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ROOT CAUSE ANALYSIS

ΚΩΝΣΤΑΝΤΟΥΛΑΚΗΣ ΙΩΑΝΝΗΣ

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CHAPTER 1
DEFINITIONS

1.1 ROOT CAUSE ANALYSIS

Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or events. The practice of RCA is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized. However, it is recognized that complete prevention of recurrence by a single intervention is not always possible. Thus, RCA is often considered to be an iterative process, and is frequently viewed as a tool of continuous improvement.

RCA, initially, is a reactive method of problem detection and solving. This means that the analysis is done after an event has occurred. By gaining expertise in RCA it becomes a pro-active method. This means that RCA is able to forecast the possibility of an event even before it could occur.

Root cause analysis is not a single, sharply defined methodology; there are many different tools, processes, and philosophies of RCA in existence. However, most of these can be classed into five, very-broadly defined "schools" that are named here by their basic fields of origin: safety-based, production-based, process-based, failure-based, and systems-based.

- Safety-based RCA descends from the fields of accident analysis and occupational safety and health.
- Production-based RCA has its origins in the field of quality control for industrial manufacturing.
- Process-based RCA is basically a follow-on to production-based RCA, but with a scope that has been expanded to include business processes.
- Failure-based RCA is rooted in the practice of failure analysis as employed in engineering and maintenance.
- Systems-based RCA has emerged as an amalgamation of the preceding schools, along with ideas taken from fields such as change management, risk management, and systems analysis.

Despite the seeming disparity in purpose and definition among the various schools of root cause analysis, there are some general principles that could be considered as universal. Similarly, it is possible to define a general process for performing RCA.

1.2 QUALITY CONTROL

In engineering and manufacturing, quality control and quality engineering are used in developing systems to ensure products or services are designed and produced to meet or exceed customer requirements.

Quality control is the branch of engineering and manufacturing which deals with assurance and failure testing in design and production of products or services, to meet or exceed customer requirements.

1.2.1 Quality assurance

One of the most widely used paradigms for quality assurance management is the PDCA (Plan-Do-Check-Act). This problem solving process was made popular by Dr. W. Edwards Deming, who is considered by many to be the father of modern quality control.

1.2.2 Failure testing

A valuable process to perform on a whole consumer product is failure testing (also known as stress testing), the operation of a product until it fails, often under stresses such as increasing vibration, temperature and humidity. This exposes many unanticipated weaknesses in a product, and the data is used to drive engineering and manufacturing process improvements.

1.2.3 Statistical control

Many organizations use statistical process control to bring the organization to Six Sigma levels of quality, in other words, so that the likelihood of an unexpected failure is confined to six standard deviations on the normal distribution. This probability is 3.4 one-millionths. Items

controlled often include clerical tasks such as order-entry as well as conventional manufacturing tasks.

Traditional statistical process controls in manufacturing operations usually proceed by randomly sampling and testing a fraction of the output. Variances of critical tolerances are continuously tracked, and manufacturing processes are corrected before bad parts can be produced.

1.2.4 Company quality

During the 1980s, the concept of "company quality" with the focus on management and people came to the fore. It was realized that, if all departments approached quality with an open mind, success was possible if the management led the quality improvement process.
The company-wide quality approach places an emphasis on three aspects:

1. Elements such as controls, job management, defined and well managed processes, performance and integrity criteria and identification of records.
2. Competence such as knowledge, skills, experience, qualifications.
3. Soft elements, such as personnel integrity, confidence, organizational culture, motivation, team spirit and quality relationships.

The quality of the outputs is at risk if any of these three aspects is deficient in any way.

1.2.5 Total quality control

Total Quality Control is the most necessary inspection control of all in cases where, despite statistical quality control techniques or quality improvements implemented, sales decrease.

If the original specification does not reflect the correct quality requirements, quality cannot be inspected or manufactured into the product.

For instance, all parameters for a pressure vessel should include not only the material and dimensions but operating, environmental, safety, reliability and maintainability requirements.

1.3 FAILURE ANALYSIS

Failure analysis is the process of collecting and analyzing data to determine the cause of a failure and how to prevent it from recurring. It is an important discipline in many branches of manufacturing industry, such as the electronics industry, where it is a vital tool used in the development of new products and for the improvement of existing ones. It relies on collecting failed components for subsequent examination of the cause or causes of failure using a wide array of methods, especially microscopy and spectroscopy. The NDT or nondestructive testing methods are valuable because the failed products are unaffected by analysis, so inspection always starts using these methods.

1.3.1 Forensic investigation

Forensic inquiry into the failed process or product is the starting point of failure analysis. Such inquiry is conducted using scientific analytical methods such as electrical and mechanical measurements, or by analysing failure data such as product reject reports or examples of previous failures of the same kind. The methods of forensic engineering are especially valuable in tracing product defects and flaws. They may include fatigue cracks, brittle cracks produced by stress corrosion cracking or environmental stress cracking, for example. Witness statements can be valuable for reconstructing the likely sequence of events and hence the chain of cause and effect. Human factors can also be assessed when the cause of the failure is determined. There are several useful methods to prevent product failures occurring in the first place, including Failure Mode and Effects Analysis(FMEA) and Fault Tree Analysis (FTA), methods which can be used during prototyping to analyse failures before a product is marketed.

Failure theories can only be constructed on such data, but when corrective action is needed quickly, the precautionary principle demands that measures be put in place. In aircraft accidents, for example, all planes of the type involved can be grounded immediately pending the outcome of the inquiry.

Another interesting aspect of failure analysis is associated with No Fault Found (NFF) which is a term used in the field of failure analysis to describe a situation where an originally reported mode of failure can not

be duplicated by the evaluating technician and therefore the potential defect can not be fixed.

