A Systems Approach to Investigation and Problem Solving

(N.B. This is partly an extract from a longer paper)

Abstract

The terms 'Accident' and 'Incident', while in general accepted usage, are not helpful to professional in-company investigators. The proposition is that it is more useful to consider such events as failures of 'Human Activity Systems'. This methodology was initially developed to give offshore oil managers a means of investigation that was relatively easy to learn and apply. Practical and reliable in its outcome it is now used in over forty countries with over 30,000 trained users. The principle need of the methodology was to establish the causes of failures and accidents or incidents and, in particular, to ensure the prevention of injury and loss of life. Importantly, the methodology is based on systems theory, but is original, in its thinking and application. and has been extended and expanded to cover most industrial and commercial sectors and applied to a wide variety and business failures.

Key Terms.

Accident, Incident, Indicators, Bias, Hard and Soft Systems, Change, Failure, Causes, Human Activity Systems, Hazard, Risk, Personal Styles, Root Cause Analysis, Human Factors, Safety, Barriers and Defenses, Event, Problem Definition, Methodologies, In-Company, Organisational Rust.

The Problem

Devise and teach a practical incident investigation and problem solving methodology for use by non-specialist investigators in the offshore oil exploration and production industry.

Post the Piper Alpha Disaster on 6 July 1988 with the loss of 167 lives and the subsequent public enquiry report by The Hon Lord Cullen (Nov 1990 HMSO) there was a demand by oil production and exploration companies to conduct investigations. One of the major oil companies sought training for some staff on how to conduct investigations.

At that time and also more recently there were and are few practical methodologies available:

- Bhagwati in 2006 in referring to accident investigation said "My experience has shown that this is the weakest point in nearly all the organisations I have consulted"

- Strauch in 2014 stated "Without the proper understanding those investigating error may apply investigative procedures incorrectly and fail to understand how the error came about" He went on to say, although researchers have extensively examined error, (quoting Reason 1990 & 1997 and Woods, Johannesen Cook and Sarter 1994) there is little material that is available to guide those wishing to investigate error".

- Leveson N.G., in the introduction to her CAST Handbook. 2019 said "There are many accident analysis tools that have been created, particularly by academics, but few have significantly reduced accidents in real systems or even been used widely."

Following on from Leveson Caldwell & Klausinger 2022 said about Friedrich Hayek, the Economist, that his theorising was abstract but his purpose was practical. So is the aim here, to give a practical tool that is based in sound systems theory.

This particular methodology, which is now widely adopted and applied, was initially developed for the offshore oil industry where a drilling rig or production platform has been described as a combination of factory, airport, hotel and harbour and for some platforms such as the ill-fated Deepwater Horizon they are not anchored but held in place by dynamic positioning (DP) and are therefore legally ships, and as such have a captain.

(Weick, K,E 1976) talks about loosely coupled systems, but while this was explored in terms of educational establishments, such as schools and colleges, the term also fits most industrial and business situations. A failure in any of these interdependent or 'loosely connected' sub-systems has the potential to require a shutdown which can cost $millions per day but even more significantly loss of life. The following are examples of where a subsystem failure has ultimately resulted in the loss of many lives and, in each case, of the whole rig.

Alexander L. **Kielland** Oil rig capsize in 1980 loss of 123 lives due to a failure of the sub-sea leg bracing system

Piper Alpha Oil rig explosion and loss in 1988 of 167 lives initially triggered by the failure of the permit system

Deepwater Horizon explosion in 2010 with the loss of 11 lives due to the failure of the well control system.

Many other factors contributed to the above losses, but the initial causes were failures of a system within the much larger total system of an offshore oil platform.

As can be seen from the following influence diagram an oil production platform is a microcosm great systems complexity on an artificial steel island.

