite the presence of many safety indicators and measures.

It is the involved parties lack of overview and ability to recognise precursors, their underlying organizational root causes (the latent conditions) and their possible effects on pipeline defences that made these incidents possible.

Corrosion causes:

In case of corrosion causes a lack of data alignment, lack of clear communication and lack of fully understanding the technologies in use created the opportunity for safety risks in the operational pipeline process, despite the presence of many safety indicators and measures.

Design and construct cause:

Design and construct as cause is often related to human error and deviation of organizational procedures, however the cases often report this cause in conjunction with the transport of pipes and the initiation of longitudinal cracks or with ERW welded pipe and longitudinal seam failures.

Pipeline operation:

In case of pipeline operation as cause where clear failures, like causing a rupture by start to pump against a closed line valve and restarting the pumps after a pipeline was ruptured (report PAB 9903) or increasing the flow rate after a pipeline rupture due to misinterpretation of SCADA data (reports PAB 0702, PAB 0101, PAB 0102) were identified, one can argue the underlying cause to be lack of data alignment, clear communication and deviation of organizational procedures by the operator thus creating the opportunity for safety risks in the operational pipeline process, despite the presence of many safety indicators and measures.

It is also lack of data alignment when the operator is not capable to interpret the SCADA data correctly or when he is not capable to connect an evolving situation to the companies procedures.

The cases where the operator wrongly anticipated on locally independently developing accidents also showed lack good communication and data alignment.
In many cases the lack of good public awareness programs and public education programs

6.6.1 Parallels in Europe

With respect to the recorded causes of pipeline incidents in the United States and Europe Figure 28 and figure 29 show quit some similarity.

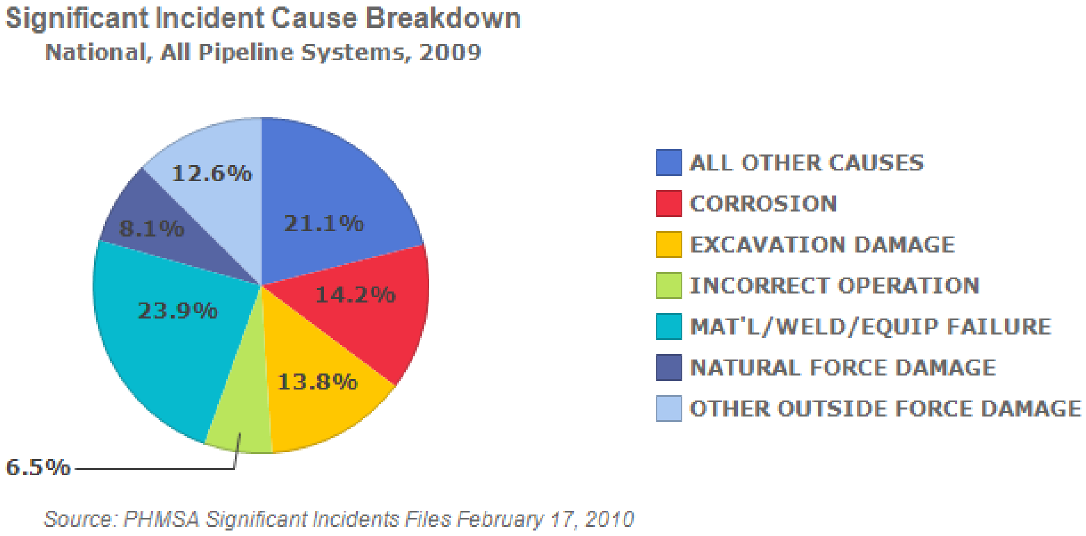


Figure 28: Significant incidents all pipelines (source: PHMSA)