NFF can be attributed to oxidation, defective connections of electrical components, temporary shorts or opens in the circuits, software bugs, temporary environmental factors, but also to the operator error. Large number of devices that are reported as NFF during the first troubleshooting session often return to the failure analysis lab with the same NFF symptoms or a permanent mode of failure.

The term Failure analysis also applies to other fields such as business management and military strategy.

1.4 SYSTEMS ANALYSIS

Systems analysis is the interdisciplinary part of science, dealing with analysis of sets of interacting entities, the systems, often prior to their automation as computer systems, and the interactions within those systems. This field is closely related to operations research. It is also an explicit formal inquiry carried out to help someone, referred to as the decision maker, identify a better course of action and make a better decision than he might have otherwise made.

1.4.1 Overview

The terms analysis and synthesis come from classical Greek where they mean respectively "to take apart" and "to put together". These terms are used in scientific disciplines from mathematics and logic to economy and psychology to denote similar investigative procedures. In general, analysis is defined as the procedure by which we break down an intellectual or substantial whole into parts or components. Synthesis is defined as the opposite procedure: to combine separate elements or components in order to form a coherent whole.

The systems discussed within systems analysis can be within any field such as: industrial processes, management, decision making processes, environmental protection processes, etc. The brothers Howard T. Odum and Eugene Odum began applying a systems view to ecology in 1953, building on the work of Raymond Lindeman (1942) and Arthur Tansley (1935).

Systems analysis researchers apply mathematical methodology to the analysis of the systems involved trying to form a detailed overall picture.

1.4.2 Practitioners

Practitioners of systems analysis are often called upon to dissect systems that have grown haphazardly to determine the current components of the system. This was shown during the year 2000 re-engineering effort as business and manufacturing processes were examined and simplified, as part of the Year 2000 Problem (also known as the Y2K problem or the millennium bug) automation upgrades. Current employment titles utilizing systems analysis include, but are not limited to, Systems Analyst, Business Analyst, Manufacturing Engineer, Enterprise Architect, etc.

While practitioners of systems analysis can be called upon to create entirely new systems, their skills are more often used to modify, expand or document existing systems (processes, procedures and methods).

1.5 GENERAL PRINCIPLES OF ROOT CAUSE ANALYSIS

1. Aiming performance improvement measures at root causes is more effective than merely treating the symptoms of a problem.
2. To be effective, RCA must be performed systematically, with conclusions and causes backed up by documented evidence.
3. There is usually more than one root cause for any given problem.
4. To be effective the analysis must establish all known causal relationships between the root cause(s) and the defined problem.
5. Root cause analysis transforms an old culture that reacts to problems to a new culture that solves problems before they escalate, creating a variability reduction and risk avoidance mindset.

CHAPTER 2

GENERAL PROCESS FOR PERFORMING AND DOCUMENTING AN RCA – BASED CORRECTIVE ACTION

Every root cause investigation and reporting process should include five phases. While there may be some overlap between phases, every effort should be made to keep them separate and distinct. [1]

Phase I. Data Collection. It is important to begin the data collection phase of root cause analysis immediately following the occurrence identification to ensure that data are not lost. (Without compromising safety or recovery, data should be collected even during an occurrence). The information that should be collected consists of conditions before, during, and after the occurrence; personnel involvement (including actions taken); environmental factors; and other information having relevance to the occurrence.

Phase II. Assessment. Any root cause analysis method may be used that includes the following steps:
1. Identify the problem.
2. Determine the significance of the problem.
3. Identify the causes (conditions or actions) immediately preceding and surrounding the problem.
4. Identify the reasons why the causes in the preceding step existed, working back to the root cause (the fundamental reason which, if corrected, will prevent recurrence of these and similar occurrences throughout the facility).

Phase III. Corrective Actions. Implementing effective corrective actions for each cause reduces the probability that a problem will recur and improves reliability and safety.

Phase IV. Inform. Entering the report on the Occurrence Reporting and Processing System (ORPS) is part of the inform process. Also included is discussing and explaining the results of the analysis, including corrective actions, with management and personnel involved in the occurrence. In addition, consideration should be given to providing information of interest to other facilities.

Phase V. Follow-up. Follow-up includes determining if corrective action has been effective in resolving problems. An effectiveness review is essential to ensure that corrective actions have been implemented and are preventing recurrence. Management involvement and adequate allocation of resources are essential to successful execution of the five root cause investigation and reporting phases.

2.1 PHASE I – DATA COLLECTION

As mentioned before, is important to begin the data collection phase of the root cause process immediately following occurrence identification to ensure that data are not lost. (Without compromising safety or recovery, data should be collected even during an occurrence). The information that should be collected consists of conditions before, during, and after the occurrence; personnel involvement (including actions taken); environmental factors; and other information having relevance to the condition or problem. For serious cases, photographing the area of the occurrence from several views may be useful in analyzing information developed during the investigation. Every effort should be made to preserve physical evidence such as failed components, ruptured gaskets, burned leads, blown fuses, spilled fluids, partially completed work orders and procedures. This should be done despite operational pressures to restore equipment to service. Occurrence participants and other knowledgeable individuals should be identified.

Once all the data associated with this occurrence have been collected, the data should be verified to ensure accuracy. The investigation may be enhanced if some physical evidence is retained. Establishing a quarantine area, or the tagging and segregation of pieces and material, should be performed for failed equipment or components.

The basic need is to determine the direct, contributing and root causes so that effective corrective actions can be taken that will prevent recurrence. Some areas to be considered when determining what information is needed include:

- Activities related to the occurrence
- Initial or recurring problems
- Hardware (equipment) or software (programmatic-type issues) associated with the occurrence
- Recent administrative program or equipment changes

- Physical environment or circumstances.