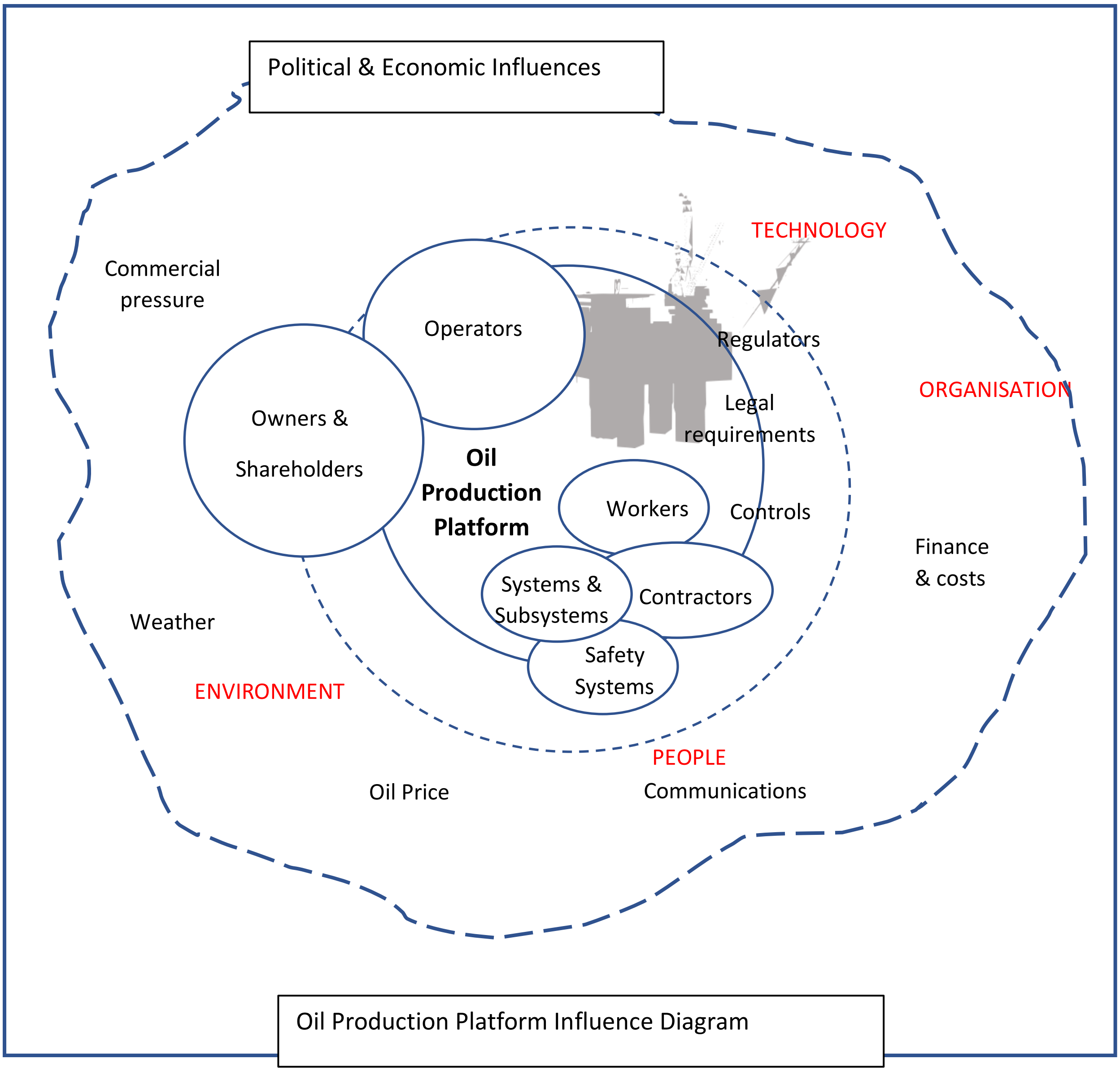

Diagram 1

In order to devise a practical investigation and problem solving methodology the first step was to consider who would be the likely users or investigators and what do they need?

The target audience or users were in-company personnel who were unlikely to be investigation specialists. Also, while they may come from a safety discipline, they were most unlikely to have a full time investigating or problem solving role. The particular significance of this is that the individuals chosen are likely to be managers with another, or quite separate, role within the company i.e. their investigation role is likely to be only in 'an as needed basis', and therefore having a useable and accessible methodology will be essential.

Many companies train in-company staff to investigate less serious incidents and are therefore seeking an effective combined investigation and analysis methodology that is straightforward to learn and apply. Some other well researched methodologies including Tripod Beta, (Energy Institute 2015) and CAST (Leveson 2019) while academically sound, are quite difficult for the non-specialist to learn and apply. On the other hand Systematic Cause and Analysis Technique (SCAT) is a simple chart based approach that helps the users identify corrective actions. Variants of this approach are used by a variety of companies, but are not full investigation methodologies.

There are a number of, mainly commercial, incident investigation methodologies in wide use and most have the components of Planning, Determining Causes, Root Cause Identifiction, Proposing solutions. This methodology considers all incidents as 'Systems Failures' so that all investigations are conducted on that basis.

Von Bertalanffy, L. 1968 stated that, independently of each of other, similar problems and conceptions have evolved in widely different fields including Human Activity Systems and it was considered that this fitted well with the intense and compressed multi-disciplinary operations on an offshore platform. To develop the practical working investigation system or methodology the starting points were Checkland's 1971 'A systems map of the universe' and Jenkin's 1967 step by step 'The Systems Approach'. In a later revision of the development of the methodology, of particular value was (Checkland & Scholes 1990 and Checkland 1993) illustration of the practical application of systems theory to real industrial and Organisational problems with particular reference to 'Human Activity Systems' and 'Hard and Soft Systems'

Referring back to the foregoing influence diagram of an oil production platform it can be seen that there is a mixture of Hard and Soft Systems illustrated here:

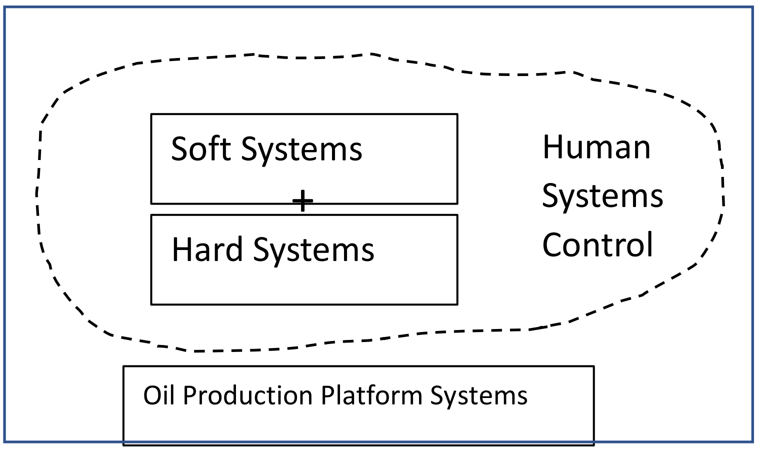

Diagram 2

While much of what is seen on an offshore platform appears to fit the term Hard Systems in that the machinery is functionalist everything, including design, is under the control of Human or Soft Systems.