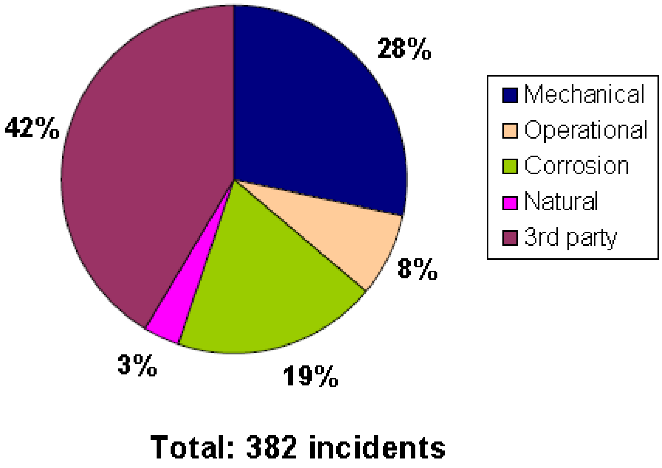


Figure 29: Distribution of major spillage causes (source: Concawe report 7/08)

In Europe the main incident causes are TPI (42%) and Mechanical (28%) as in the United States TPI (26,4% (= 12,6% + 13,8%)) and Mechanical (23,9%).

6.6.1.1 Third party interference

Third party interference is one of the main causes for pipeline incidents and accidents.
The effectiveness of the former Dutch KLIC notifications for excavations nearby high pressure gas transmission pipelines was investigated by Gasunie (N.V. Nederlande Gasunie, 2004) the Dutch natural gas pipeline operator.
This investigation showed that even with notification pipelines were damaged by excavation.
Gasunie came to the following results :

65% of all excavations nearby high pressure gas pipelines was notified
48% of the damaged pipelines due to excavation was notified

The causes for the damaging of the pipelines when notified are:

- the start of the excavations is not communicated	36%
- deviation of the original time schedule	19%
- despite agreement over supervision, start without	14%
- inadequate communication between parties	7%
- pipeline incorrectly marked	7%
- KLIC notification misinterpreted	5%
- Unknown	12%

6.6.1.2 Material failure

The cases show many pipeline ruptures of which many are related to the fabrication process of the longitudinal weld seam.
In Europe the phenomenon is not so clear, perhaps because the American and Canadian pipelines are older or the welding processes differ.
Also significant more pipeline ruptures are reported in the United States and Canada than in Europe, perhaps a lack of understanding the correct terminology.
It could also be that the reporting in Europe is not as extensive as in America and Canada

Chapter 7 Answers to the research questions

In this Chapter the research questions will be answered and the hypothesises tested. The Chapter starts with the answering of the constructed sub question, leading to the answering of the research questions. The Chapter ends with the testing of the two hypothesises.

7.1 Sub questions

How can layers of protection be assessed and controlled?

Layers of protection can be assessed by applying the following definitions:

- A primary defence is the system's feature or a quality, generically enabling that system or part of it to withstand the effects evoked on it by failure types.
- A secondary defence is the system's feature or a quality, which conjointly with a primary defence enables that system or part of it to withstand the effects evoked on it by failure types.
- A tertiary defence is the system's feature or a quality, which conjointly with a secondary and/or a primary defence enables that system or part of it to withstand the effects evoked on it by failure types and so on

Layers of protection can be controlled by checking the system

How can all the actors involved in the risk management process be identified as well as their influences and interactions?

Legislation provides means of protecting the pipelines' ROW, this makes any initiatives in the ROW mandatory for notification whether these are short term or long term initiatives. Good communication and data alignment are the keys to identifying influences and interactions,

How can legislatorial and societal influence on pipeline operation be translated into a defence management process?

For both Society and pipeline operator legislation concerning pipelines can be considered a defence. The legislation intrinsically brings the societal influence op pipeline operation into the defence management process.

What would be the minimum requirements for a defence management process?

The minimum requirements for a defence management process are:

- data alignment within layers of protection as well as between layers of protection
- adaptive learning loops over the effectiveness of layers of protection

How can these defence management concepts be tested?

In a case the effects of the applying of the defence management concepts can be tested. The alternated realities of the outcome is a measure for the concepts' effectiveness.

What conclusions can be drawn from the test, with respect to the model's definition and how can these conclusions be translated into the model's definition?