Some methods of gathering information include:

- Conducting interviews/collecting statements - Interviews must be fact finding and not fault finding. Preparing questions before the interview is essential to ensure that all necessary information is obtained.

  Interviews should be conducted, preferably in person, with those people who are most familiar with the problem. Individual statements could be obtained if time or the number of personnel involved make interviewing impractical. Interviews can be documented using any format desired by the interviewer. Consider conducting a "walk-through" as part of this interview if time permits.

  Although preparing for the interview is important, it should not delay prompt contact with participants and witnesses. The first interview may consist solely of hearing their narrative. A second, more-detailed interview can be arranged, if needed. The interviewer should always consider the interviewee's objectivity and frame of reference.
- Interviewing others - Consider interviewing other personnel who have performed the job in the past. Consider using a "walk-through" as part of the interview.
- Reviewing records - Review relevant documents or portions of documents as necessary and reference their use in support of the root cause analysis. Record appropriate dates and times associated with the occurrence on the documents reviewed. Examples of documents include the following:

  Operating logs
  Correspondence
  Inspection/surveillance records
  Maintenance records
  Meeting minutes
  Computer process data
  Procedures and instructions
  Vendor Manuals
  Drawings and specifications
  Functional retest specification and results
  Equipment history records

Design basis information
Safety Analysis Report (SAR)/Technical Specifications
Related quality control evaluation reports
Operational Safety Requirements
Safety Performance Measurement System/Occurrence Reporting and Processing System (SPMS/ORPS) Reports
Radiological surveys
Trend charts and graphs
Facility parameter readings
Sample analysis and results (chemistry, radiological, air, etc.)
Work orders

- Acquiring related information - Some additional information that an evaluator should consider when analyzing the causes includes the following:

  Evaluating the need for laboratory tests, such as destructive/nondestructive failure analysis. Viewing physical layout of system, component, or work area; developing layout sketches of the area; and taking photographs to better understand the condition. Determining if operating experience information exists for similar events at other facilities. Reviewing equipment supplier and manufacturer records to determine if correspondence has been received addressing this problem.

2.2 PHASE II – ASSESSMENT

The assessment phase includes analyzing the data to identify the causal factors, summarizing the findings, and categorizing the findings by the cause categories. The major cause categories are:

- Equipment/Material Problem
- Procedure Problem
- Personnel Error
- Design Problem
- Training Deficiency
- Management Problem
- External Phenomena

These categories have been carefully selected with the intent to address all problems that could arise in conducting DOE operations. Those elements necessary to perform any task are equipment/material, procedures (instructions), and personnel. Design and training determine the quality and effectiveness of equipment and personnel. These five elements must be managed; therefore, management is also a necessary element. Whenever there is an occurrence, one of these six program elements was inadequate to prevent the occurrence. (External phenomena beyond operational control serves as a seventh cause category.) These causal factors can be associated in a logical causal factor chain. (Note that a direct, contributing, or root cause can occur any place in the causal factor chain; that is, a root cause can be an operator error while a management problem can be a direct cause, depending on the nature of the occurrence.)

2.2.1 Assessment and Reporting Guidance

To perform the assessment and report the causal factors and corrective actions:

2.2.1.1 Analyze and determine the events and casual factor chain

Any root cause analysis method that includes the following basic steps maybe used.

(a) Identify the problem. Remember that actuation of a protective system constitutes the occurrence but is not the real problem; the unwanted, unplanned condition or action that resulted in actuation is the problem to be solved. For an example, dust in the air actuates a false fire alarm. In this case, the occurrence is the actuation of an engineered safety feature. The smoke detector and alarm functioned as intended; the problem to be solved is the dust in the air, not the false fire alarm. Another example is when an operator follows a defective procedure and causes an occurrence. The real problem is the defective procedure; the operator has not committed an error. However, if the operator had been correctly trained to perform the task and, therefore, could reasonably have been expected to detect the defect in the procedure, then a personnel problem may also exist.

(b) Determine the significance of the problem. Were the consequences severe? Could they be next time? How likely is recurrence?

Is the occurrence symptomatic of poor attitude, a safety culture problem, or other widespread program deficiency? Base the level of effort of subsequent steps of your assessment upon the estimation of the level of significance.

(c) Identify the causes (conditions or actions) immediately preceding and surrounding the problem (the reason the problem occurred).

(d) Identify the reasons why the causes in the preceding identification step existed, working your way back to the root cause (the fundamental reason that, if corrected, will prevent recurrence of this and similar occurrences throughout the facility and other facilities under your control). This root cause is the stopping point in the assessment of causal factors. It is the place where, with appropriate corrective action, the problem will be eliminated and will not recur.

2.2.1.2 Summarize findings, list the casual factors, and list corrective actions

Summarize your findings, and classify each finding or cause by the cause categories.

Select the one (most) direct cause and the root cause (the one for which corrective action will prevent recurrence and have the greatest, most widespread effect). In cause selection, focus on programmatic and system deficiencies and avoid simple excuses such as blaming the employee. Note that the root cause must be an explanation (the why) of the direct cause, not a repeat of the direct cause. In addition, a cause description is not just a repeat of the category code description; it is a description specific to the occurrence. Also, up to three (contributing) causes may be selected. Describe the corrective actions selected to prevent recurrence, including the reason why they were selected, and how they will prevent recurrence. Collect additional information as necessary.

2.3 PHASE III – CORRECTIVE ACTIONS

The root cause analysis enables the improvement of reliability and safety by selecting and implementing effective corrective actions. To begin, identify the corrective action for each cause; then apply the following criteria to the corrective actions to ensure they are viable. If the corrective actions are not viable, re-evaluate the solutions.