Considering everything as a system means that when things do go wrong it is in fact the loss of control of the system. This is the case whether it is a component system within a larger entity such as an oil rig or any other complex system such as a railway, aircraft or chemical factory.

Piper Alpha survivor, Steve Rae, says that “Hard systems should be soft systems”, this really makes the point that everything has a human element, and this has to be managed.

This paper addresses this need. The drive for ‘simplicity in use’ in dealing with potentially complex problems goes back a long way (Ockham 1287 – 1347) and (Einstein 1879 – 1955) who said “Everything should be made as simple as possible, but no simpler”. This methodology attempts to follow this principle. However, some methodologies are difficult to use for the non-specialist and are not in wide use (Leveson 2019).

However, when very serious or major incidents occur, particularly where there are serious injuries and fatalities or high value losses, companies often use the services of external investigation specialists. This is often because regulators, lawyers and insurance companies require an independent professional report.

Referring back to the influence diagram with its complexity of many systems and subsystems the aim was to produce a simplified systems diagram that could incorporate all of these and be the basis of an investigation methodology. The version developed for this methodology has grouped broad industrial processes into the sub-processes of Technology, Organisation, People, Similar Events, Environment all tied to a time base during the investigation (TOP-SET). This is shown in the following systems diagram.

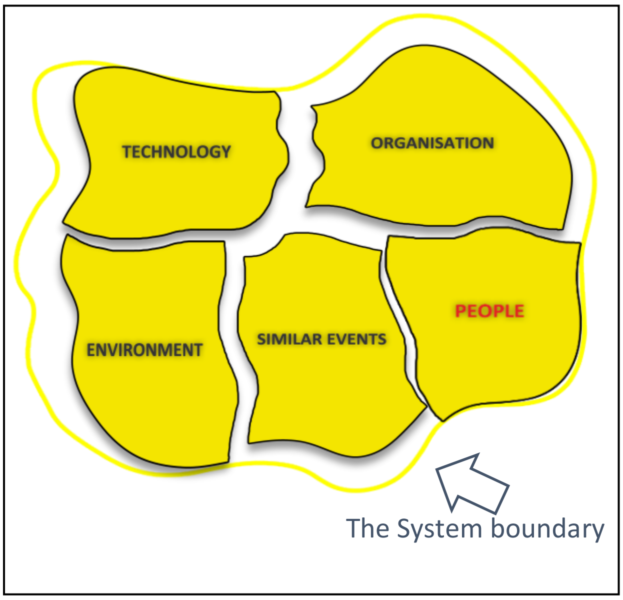

Diagram 3

The key elements shown in this diagram of Technology, Organisation, People and Environment are highlighted in red in the influence diagram (Diagram 1)

Based on the above systems map, the initial aim was to produce an easy to use straightforward step by step methodology that could be applied by specialist and non-specialist investigators initially in the offshore oil and gas exploration industry post Piper Alpha where significant shortcomings had been identified (the Lord Cullen 1990 Enquiry).

The model (Ramsay, D.K. 2005) that was developed and has been successfully used for thirty years in many industries worldwide, is shown in the later diagram (Diagram 7) and is based on six clear steps of:

1. Write an Incident Statement
2. Plan
3. Investigate
4. Analyse
5. Write a report with Recommendations
6. Take Action and Review

The first critical step is defining the problem with an incident statement. This is based on only what is actually known at the time and must avoid any speculation. In any analysis of a system it is essential to define clearly what the problem being studied is so that the investigation is not skewed in the wrong direction by supposition. With the Deepwater Horizon Investigation for the asset owners in 2010 the immediate information was overwhelming and it was difficult to see where to start. Comment such as “it’s a blowout” and the “the blowout preventor (BOP) has failed” were not helpful. While these proved to be part of the story the facts were only established during the in-depth investigation. In this example all that could truly said was that there had been a massive explosion.

We consider what is seen to have happened and the consequences, so for Deepwater Horizon:

What Happened was

- A massive explosion (Ignition of Hydrocarbons)

Consequences (Some of)

- Loss of life
- Injury
- Loss of Vessel
- Huge uncontrollable oil loss and pollution
- Financial loss
- Prosecution

The following chart gives examples of five other actual events and their initial incident statement. Mostly the first notification of an event is by telephone, so writing a first draft incident statement enables the planning of the investigation and the selection of appropriate investigators.

First information is usually received by telephone

What Happened **The initial change that triggered the consequences in right column**	**Consequences** **The event which is the outcome of the initial change in the left column**
1. Broken rail	Train derailment
2. Failure of gas containment	High pressure gas release (narrowly misses worker)
3. Insufficient clearance for train in tunnel	Underground train hits electrical junction box on tunnel wall
4. Fire on board ship	Electrical control module burnt out
5. Unplanned fall of lifeboat into sea	Man killed

Diagram 4

Having established the incident statement attention can then be directed at the areas where the known problems had occurred. Depending on the nature and size of the incident a ‘Scope of Work’ or ‘Terms of Reference’ can be established and an appropriate team selected.

With really large investigations such as Deepwater the principles are the same, but the team structure will be very different and may use a group approach such as with major air crashes (Sleight, P. AAIB).

There can be sub-teams dealing with different systems e.g.

- Human Factors
- Engineering
- Control systems
- Legal aspects etc

The investigators are not the ‘First Response’ team and therefore time taken to plan is essential and will often shorten the time taken to investigate and report.

Having prepared an Incident Statement and selected a team the next question is what has changed?

Change

Incidents only occur when the system that was running normally has changed in some way.