One may conclude whether to change the model's defence strategies.

7.2 Research questions

How can pipeline accidents still happen, when all pipeline failure types have been identified and all appropriate defences are in place?

Pipeline accidents can still happen because layers of protection become breached as shown by the generic pipeline failure route (§ 4.4, Figure 13)

How can layers of protection become breached?

The accident reports from NTSB and TBS revealed in case of external interference causes a lack of overview regarding precursors, their underlying organizational root causes (the latent conditions) and their possible effects on defences. This lack of overview created the opportunity for safety risks in the operational pipeline process, despite the presence of many safety indicators and measures.
In case of corrosion or design and construct causes where the reports state the findings of the cause analysis and investigations of the performance during the emergency response similar behaviour is seen. Often, when in this long distance anticipating on locally independently developing accidents, good communication and data alignment is of primary concern.
In case of pipeline operation as cause it is often the combination of operator errors and SCADA misinterpretations.

REMARK:
The defining of the layers of protection principle lead to an intrinsic coupling of the two research questions.

7.3 Testing the hypothesises

The problem is clear and two research questions and the six (6) sub questions have been answered and based on this information the first hypothesis can be responded to as

Yes, based on reliable thread assessment and insight in third party activities a pipeline defence management system can control risks at an operational and tactical level.

The second hypothesis can be responded to as:

Yes, without data alignment there is no defence management possible.

Both hypothesises have been tested to be true.

Chapter 8 Pipeline defence(s)

In this Chapter the Pipeline Defence Model is introduced. This model is adapted from the reasoning and possibilities model (Körvers, 2004) The model shows where defence strategies are most effectfull. When developing defence strategies it is nescessary to understand the basic principles of the threads and the defences.

8.1 Introduction

The incident data bases show incidents reported by their causes, each type of defect has a specific defence approach, and interactions between defect types lead to deviation of the common approach thus creating precursors, which introduce opportunities for safety risks.
The reasoning and possibilities model (Körvers, 2004) pictures the interacting of latent conditions and ineffective control elements leading to an accident, but it also shows possibilities for interventions or defences to arrest the development of an accident as represented by the letters A to C.

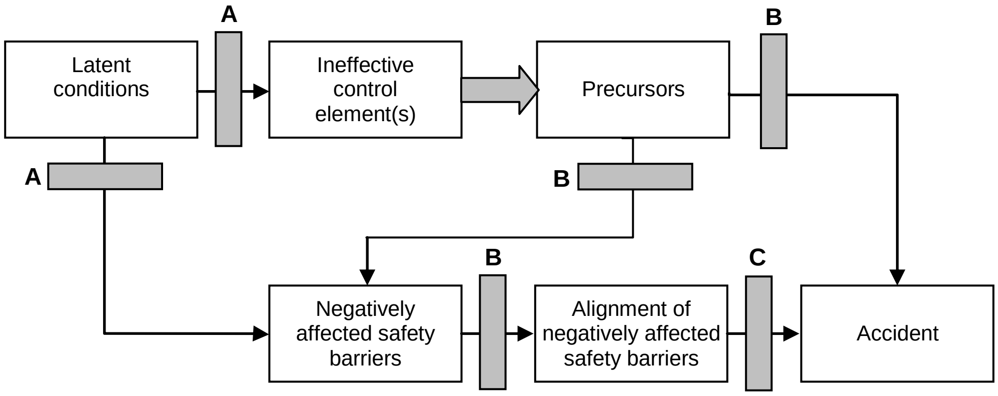


Figure 30: Reasoning and possibilities model of Körvers (P. Körvers, 2004)

The defences react to the situation as shown prior to them. The thick arrow represents a cause effect relationship that is so direct, no intervention can be implemented preventing the effect from occurring if the cause is not removed. In Figure 30 one relation is present, between the initial ineffective control elements and the precursors, implying that if latent conditions are present, the initial ineffective control elements are automatically present to and will automatically result into precursors (Körvers, 2004).
The order of the letters identifies the most effective defence (removing the cause: A) till the least effective defence (removing a sign: C). The possible defence strategies are stated below:

A. Removal of the latent conditions initially causing the accident scenario. This is the most effective defence strategy. The strategy requires alterations in the organizational system, e.g. changing the retrieval and analyses process of data, redesigning equipment, enhancing the training programs, etc.
B. Operators are able to recover deviations, meaning they react to deviations or ineffective safety barriers, alleviating the effects from these problems, Kanse (Kanse, 2004). This defence strategy is less effective than removing the latent conditions, although these recovery actions/strategies can be used to enhance the learning cycles in an organization.
C. By maintaining an overview of effective and ineffective safety barriers, accidents can be prevented by making sure that no alignment of ineffective safety barriers can take place. Therefore, the overview has to be known to all the actors inside an organization and has to be constantly updated, which requires enormous amounts of resources, e.g. time and money. This form of defence strategy can be seen as the least effective way of intervening

8.2 Pipeline Defence Model

Based on the reasoning and possibilities model (Körvers, 2004) the pipeline defence model was developed. The model shows the generalized causes, as used for the case study and their influence on the pipeline.
For the pipeline the causes can be seen as latent conditions:

- the latent condition type pipeline operations is always present in the form of pressure, pressure cycling and product.
- the latent condition type external interference is always present in the form of the pipeline route, the depth of cover, the ground pressure, the soil type.
- the latent condition type corrosion is always present in the form of the coating of the pipe, the pipe surface potential, the cathodic protection.
- the latent condition type design and construction is always present because the pipeline is present.

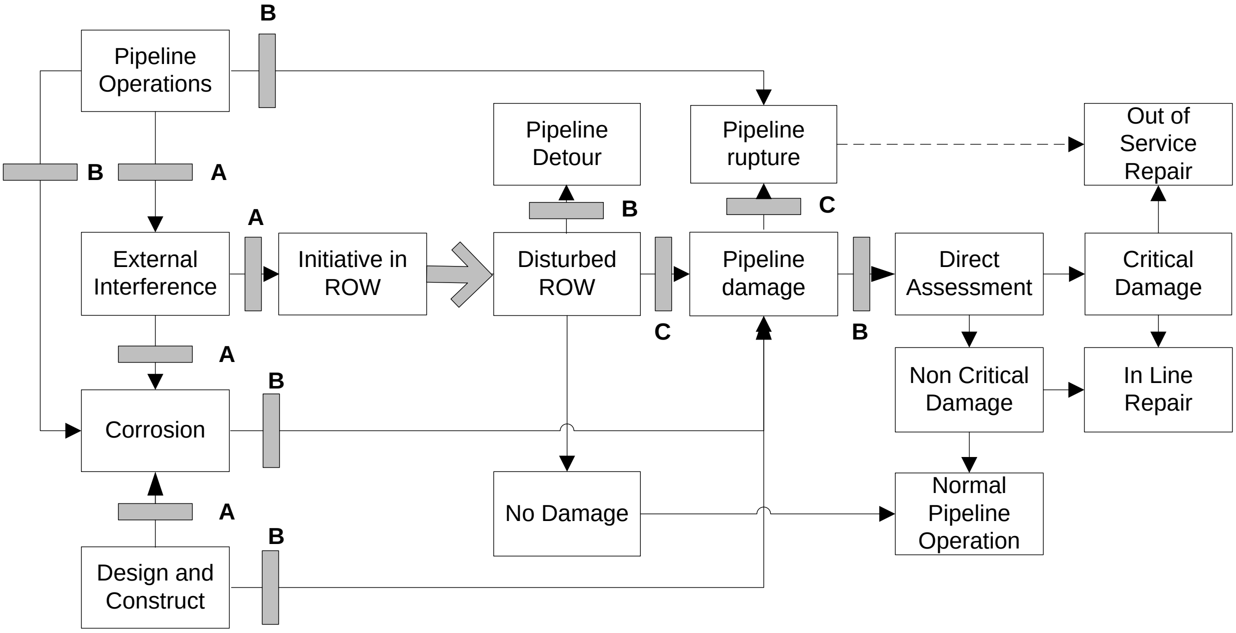
As the model shows for the external interference cause and corrosion cause, other causes can been as latent condition:
External interference:

- the latent condition type pipeline operations is always present in the form as initiative taker in the ROW.