1. Will the corrective action prevent recurrence?
2. Is the corrective action feasible?
3. Does the corrective action allow meeting primary objectives or mission?
4. Does the corrective action introduce new risks? Are the assumed risks clearly stated? (The safety of other systems must not be degraded by the proposed corrective action.)
5. Were the immediate actions taken appropriate and effective?

A systems approach, such as Kepner-Tregoe (is the creation of structured, systematic processes which are used to maximize the critical thinking skills of key stakeholders in a particular situation, problem, potential or real, decision or opportunity), should be used in determining appropriate corrective actions. It should consider not only the impact they will have on preventing recurrence, but also the potential that the corrective actions may actually degrade some other aspect of nuclear safety. Also, the impact the corrective actions will have on other facilities and their operations should be considered. The proposed corrective actions must be compatible with facility commitments and other obligations. In addition, those affected by or responsible for any part of the corrective actions, including management, should be involved in the process. Proposed corrective actions should be reviewed to ensure the above criteria have been met, and should be prioritized based on importance, scheduled (a change in priority or schedule should be approved by management), entered into a commitment tracking system, and implemented in a timely manner. A complete corrective action program should be based, not only on specific causes of occurrences, but also on items such as lessons learned from other facilities, appraisals, and employee suggestions.

A successful corrective action program requires management that is involved at the appropriate level and is willing to take responsibility and allocate adequate resources for corrective actions.

Additional specific questions and considerations in developing and implementing corrective actions include:

- Do the corrective actions address all the causes?
- Will the corrective actions cause detrimental effects?
- What are the consequences of implementing the corrective actions?
- What are the consequences of not implementing the corrective actions?
- What is the cost of implementing the corrective actions (capital costs, operations, and maintenance costs)?
- Will training be required as part of the implementation?
- In what time frame can the corrective actions reasonably be implemented?
- What resources are required for successful development of the corrective actions?
- What resources are required for successful implementation and continued effectiveness of the corrective actions?
- What impact will the development and implementation of the corrective actions have on other work groups?
- Is the implementation of the corrective actions measurable?

2.4 PHASE IV – INFORM

Electronic reporting to ORPS (Occurrence Reporting and Processing System) is part of the inform process for all occurrences. (For those occurrences containing classified information, an unclassified version shall be entered into ORPS.) Effectively preventing recurrences requires the distribution of these reports (especially the lessons learned) to all personnel who might benefit. Methods and procedures for identifying personnel who have an interest is essential to effective communications.

In addition, an internal self-appraisal report identifying management and control system defects should be presented to management for the more serious occurrences. The defective elements can be identified using MORT (Management Oversight and Risk Tree Analysis) or Mini-MORT.

Consideration should be given to directly sharing the details of root cause information with similar facilities where significant or long-standing problems may also exist.

2.5 PHASE V – FOLLOW-UP

Follow-up includes determining if corrective actions have been effective in resolving problems. First, the corrective actions should be tracked to ensure that they have been properly implemented and are functioning as intended. Second, a periodic structured review of the corrective action tracking system, normal process and change control system, and occurrence tracking system should be conducted to ensure that past corrective actions have been effectively handled. The recurrence of the same or similar events must be identified and analyzed. If an occurrence recurs, the original occurrence should be re-evaluated to determine why corrective actions were not effective. Also, the new occurrence should be investigated using change analysis. The process change control system should be evaluated to determine what improvements are needed to keep up with changing conditions. Early indications of deteriorating conditions can be obtained from tracking and trend analyses of occurrence information. In addition, the ORPS database should be reviewed to identify good practices and lessons learned from other facilities. Prompt corrective actions should be taken to reverse deteriorating conditions or to apply lessons learned.

CHAPTER 3

ROOT CAUSE ANALYSIS METHODS

Many of the Root Cause Analysis (RCA) methods are specialized and apply to specific situations or objectives. Most have their own cause categorizations, but all are very effective when used within the scope for which they were designed.

The most common methods are:

- Barrier analysis - a technique often used in particularly in process industries. It is based on tracing energy flows, with a focus on barriers to those flows, to identify how and why the barriers did not prevent the energy flows from causing harm.
- Bayesian inference.
- Causal factor tree analysis - a technique based on displaying causal factors in a tree-structure such that cause-effect dependencies are clearly identified.
- Change analysis - an investigation technique often used for problems or accidents. It is based on comparing a situation that does not exhibit the problem to one that does, in order to identify the changes or differences that might explain why the problem occurred.
- Current Reality Tree A method developed by Eliahu M. Goldratt in his Theory of Constraints that guides an investigator to identify and relate all root causes using a cause-effect tree whose elements are bound by rules of logic (Categories of Legitimate Reservation). The CRT begins with a brief list of the undesirables things we see around us, and then guides us towards one or more root causes. This method is particularly powerful when the system is complex, there is no obvious link between the observed undesirable things, and a deep understanding of the root cause(s) is desired.
- Failure mode and effects analysis, also known as FMEA.
- Fault tree analysis.
- 5 Whys.
- Ishikawa diagram, also known as the fishbone diagram or cause and effect diagram.
- Kepner-Tregoe Problem Analysis - a root cause analysis process developed in 1958, which provides a fact-based approach to systematically rule out possible causes and identify the true cause.
- Pareto analysis.

- RPR Problem Diagnosis - An ITIL-aligned method for diagnosing IT problems.