Case Example

Looking at number 4 (Fire onboard ship) in the above diagram, the incident was that a large electrical unit approximately 4m x 3m x 3m which was part of a large ship, had caught fire and burnt out despite being unconnected to any power source. The cause of the fire appeared to be a total mystery and earlier investigations by the shipyard and external specialists had failed to establish the causes and in particular the source of ignition.

To establish how the electrical module could have caught fire when there seemed to be no possible ignition sources in the area required a detailed search for what had changed. Further complications were that there was nothing in the area that could have remotely been considered an ignition source, and the fire had occurred during a weekend shut down and, also the access permitting system showed that no work had gone on the area. After two days of looking for change it was found that high voltage cables to run a nearby arc welding plant had been present but subsequently removed. There had been no records of this work.

The change which had started the fire was the presence of heat from the earlier welding, but the equipment had been cleared away and no one had checked if there had been a residual area of heat or smoldering.

The systems which had failed were the control of unrelated maintenance and construction work and the work permit system. Soft Systems Failures - Human Factors

Changes may be dramatic such as with an explosion or it may be a degradation over time. Changes that have been happening but gone on unseen are latent failures

Within every organisation hidden changes can have been going on unseen, unnoticed, ignored or even considered unimportant for years until a set of circumstances come together on a particular day. An extreme example of this was the Aberfan Disaster of 1966 with the deaths of 28 adults and 116 children where a coal spoil tip built on a slope over a stream and with a build up of rain water eventually slipped down the hill with disastrous consequences. A preventable failure in a waste handling system.

The following diagram of systems degradation over time or ‘Organisational Rust’ illustrates how such failures can creep up unnoticed.

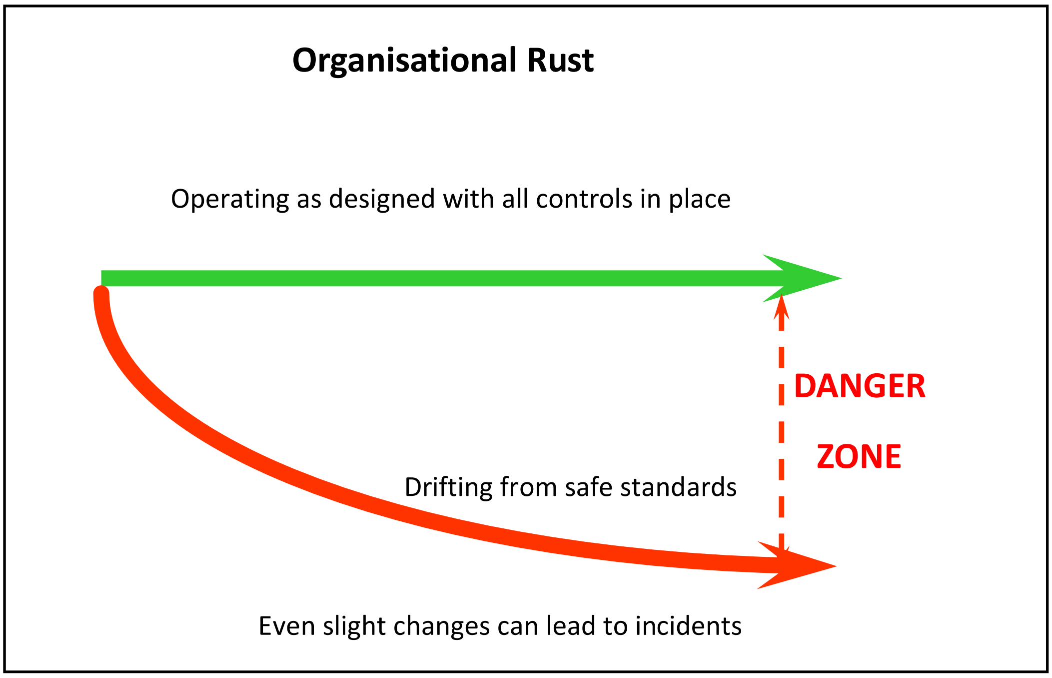

Diagram 5

To help decide where to look for change there is an Indicator Card to suggest areas under the TOP-SET categories where investigators might start to look for change. The initial list of forty indicators is not meant to be exhaustive (there is one with over 600 also available) but to help direct attention and avoid bias.

Bias is natural. We are all biased (Heffernan 2015). The brain achieves its efficiency by searching for information matched with previous experiences and takes a shortcut and trusts this because it seems roughly the same as something seen or experienced before.

1. Normal Bias: e.g. fits what was expected – a solution has been found

2. Confirmation Bias: e.g. seeking evidence to confirm what they believe has happened (Pinker 2021) and unconscious filtering (Roberto 2009)

3. Hindsight Bias; e.g. investigators see clearly what should have been done – not why.

4. Cognitive Bias (Dunning-Kruger Effect): e.g. investigators have an inflated belief in their own competence/judgement/experience.

Overcoming bias is helped by the use of the Indicators. As stated, the initial aim was to develop a practical incident investigation and problem-solving methodology for use by non-specialist investigators in the offshore oil exploration and production industry. Essentially technical managers. By using Myers Briggs personality tests on a sample size of over 500 individuals it was found that 75% fell into two of sixteen possible categories. The categories were not important in themselves, but rather illustrated that three quarters of the investigators were in danger of seeing problems in the same way and may not have had a sufficiently open view to consider a wide range of possibilities. It is suggested that there is a possible challenge to help technologists and engineers to widen their thinking to avoid having purely technical solutions. The indicators are to help widen thinking by looking for change in each of the areas shown and by paying particular attention to:

1. What has changed or is different?
2. What controls have been defeated?
3. What can witnesses tell you?

Diagram 6

This set of indicators is the starting place for planning the investigation and is also a refence point throughout, to ensure that everything has been covered.