Corrosion:

- the latent condition type pipeline operations is always present in form of the product specifications.
- The latent condition type design and construct is always present in the form of design specs concerning corrosion.

When latent conditions are present , the ineffective control elements are automatically present too and will automatically result in precursors (Körvers, 2004)



Pipeline Defence model

Figure 31: Pipeline defence model

The thick arrow represents a cause effect relationship that is so direct, no intervention can be implemented preventing the effect from occurring if the cause is not removed; an initiative in the ROW leads to disturbance in the ROW.

The order of the letters ranks the effectiveness of the defence. The possible defence strategies are stated below:

A. Removal of the latent conditions initially causing the accident scenario. This is the most effective defence strategy. The strategy requires alterations in the legislatorial system, e.g. limiting the possibility of not notified digging in the ROW, redesigning procedures, enhancing the training programs, etc.
B. Pipeline operators are able to recover deviations, meaning they monitor and react to situations evolving within their span of control. This defence strategy is less effective than removing the latent conditions, although these recovery actions/strategies can be used to enhance the learning cycles in an organization.
C. By maintaining an overview of effective and ineffective safety barriers, accidents can be prevented by making sure that no alignment of ineffective safety barriers can take place. Therefore, the overview has to be known to all the actors inside an organization and has to be constantly updated, which requires enormous amounts of resources, e.g. time and money. This form of defence strategy can be seen as the least effective way of intervening

Regarding the defence strategy types A, B and C one can argue as follows:

Defence strategy type A
This strategy is the most difficult one to imply. Although a pipeline is embedded in the society, its presence is not always noted thus introducing safety risks as seen in the cases studied. A defence strategy should be solid because the mere existence of many actors introduces the opportunity of deviation from a chosen approach, many points of view to regard. The cases studied show the existence of these situations.

Defence strategy type B
This defence strategy comprises many elements of normal pipeline operation. The monitoring and adapting to changing situations are part of the daily operation.

Defence strategy type C
This defence strategy is often applied by line riding (pipeline route inspection) where a constant trade off between the necessity to inspect and the totality to inspect might easily lead to alignment of ineffective safety barriers.

Where defence strategies compel third parties to act in a prescribed manner this can only be achieved when supported by legislation.
It is impossible for a pipeline operator to enforce his defences against external threads without a legislatorial base, on the other side it is also true that Society cannot be protected against pipeline operation threads without the same legislatorial base.
This makes this legislatorial base for both Society and pipeline operator a defence.

8.3 Legislation and pipelines

8.3.1 Introduction.

In the Unites States the first pipelines for oil were constructed in the late 19th century and in 1906 the Hepburn act, brought the first regulation in the ruling on the interstate transport of oil. The free entry en exit in the oil transport market lead to aggressive market behavior and made more regulation, ruling on market issues necessary.
Gradually gas transmission pipelines were being built, a market which was very restricted and regulated.
In Europe gas pipelines were known but only in local city gas distribution grids. With the pipelines came the regulation; by law on aspects like concession, expropriation, taxes and local by provincial permitting on technical details and ROW aspects.