3.1 BAYESIAN INFERENCE

Bayesian inference is statistical inference in which evidence or observations are used to update or to newly infer the probability that a hypothesis may be true. The name "Bayesian" comes from the frequent use of Bayes' theorem in the inference process. Bayes' theorem was derived from the work of the Reverend Thomas Bayes. [2]

3.1.1 Evidence and changing beliefs

Bayesian inference uses aspects of the scientific method, which involves collecting evidence that is meant to be consistent or inconsistent with a given hypothesis. As evidence accumulates, the degree of belief in a hypothesis ought to change. With enough evidence, it should become very high or very low. Thus, proponents of Bayesian inference say that it can be used to discriminate between conflicting hypotheses: hypotheses with very high support should be accepted as true and those with very low support should be rejected as false. However, detractors say that this inference method may be biased due to initial beliefs that one holds before any evidence is ever collected. (This is a form of inductive bias).

Bayesian inference uses a numerical estimate of the degree of belief in a hypothesis before evidence has been observed and calculates a numerical estimate of the degree of belief in the hypothesis after evidence has been observed. (This process is repeated when additional evidence is obtained.) Bayesian inference usually relies on degrees of belief, or subjective probabilities, in the induction process and does not necessarily claim to provide an objective method of induction. Nonetheless, some Bayesian statisticians believe probabilities can have an objective value and therefore Bayesian inference can provide an objective method of induction.

3.2 CURRENT REALITY TREE

One of the Thinking Processes in the Theory of Constraints, a Current Reality Tree (CRT), is a way of analyzing many system or

organizational problems at once. By identifying root causes common to most or all of the problems, the CRT can greatly aid focused improvement of the system. [3]

3.2.1 Simplified explanation

This process treats multiple problems as symptoms arising from a few ultimate root causes. It describes, in a simple visual drawing, the main perceived symptoms (along with secondary/hidden ones that lead up to the perceived symptom(s)) of a problem scenario and ultimately the apparent root cause(s) or conflict. The benefit of doing this is that it is much easier to identify the connections or dependencies among these. Thus, focus can be placed on the bits which would cause the biggest positive change if tackled. [4]

3.2.2 Contextual explanation

A current reality tree is a statement of an underlying core problem and the symptoms that arise from it. It maps out a sequence of cause and effect from the core problem to the symptoms. Most of the symptoms will arise from the one core problem or a core conflict. Remove the core problem and we may well be able to remove each of the symptoms as well. Operationally we work backwards from the apparent undesirable effects or symptoms to uncover or discover the underlying core cause. [5]

3.2.3 Example

A CRT begins with a list of problems, known as undesirable effects (UDEs.) These are assumed to be symptoms of a deeper common cause. To take a somewhat frivolous example, a car owner may have the following UDEs:

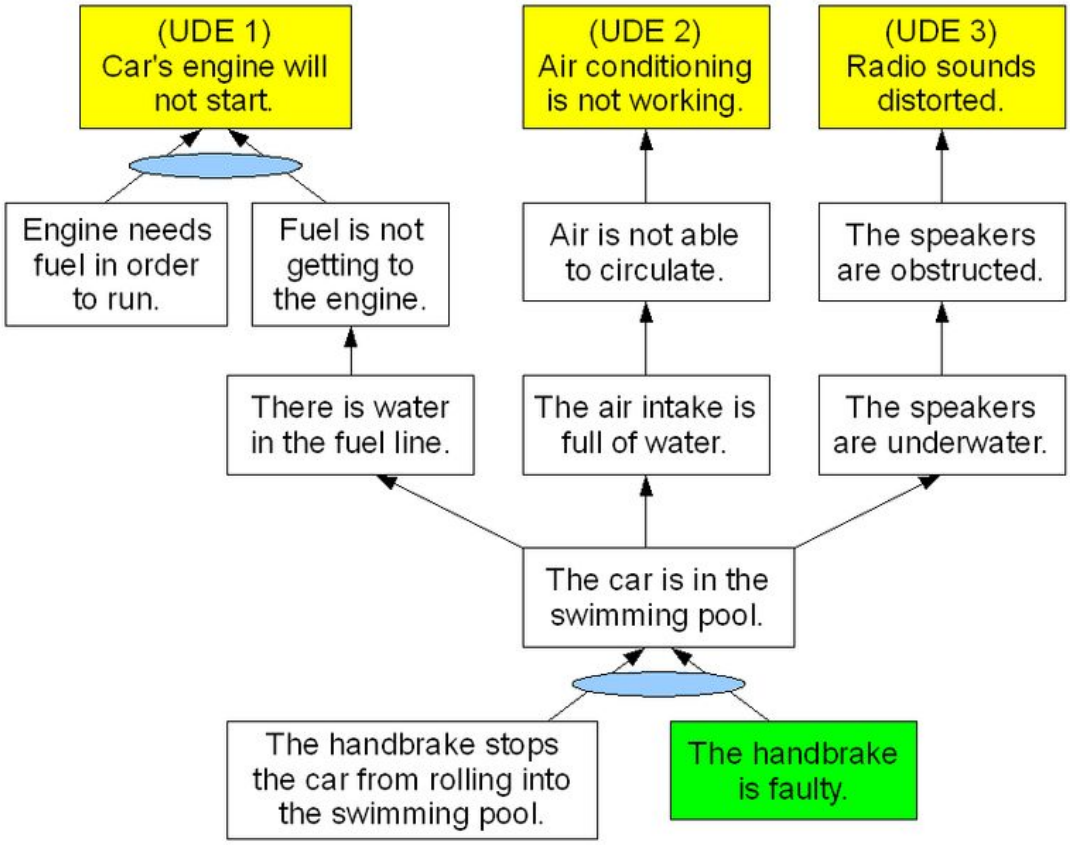
1. The car's engine will not start.
2. The air conditioning is not working.
3. The car's radio sounds distorted.

The CRT depicts a chain of cause-and-effect reasoning (IF...AND...THEN) in graphical form, where ellipses or circles represent an "AND".