Incidents, or systems failures, are departures from the norm. The challenge is to search for unexpected, unseen and unwanted Change. Without finding out what these changes have been will prevent the investigation reaching a satisfactory conclusion. The investigator must look for what change, or changes have occurred in the failed system that enabled the event to occur, (Reason 1990) because without change, the process whether a car journey, an industrial process, or a financial performance would continue as normal. This is in someway, analogous to Newton's First Law of Motion:

'A body at rest or in uniform motion will continue to be in rest or uniform motion until and unless a net external force acts upon it' (Isaac Newton 1642 – 1726) (McFadden 2021)

Expressed another way, is to say that things will continue as they are unless some other factor or force acts upon it. Therefore, it is the investigator's job to identify what these factors are so that deeper investigation can take place to identify all of the causal factors can be identified before remedies can be proposed.

Clearly change in itself is not the issue, because we manage, control and develop businesses through change (Burnes 2017); it is the uncontrolled and unexpected change that is at the heart of every incident. Specifically, the investigator should be looking for changes in 'Human Activity Systems' (Checkland 1993) and having established any change, it is then necessary to consider if it had significance.

Maintenance, of necessity, involves change. (Kletz 1994) identifies that 40% of pipeline failures involved maintenance. By identifying changes this can lead to identifying where the problems arose (Kepnor Tragoe 1981). Also, (Reason 1997) illustrates complexity and how the complexity of maintenance can introduce error and hence potential and actual incidents.

Consideration of Similar Events is important. Sadly, events that are amazingly similar happen again and again. And it can be argued that we often fail to learn from the past.

Bank crises and failures go back to at least the South Sea Bubble in 1711 (Beckman 1990) through the 1929 Great Crash (Galbraith 1954) right up to the bank failures of 2008 (Brummer 2014). Failure to learn from similar events and from the past occur in every field. Major life losses have occurred with sporting stadia over decades (Elliot & Smith 1993) and with very many tower-block and major building fires of which Garnock Court, Irvine 1999 and Grenfell Tower, London 2017 are just two examples (Kernick 2021) (Cohen-Hatton 2019)

While Indicators are essential to planning the investigation they should used as constant reference to confirm that all possible factors have been covered and to help consider if other items should be looked at. There are many components to the investigation part of the methodology and these are unlikely to follow sequential steps, nor is there a need to because, depending on the size of the team some elements can be run in parallel with regular reporting back. Also, investigation is iterative process, and elements are likely to be revisited, perhaps several times in order to establish and confirm facts.

These elements are;

a. Visit the scene – a huge amount of information can be gained but not only looking at the scene but also the surrounding general conditions.
b. Make drawings – even rough sketches can help the team understand positions of equipment and people. Noting scales and distances is important.
c. Take photographs and videos. Easy to do with modern technology, but important to include a scale and to number all photos and to have dedicated backup.
d. Check records. This can be quite extensive and will require someone who is good at detail.
e. Interview. This is a critical step that requires great skill.
f. Test equipment. This may be done on site if necessary, or in some cases sent off to a specialist contractor or university.
g. Reconstruct. Usually, a reconstruction is best as a simulation, because there is always the danger of recreating the incident (it has been known).
h. Develop a story board with a timeline or time log

Only after the above steps are completed will there be enough factual information to move on to the production of Root Cause Analysis and Diagram followed by reports, recommendations and remedial action plans.

The following diagram illustrates the whole investigation process.

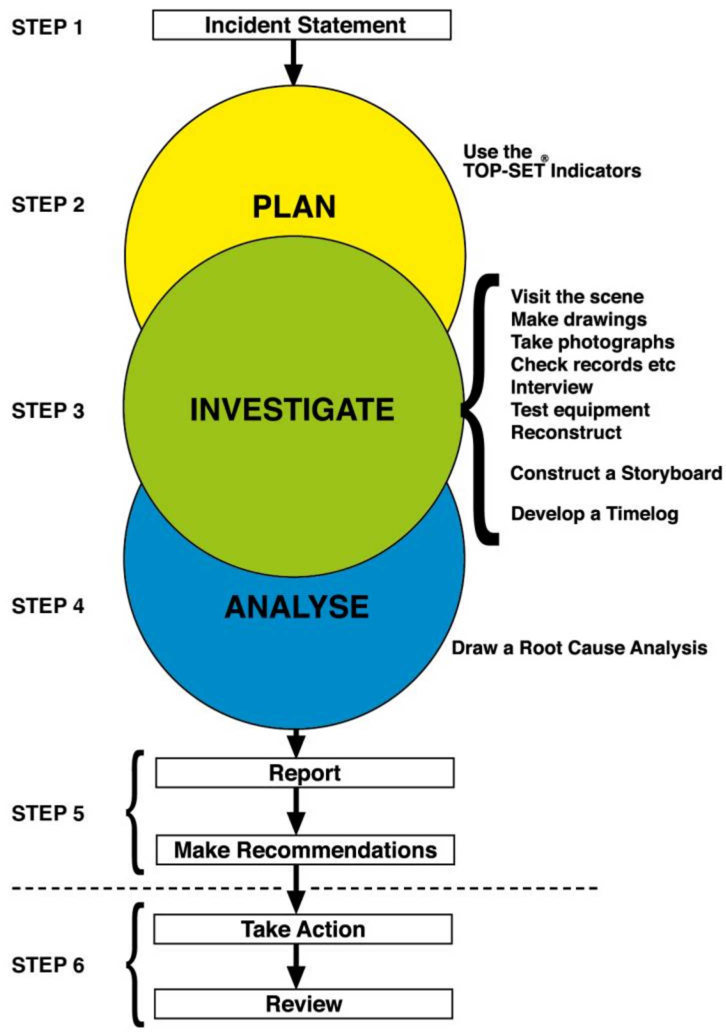
STEP 1
Incident Statement
STEP 2
PLAN
Use the TOP-SET® Indicators
STEP 3
INVESTIGATE
Visit the scene
Make drawings
Take photographs
Check records etc
Interview
Test equipment
Reconstruct
Construct a Storyboard
Develop a Timelog
STEP 4
ANALYSE
Draw a Root Cause Analysis
STEP 5
Report
Make Recommendations
STEP 6
Take Action
Review