8.3.2 Legislation history in the Netherlands

The finding of gas in Slochteren in 1959 accelerates the construction of pipelines for the distribution of the gas and parliament (Dutch: Tweede Kamer) starts to worry about the safety of these gas distribution systems as to the difference between the city gas and the natural gas many distribution systems start leaking and although the natural gas is not that toxic as the city gas it is more explosive.
The gas eruption at Sleen in 1965 evoked regulatory supervision during drilling operations, this is one of the first examples of precautionary legislation.
The expanding chemical industry and gas distribution lead to an increase in pipeline construction and with the pipelines came the regulation; by law on aspects like concession, expropriation, taxes and local by provincial permitting on technical details and ROW aspects
The Netherland government has always been proponent to self regulation of the business.
Urban expansion started to interfere with the existing pipeline route and third party activities increased over the years, leading to the foundation of KLIC (dutch: Kabel en Leiding Informatie Centrum) in 1986.
KLIC is a one call orgainsation streamlining the notifications of all excavation activities in the neighbourhood of pipelines and cables which started off on a voluntary basis, meaning no legislatorial basis to enforce notification of works by digging companies. Once the cooperation with the insurance companies in 2002 was a fact the notification was enforced by the rule: no notification, no coverage by the insurance company involved.

In 2006 all legislatorial supervision is being transferred to one Ministry, the Ministry of Housing, Spatial Planning and the Environment, this gives both the government and the pipeline operators a focal point.
Since October 2008 the so-called ‘Excavation Regulation’ took affect making the excavation notification mandatory and compel the pipeline operators to deliver accurate digital information of their pipeline routes to the Land Registry. The intention is to have the computer systems of the Pipeline Operators and the Land Registry connected so that this combined system will evaluate the notification and this system will contact the excavating party and the Pipeline Operator involved.

As of August 2009 the law External Safety Pipelines regulates society’s safety by ruling on issues like the safety distances. This law also protects Society from incorrect urban planning and incorrect real estate project development.

8.4 Single case PDM simulation

When PDM concepts would be applied on the Bellingham Washington case the following could have taken place:

- Olympic's contacts within the Urban Planning Committee of the city of Bellingham would not have permitted the building of the water treatment plant in the vicinity of Olympic's ROW.
- If the initiative could not be smothered in the Urban Planning Committee then in the pre engineering phase where Bellingham contracted Barrett Consulting Group to design the modifications of the water treatment plant and inspect the construction thereof, Olympic would have made certain that her ROW would not be compromised.
- When that would not have been effective then Olympic would have attended every meeting concerning the modification of the water treatment plant and the construction of a 72" water pipeline crossing Olympic's ROW.
- All data would have been available for both Olympic's staff as for the contracted parties and the city of Bellingham.
- Olympic's pipeline would have been located as procedure prescribes and its depth of cover would have been appropriately established. This data would have been aligned.
- Olympic would have opened and sustained good communication and contacts with Bellingham's contractor IMCO, making sure that no unattended work would be done in the ROW, all data would have been aligned.
- The time and date of the actual crossing of Olympic's ROW would most certainly known and attended to.
- The Olympic pipeline would not have been damaged during these works.

However the defence strategy for pipeline operations would not have solved the problem with the spurious valve trip, nor would it have prevented the SCADA programming or the misinterpretation of SCADA data by the operator.
But the pressure surge would not have caused the pipe to rupture as it did.

Chapter 9 Conclusions and research opportunities

This Chapter concludes this thesis with the evaluation of the single case simulation and some overall conclusions regarding risk management in the business. This Chapters ends with some suggestions for further research on the PDM concepts.

9.1 Conclusions on single case PDM simulation

The single case evaluation of the Bellingham incident show that although the pipeline operations strategy did not prevent the pressure surge, the third party interference strategy prevented the pipeline from getting damaged.
The net result is that the pipe could withstand the pressure surge and did not rupture.
The model conceives the pipeline operator to be pro-active in his defence approaches, meaning:

A pipeline operator should step forward into societies eye when his pipelines are not.

9.2 Overall conclusions

This thesis concludes that pipeline operation is still a safe means of transport.

The alignment of latent conditions leading to the breaching of layers of protection will become more difficult when pipeline operators start to focus more on their defence management capacities and enhance their data alignment.

9.3 Research opportunities

Further research will be necessary on:
- the testing of the defence model's concepts
- the documentation and modelling of all pipeline failure routes
- the translation of the defence model into a workable computer model comprising of layers of protection analysis capability.

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