The graphic is constructed by:

- attempting to link any two UDEs using cause-and-effect reasoning. For example, **IF** the engine needs fuel in order to run **AND** fuel is not getting to the engine, **THEN** the car's engine will not start.
- elaborating the reasoning to ensure it is sound and plausible. For example, **IF** the air intake is full of water **THEN** air conditioning is not working. Elaboration (**because** air is not able to circulate) gets added as in-between step.
- linking each of the remaining UDEs to the existing tree by repeating the previous steps.

This approach tends to converge on a single root cause. In the illustrated case, the root cause of the above UDEs is seen as being a faulty handbrake.



3.3 FAILURE MODE AND EFFECTS ANALYSIS

A failure modes and effects analysis (FMEA) is a procedure in operations management for analysis of potential failure modes within a system for classification by severity or determination of the effect of failures on the system. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry. Failure modes are any errors or defects in a process, design, or item, especially those that affect the customer, and can be potential or actual. Effects analysis refers to studying the consequences of those failures. [6]

3.3.1 History

Learning from each failure is both costly and time consuming, and FMEA is a more systematic method of studying failure. As such, it is considered better to first conduct some thought experiments.

FMEA was formally introduced in the late 1940s for military usage by the US Armed Forces. Later it was used for aerospace/rocket development to avoid errors in small sample sizes of costly rocket technology. An example of this is the Apollo Space program. The primary push came during the 1960s, while developing the means to put a man on the moon and return him safely to earth. In the late 1970s the Ford Motor Company introduced FMEA to the automotive industry for safety and regulatory consideration after the Pinto affair. They also used it to improve production and design. [7]

Although initially developed by the military, FMEA methodology is now extensively used in a variety of industries including semiconductor processing, food service, plastics, software, and healthcare. It is integrated into Advanced Product Quality Planning (APQP) to provide primary risk mitigation tools and timing in the prevention strategy, in both design and process formats. The Automotive Industry Action Group (AIAG) requires the use of FMEA in the automotive APQP process and publishes a detailed manual on how to apply the method. Each potential cause must be considered for its effect on the product or process and, based on the risk, actions are determined and risks revisited after actions are complete. Toyota has taken this one step further with its Design Review Based on Failure Mode (DRBFM) approach. The method is now supported by the

American Society for Quality which provides detailed guides on applying the method.

3.3.2 Implementation

In FMEA, failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. An FMEA also documents current knowledge and actions about the risks of failures for use in continuous improvement. FMEA is used during the design stage with an aim to avoid future failures. Later it is used for process control, before and during ongoing operation of the process. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service.

The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. It may be used to evaluate risk management priorities for mitigating known threat vulnerabilities. FMEA helps select remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault).

3.3.3 Using FMEA when designing

FMEA can provide an analytical approach, when dealing with potential failure modes and their associated causes. When considering possible failures in a design – like safety, cost, performance, quality and reliability – an engineer can get a lot of information about how to alter the development/manufacturing process, in order to avoid these failures. FMEA provides an easy tool to determine which risk has the greatest concern, and therefore an action is needed to prevent a problem before it arises. The development of these specifications will ensure the product will meet the defined requirements.

3.3.4 Timing of FMEA

The FMEA should be updated whenever:

- A cycle begins (new product/process)
- Changes are made to the operating conditions
- A change is made in the design

- New regulations are instituted
- Customer feedback indicates a problem

3.3.5 Uses of FMEA

- Development of system requirements that minimize the likelihood of failures.
- Development of methods to design and test systems to ensure that the failures have been eliminated.
- Evaluation of the requirements of the customer to ensure that those do not give rise to potential failures.
- Identification of certain design characteristics that contribute to failures, and minimize or eliminate those effects.
- Tracking and managing potential risks in the design. This helps avoid the same failures in future projects.
- Ensuring that any failure that could occur will not injure the customer or seriously impact a system.
- To produce world class quality products.

3.3.6 Advantages

- Improve the quality, reliability and safety of a product/process.
- Improve company image and competitiveness.
- Increase user satisfaction.
- Reduce system development timing and cost.
- Collect information to reduce future failures, capture engineering knowledge.
- Reduce the potential for warranty concerns.
- Early identification and elimination of potential failure modes.
- Emphasis in problem prevention.
- Minimize late changes and associated cost.
- Catalyst for teamwork and idea exchange between functions.
- Reduce the possibility of same kind of failure in future.

3.3.7 Limitations

Since FMEA is effectively dependent on the members of the committee which examines product failures, it is limited by their experience of previous failures. If a failure mode cannot be identified, then external help is needed from consultants who are aware of the many different types of product failure. FMEA is thus part of a larger system of quality control, where documentation is vital to implementation. General texts and detailed publications are available in forensic engineering and failure analysis. It is a general requirement of many specific national and international standards that FMEA is used in evaluating product integrity. If used as a top-down tool, FMEA may only identify major failure modes in a system. Fault tree analysis (FTA), discussed in 3.4, is better suited for "top-down" analysis. When used as a "bottom-up" tool FMEA can augment or complement FTA and identify many more causes and failure modes resulting in top-level symptoms. It is not able to discover complex failure modes involving multiple failures within a subsystem, or to report expected failure intervals of particular failure modes up to the upper level subsystem or system.

Additionally, the multiplication of the severity, occurrence and detection rankings may result in rank reversals, where a less serious failure mode receives a higher Risk Priority Number (RPN) than a more serious failure mode. The reason for this is that the rankings are ordinal scale numbers, and multiplication is not a valid operation on them. The ordinal rankings only say that one ranking is better or worse than another, but not by how much. For instance, a ranking of "2" may not be twice as bad as a ranking of "1," or an "8" may not be twice as bad as a "4," but multiplication treats them as though they are.