Diagram 7

A crucial step is the development of a story board where all of the questions and findings are placed relative to a timescale that shows all of the potential causal factors running up to the time of the event. For smaller events this may be a matter of days, weeks or even months, but other major events can go back many years. These findings are expressed on a large chart using' Post-its' or similar. This is very much a physical sharing device to which every team member contributes. It is a vehicle for discussion and debate and the use of paper' Post-its' on a chart is preferable to an electronic production because everyone can and should be involved and not just the person on the keyboard. Clearly in major incidents where there are hundreds, if not thousands of items to display then an electronic system may be a necessary choice.

Example Storyboard from a Train Derailment

It is important to recognise the difference between investigation and analysis. Some systems focus heavily on Root Cause Analysis, but this cannot be effective until all of the facts have been established. Of course, it is an iterative process, but the danger is to conduct the analysis phase too early and to miss some of the crucial facts. Again, referring to bias, findings can fit, or be made to fit, what was expected, and a solution has been found.

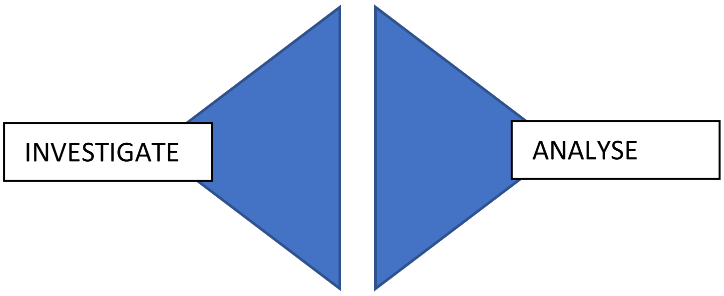

Diagram 8 Example Investigation and Analysis

The investigation phase requires open thinking looking for change and failed defences and barriers and should not proceed to analysis, such as the preparation of a Root Cause Diagram until all of the facts have been established. However, the whole investigation process should iterative, constantly reviewing findings.

Case Study – Boat Adrift at Sea

In the following example of an actual potential serious incident, the use of the methodology is demonstrated. It also illustrates examples of

a. Hard systems failure – engine breakdown
b. Soft systems failure – being in a situation of having no safe back-up
c. Change

It also illustrates that Human Factors are at the heart of everything including design, maintenance, and manufacture.

Bias, Hindsight Bias, Hard and Soft Systems, Change, Failure, Contingency, Irrational Behaviour are apparent.

In this case study the event was a small cabin cruiser (7.0 M) with two persons on board had an engine failure approximately 1 Mile South West of Largs Marina on the Firth of Clyde in the West of Scotland. This was an incident of high potential.

Instead of focusing on just the engine failure, a full systems analysis was conducted by first defining the problem at its simplest level.

- Consequences (Event) – boat adrift at sea with two people on board
- What Happened (Initial Cause) – Engine stopped
- Potential consequences – loss of vessel, loss of life.

The system was considered to have the following elements:

1. Technology
2. Organisation
3. People
4. Similar Events (that could be learned from)
5. Environment
6. Time

The first question was what had changed, and it is clear the engine had stopped and the reasons for this are covered in the following analysis as are also the controls, i.e. barriers and defences that had failed.

By analysing all of these elements using the indicators and looking for significant changes, a much bigger picture emerged.

1. **Technology** – The engine was a Volvo Penta and on examination it was found that a composite belt driving auxiliary equipment had caught on a rough edge of an adjacent housing. A small piece of the belt then went under the Timing Belt housing. The Timing Belt which is notched, is a critical component that matches with a notched wheel which is part of the engine drive system. If the belt jumps by even one notch the various components in the engine including valves and pistons run out of sequence and can hit each other at high speed thereby wrecking the engine.
   This timing belt is a critical part of any engine and the following diagram illustrates the relationship between the notched timing belt and the similarly notched gear wheels that are significant components of the engine. Once the belt has jumped from its normal position the damage has been done and there is nothing that the operator can do to mitigate the problem. It is a total engine failure.

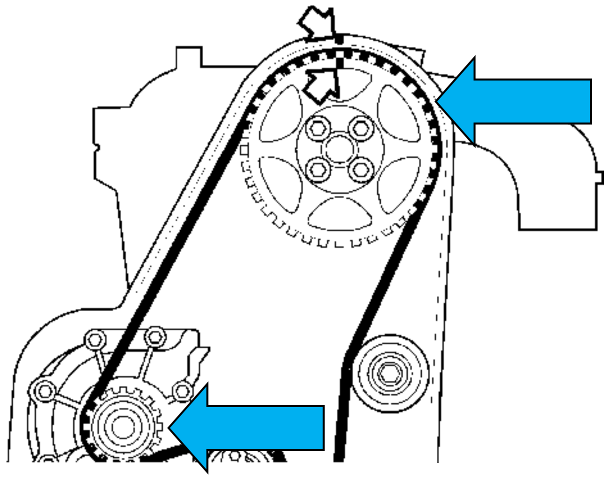

Diagram 9

   A whole series of questions emerged from this including engine maintenance, run time, design and manufacture.

   It was established that there was no back up system to the failed inboard engine. It is recommended that a separate outboard motor is carried for such emergencies especially when operating in the open sea.

2. **Organisation** – This included the mooring and storage of the vessel, periods of use. Preparedness for emergencies including engine failure.

3. **People** – it was established that the owner was adequately trained and held a sea going Yacht-Master certificate and had owned the boat for approximately two years and was experienced in its use. However, while he couldn't reasonably have been expected to have a full detailed mechanical knowledge, he was aware of the recommendation to have back-up power while operating in open water. He had chosen not to do this in order to maximise available space in the boat and also minimise weight.

4. **Similar Events –** there can be considerable learnings where something broadly similar has occurred elsewhere. In this particular case, an identical failure with a Volvo Penta engine was found to occurred on another similar boat. Also the author had many years previously had a timing belt failure on a Volvo petrol car engine with subsequent major damage (which Volvo paid to repair).

5. **Environment –** in this particular case the weather was fine with a moderate sea state and little wind. However, the vessel was adrift in a major sea lane with working ferries and at that time massive ore carrying ships and tugs operating in the channel. In the West of Scotland, the weather can change very rapidly and vessels without power could be swamped or driven onto rocks.

6. **Time –** there were several time elements here including the time from the last engine service. Age of the vessel. One possible significant factor was that owner had taken off with a female work colleague for a 'quick' island trip over a lunch break.

In looking at this as a total system it was found that there were three principal failures

a. Engine design –
    i. Possible learnings for the engine manufacturer
    ii. Quality of drive belts
    iii. Shape of belt housings
b. Engine maintenance
    i. Checking of belt housing conditions – no sharp edges
c. Attitude of the owner
    i. No back up system
    ii. Attitude to risk

This was financially very costly for the owner, but if it had happened further out to sea and the weather had changed lives could have been lost. As it happened, he was sufficiently close to the marina to radio for assistance and was towed back to dock.

Validation

No investigation methodology is unique. To establish which features of this methodology were different from others available in the marketplace, a number experienced investigators who had used other systems were consulted as were methodology reviews (Cojazzi, G. 1993) & (Sklet, S. 2002)

1. **Event**. This term or Top Event is widely used in a number of methodologies
2. **Incident Statement**. This approach with its simplified key elements is unique to TOP-SET
3. **Categorisation** of possible findings. Similar with ICAM
4. **Storyboard**. Similar with Taproot
5. **Investigation**. i.e. how to gather information e.g. site visits, interviewing etc. Not well covered in other systems outside police (where the goal may be different e.g. prosecution)
6. **Questions**. Preplanned use in some systems including SCAT and Taproot
7. **Analysis**. Most systems, including Tripod & CAST concentrate on analysing the 'found facts' rather also how to gather the facts
8. **Change**. Implicit in some systems but explicit with this methodology (TOP-SET) and the basis of Change Analysis (DOE 2012 USA)
9. **Indicators**. Identifying change and avoiding bias

10. **Ease of use**. This varies widely across all methodologies as does the accuracy and consistency of results
11. **Planning**. TOP-SET puts a big emphasis here for both before and during the investigation

This list is not exhaustive, nor is it meant to be a review of all methodologies, but, this TOP-SET methodology contains all of the above elements with the exception of number 6. Pre-prepared questions although Indicators for guidance and avoidance of bias are widely used.

While the initial purpose of the methodology was for use by non-specialist investigators in the offshore oil exploration and production industry the following chart illustrates a few of the wider applications.

1.	Dropped 240 Tonne Load	Russia	Project time loss & 2 possible fatalities
2.	Major Gas Release	South Africa	Potential Disaster
3.	Explosion	Germany	1 Fatality & wrecked plant
4.	Railway Fault	London	Potential derailment
5.	Explosion	USA	Potential fatalities
6.	Offshore Disaster	USA	Fatalities, major pollution, rig loss
7.	Railway electrocution	England	1 Fatality
8.	Oil rig faults	North Sea	Financial and time loss
9.	Ship Propulsion Problems	Nigeria/Spain	Potential loss of ship and gas cargo
10.	Fall on Ship	Mexico	Potential injury
11.	Oil rig adrift in Typhoon	Vietnam	Potential multiple fatality and loss of rig

Conclusions

This methodology is essentially a systems analysis tool that is of practical value for non-specialist and specialists in conducting incident investigations. However, it has wide application in many problem solving situations.

(Leveson 2017) looks at how systems thinking can be applied to engineering a safer world and (Perrow 1999) discusses safety in depth. (Reason 2008) discusses managing the manageable as does (Groeneweg,1998) with controlling what can be controlled. A variant of the methodology was developed in conjunction with a major aerospace company to identify specific problems such as causes of downtime, but also to assist in project planning and the management of risk. The same expanded methodology can also be used to explore business risk. (Dekker 2015) stated that safety is not linear and this fits with the example earlier in the paper of oil production platforms being examples of loosely coupled systems.