3.3.8 Software

The usage of software will improve the documentation process of FMEA. When selecting the software package, it is important to choose one that is easy to learn and promotes consistent updating of the documentation. It is not necessary to spend a lot of money to have an effective, user-friendly system. Some FMEA software companies provide free upgrades, free support, and software with unlimited licenses. This is especially helpful in ensuring the long-term acceptance, understanding, and implementation of FMEAs. FMEA is applicable to all engineering process.

3.3.9 Types of FMEA

- Process: analysis of manufacturing and assembly processes.
- Design: analysis of products prior to production.
- Concept: analysis of systems or subsystems in the early design concept stages.
- Equipment: analysis of machinery and equipment design before purchase.
- Service: analysis of service industry processes before they are released to impact the customer.
- System: analysis of the global system functions.
- Software: analysis of the software functions.

3.4 FAULT TREE ANALYSIS

Fault tree analysis (FTA) is a failure analysis in which an undesired state of a system is analyzed using boolean logic to combine a series of lower-level events. This analysis method is mainly used in the field of safety engineering to quantitatively determine the probability of a safety hazard. [8]

3.4.1 History

Fault Tree Analysis (FTA) attempts to model and analyze failure processes of engineering and biological systems. FTA is basically composed of logic diagrams that display the state of the system and is constructed using graphical design techniques. Originally, engineers were responsible for the development of Fault Tree Analysis, as a deep knowledge of the system under analysis is required. Often, FTA is defined as another part, or technique, of reliability engineering. Although both model the same major aspect, they have arisen from two different perspectives. Reliability engineering was, for the most part, developed by mathematicians, while FTA, as stated above, was developed by engineers.

Fault Tree Analysis usually involves events from hardware wear out, material failure or malfunctions or combinations of deterministic contributions to the event steming from assigning a hardware/system failure rate to branches or cut sets. Typically, failure rates are carefully derived from substantiated historical data such as mean time between failure of the components, unit, subsystem or function. Predictor data

may be assigned. Assigning a software failure rate is elusive and not possible. Since software is a vital contributor and inclusive of the system operation it is assumed the software will function normally as intended. There is no such thing as a software fault tree unless considered in the system context. Software is an instruction set to the hardware or overall system for correct operation. Since basic software events do not fail in the physical sense, attempting to predict manifestation of software faults or coding errors with any reliability or accuracy is impossible, unless assumptions are made. Predicting and assigning human error rates is not the primary intent of a fault tree analysis, but may be attempted to gain some knowledge of what happens with improper human input or intervention at the wrong time.

Fault Tree Analysis was initially developed for projects where errors are intolerable (e.g., an error in a nuclear reactor is not tolerated). Bell Telephone Laboratories started the development of FTA during the early 60's for the United States Air Force's Minuteman System (Intercontinental Ballistic Missiles and Bombers). Later, U.S. nuclear power plants and the Boeing Company used the system extensively. FTA can be used as a valuable design tool, can identify potential accidents, and can eliminate costly design changes. It can also be used as a diagnostic tool, predicting the most likely system failure in a system breakdown. FTA is used in safety engineering and in all major fields of engineering.

3.4.2 Why Fault Tree Analysis?

Since no system is perfect, dealing with a subsystem fault is a necessity, and any working system eventually will have a fault in some place. However, the probability for a complete or partial success is greater than the probability of a complete failure or partial failure. Assembling a FTA is thus not as tedious as assembling a success tree which can turn out to be very time consuming.

Because assembling a FTA can be a costly and cumbersome experience, the perfect method is to consider subsystems. In this way dealing with smaller systems can assure less error work probability, less system analysis. Afterward, the subsystems integrate to form the well analyzed big system.

3.4.3 Methodology

In the technique known as "fault tree analysis", an undesired effect is taken as the root ('top event') of a tree of logic. There should be only one Top Event and all concerns must tree down from it. Then, each situation that could cause that effect is added to the tree as a series of logic expressions. When fault trees are labeled with actual numbers about failure probabilities (which are often in practice unavailable because of the expense of testing), computer programs can calculate failure probabilities from fault trees.

The Tree is usually written out using conventional logic gate symbols. The route through a tree between an event and an initiator in the tree is called a Cut Set. The shortest credible way through the tree from fault to initiating event is called a Minimal Cut Set.

Some industries use both Fault Trees and Event Trees. An Event Tree starts from an undesired initiator (loss of critical supply, component failure, etc.) and follows possible further system events through to a series of final consequences. As each new event is considered, a new node on the tree is added with a split of probabilities of taking either branch. The probabilities of a range of 'top events' arising from the initial event can then be seen.

Classic computer programs include the Electric Power Research Institute's (EPRI) CAFTA software, which is used by many of the US nuclear power plants and by a majority of US and international aerospace manufacturers, and the Idaho National Laboratory's SAPHIRE, which is used by the U.S. Government to evaluate the safety and reliability of nuclear reactors, the Space Shuttle, and the International Space Station. Outside the US, the software RiskSpectrum is a popular tool for Fault Tree and Event Tree analysis and is licensed for use at almost half of the worlds nuclear power plants for Probabilistic Safety Assessment.

3.4.4 Analysis

Many different approaches can be used to model a FTA, but the most common and popular way can be summarized in a few steps. Remember that a fault tree is used to analyze a single fault event, and that one and only one event can be analyzed during a single fault tree. Even though the “fault” may vary dramatically, a FTA follows the same

procedure for an event, be it a delay of 0.25 msec for the generation of electrical power, or the random, unintended launch of an ICBM.
FTA analysis involves five steps:

1. Define the undesired event to study

Definition of the undesired event can be very hard to catch, although some of the events are very easy and obvious to observe. An engineer with a wide knowledge of the design of the system or a system analyst with an engineering background is the best person who can help define and number the undesired events. Undesired events are used then to make the FTA, one event for one FTA; no two events will be used to make one FTA.