References

Asby, A. 2021, Thinking Systems, An Organic Language of Harmony for Human Survival, Triarchy Press, UK

Beck, U. 2007, World at Risk. Polity, Cambridge, UK

Beckman, R. 1990. Crashes, Why They Happen - What To Do, Grafton/Collins

Beishon & Peters, Ed, 1972, Systems Behaviour, OU Press

Bhagwati, K. 2006. Managing Safety, A Guide for Executives, Wiley-VCH

BowTie Risk Assessment 2020, GGE Risk Management Solutions, Netherlands

Busch.C 2016, Safety Myth 101. Carsten Busch (Self published?)

Caldwell, B. & Klausinger, D. 2022, 'Hayek, A Life 1899-1950', University of Chicago

Canadian Defence Directorate of Flight Safety Aircraft Accident Board of Enquiry Handbook 1987

Checkland, P.B., 1972, A Systems Map of the Universe, OU

Checkland, P., 1993. Systems Thinking, Systems Practice. Wiley

Checkland, P. & Scholes, J. 1990, Soft Systems Methodology in Action. Wiley

Clearfield, C. & Tilcsik, A. 2018, Meltdown, Why Our Systems Fail and What We Can Do About It. Atlantic Books, London

Cleland, D.I. & King,W.R. 1983,mSystems Analysis & Project Management, McGraw- Hill

Cohen-Hatton, S, 2020, The Heat of the Moment, A Firefighter's Stories of Life and Death Decisions

Conklin, T. 2012, Pre-Accident Investigations, An introduction to Organizational Safety. CRC Press

Collinge. M. 2021. Management Today

Dekker, S. Drift into Failure, From Hunting Broken Components to Understanding Complex Systems. CRC Press.

Dekker, S. 2014. The Field Guide to Understanding Human Error. CRC Press

Dorner, D. 1996, The Logic of Failure, Addison Wesley

Fergusson,E.S. Engineering and the Mind's Eye, 1994, MIT Press

Flood,R.l. & Jackson, M.C. 1993 , Creative Problem Solving Wiley, London

Fuller, P. & Murphy, M with Chow, M. 2020. The Leader's Guide to Unconscious Bias. Simon & Schuster

Gardner, D. 2009. Risk, The Science and Politics of Fear. Virgin Books

Gladwell, M. 2001. The Tipping Point. Abacus

Gross, V,L. 1987. Managing Risk, Systematic Loss Prevention for Executives. Omega. Virginia USA

Groeneweg, J., 1998 Controlling the controllable. The management of safety. 4th Ed. DSWO Press, Leiden University.

Harris, b. 2003, Director's and engineers' responsibilities for safety – a cautionary tale. IChemE

Heffernan, M. 2015. Beyond Measure, The Big Impact of Small Changes. TED Books

Jenkins, G.M., 1972 The Systems Approach, OU

Kahneman, D 2012, Thinking Fast and Slow, Penguin, Random House

Kernick, G. 2021. Catastrophe and Systems Change. Learning from Grenfell Tower and Other Disasters. London Publishing Partnership.

Kepnor.C.H. & Tragoe, B.B. 1981, The New Rational Manager Princeton Research Press

Kletz T,Learning from Accidents, 2nd Ed,Butterworth-Heinemann 1994

Leveson, N.G. 2019, CAST Handbook, How to Learn More from Incidents and Accidents

Leveson, N.G. 2017. Engineering a Safer World, Systems Thinking Applied to Safety, MIT Press

Li, Yuling. 2019 A systematic and Quantitative Approach to Safety Management, University of Delft

Meadows, D.H. 2008, Thinking in Systems, A Primer, Chelsea Green Publishing, London

McFadden, J. 2021, Life is Simple. Basic Books, London.

Perrow, C. 1999. Normal Accidents, Living with High-Risk Technologies, Princeton University Press

Pedrali, M., Cojazzi, G & Cacciabue,P.C. 1995, A Methodology for Retrospective Analysis of Accidents Involving Human Factors, Proceedings of the Eigth International Symposium on Aviation Psychology

Principal Conclusions and Overall Assessment of the Bloody Sunday Inquiry The Rt Hon The Lord Saville of Newdigate (Chairman) The Hon William Hoyt OC The Hon John Toohey AC

Reason, J. 2008. The Human Contribution, Unsafe Acts, Accidents and Heroic Recoveries. Ashgate

Reason, J. 1997. Managing the Risks of Organisational Accidents. Ashgate

Reason, J. 1990. Human Error. Cambridge University Press

Report of the Tribunal appointed to inquire into the events on Sunday, 30th January 1972 [Widgery Report]

Report of inquest into the deaths on Sunday, 30th January by Londonderry City Coroner, Hubert O'Neill August 1973

Roberto, M.A. 2009, Know What You Don't Know How great leaders prevent problems before they happen. Pearson

Root Cause Analysis Methodologies, 1993, Institute for Systems Engineering and Information

Rutherford, A. 2019 The Elements of Thinking in Systems. Kindle Direct Publishing

Sleight, P. A Holistic Approach to Aircraft Accident/Incident Investigation. AAIB

Stowell, F. & Welch, C. 2012, The Manager's Guide to Systems Practice. Wiley

Strauch, B. 2002, Investigating Human Error, Routledge

The Public Enquiry into the Piper Alpha Disaster, Vols 1&2, 1990, The Hon Lord Cullen, U.K. Dept of Energy, HMSO

Tuli & Apostolakis, 1996 Incorporating Organizational Issues into Root-Cause Analysis, , Trans IChemE Part B

Tripod Beta, 2015, Guidance Manual, Energy Institute, London.

Von Bertalanffy, L. 1968, General Systems Theory, George Brazziler, New York.

Wearne, P. 1999, Collapse, Why Buildings Fall Down, Channel 4 Books/Macmillan