2. Obtain an understanding of the system

Once the undesired event is selected, all causes with probabilities of affecting the undesired event of 0 or more are studied and analyzed. Getting exact numbers for the probabilities leading to the event is usually impossible, for the reason that it may be very costly and time consuming to do so. Computer software is used to study probabilities; this may lead to less costly system analysis.
System analysts can help with understanding the overall system. System designers have full knowledge of the system and this knowledge is very important for not missing any cause affecting the undesired event. For the selected event all causes are then numbered and sequenced in the order of occurrence and then are used for the next step which is drawing or constructing the fault tree.

3. Construct the fault tree

After selecting the undesired event and having analyzed the system so that we know all the causing effects (and if possible their probabilities) we can now construct the fault tree. Fault tree is based on AND and OR gates which define the major characteristics of the fault tree.

4. Evaluate the fault tree

After the fault tree has been assembled for a specific undesired event, it is evaluated and analyzed for any possible improvement or in other words study the risk management and find ways for system improvement. This step is as an introduction for the final step which will be to control the hazards identified. In short, in this step we identify all possible hazards affecting in a direct or indirect way the system.

5. Control the hazards identified

This step is very specific and differs largely from one system to another, but the main point will always be that after identifying the hazards, all possible methods are pursued to decrease the probability of occurrence.

3.5 5-WHYS

The 5 Whys is a question-asking method used to explore the cause/effect relationships underlying a particular problem. Ultimately, the goal of applying the 5 Whys method is to determine a root cause of a defect or problem.

3.5.1 Example

The following example demonstrates the basic process:

- My car will not start. (the problem)

1. Why? - The battery is dead. (first why)
2. Why? - The alternator is not functioning. (second why)
3. Why? - The alternator belt has broken. (third why)
4. Why? - The alternator belt was well beyond its useful service life and has never been replaced. (fourth why)
5. Why? - I have not been maintaining my car according to the recommended service schedule. (fifth why, a root cause)

The questioning for this example could be taken further to a sixth, seventh, or even higher level. This would be legitimate, as the "five" in 5 Whys is not gospel; rather, it is postulated that five iterations of asking

why is generally sufficient to get to a root cause. The real key is to encourage the troubleshooter to avoid assumptions and logic traps and instead to trace the chain of causality in direct increments from the effect through any layers of abstraction to a root cause that still has some connection to the original problem.

3.5.2 History

The technique was originally developed by Sakichi Toyoda and was later used within Toyota Motor Corporation during the evolution of their manufacturing methodologies. It is a critical component of problem solving training delivered as part of the induction into the Toyota Production System. The architect of the Toyota Production System, Taiichi Ohno, described the 5 whys method as "... the basis of Toyota's scientific approach ... by repeating why five times, the nature of the problem as well as its solution becomes clear." The tool has seen widespread use beyond Toyota, and is now used within Kaizen, lean manufacturing, and Six Sigma. [9]

3.5.3 Criticism

While the 5 Whys is a powerful tool for engineers or technically savvy individuals to help get to the true causes of problems, it has been criticized by Teruyuki Minoura, former managing director of global purchasing for Toyota, as being too basic a tool to analyze root causes to the depth that is needed to ensure that the causes are fixed. Reasons for this criticism include:

- Tendency for investigators to stop at symptoms rather than going on to lower level root causes.
- Inability to go beyond the investigator's current knowledge - can't find causes that they don't already know
- Lack of support to help the investigator to ask the right "why" questions.
- Results aren't repeatable - different people using 5 Whys come up with different causes for the same problem.
- The tendency to isolate a single root cause, whereas each question could elicit many different root causes

These can be significant problems when the method is applied through deduction only. On-the-spot verification of the answer to the current

"why" question, before proceeding to the next, is recommended as a good practice to avoid these issues.

3.6 ISHIKAWA DIAGRAM

Ishikawa diagrams (also called fishbone diagrams or cause-and-effect diagrams) are diagrams that show the causes of a certain event. Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect.

3.6.1 Overview

Ishikawa diagrams were proposed by Kaoru Ishikawa in the 1960s, who pioneered quality management processes in the Kawasaki shipyards, and in the process became one of the founding fathers of modern management. [10]

It was first used in the 1960s, and is considered one of the seven basic tools of quality management, along with the histogram, Pareto chart, check sheet, control chart, flowchart, and scatter diagram. It is known as a fishbone diagram because of its shape, similar to the side view of a fish skeleton.

Mazda Motors famously used an Ishikawa diagram in the development of the Miata sports car, where the required result was "Jinba Ittai" or "Horse and Rider as One". The main causes included such aspects as "touch" and "braking" with the lesser causes including highly granular factors such as "50/50 weight distribution" and "able to rest elbow on top of driver's door". Every factor identified in the diagram was included in the final design.

3.6.2 Causes

Causes in the diagram are often categorized, such as to the 4 M's, described below. Cause-and-effect diagrams can reveal key relationships among various variables, and the possible causes provide additional insight into process behavior.

Causes can be derived from brainstorming sessions, successively sorted through affinity-grouping to collect similar ideas together. These groups can then be labeled as categories of the fishbone. They will typically be one of the traditional categories mentioned above but may be something unique to the application in a specific case. Causes can be traced back to root causes with the 5 Whys technique.

3.6.3 Categories

The original 4 M's

- Machine (Equipment)
- Method (Process/Inspection)
- Material (Raw,Consumables etc.)
- Man power

More categories

- Mother Nature (Environment)
- Man Power (physical work)
- Mind Power (Brain Work): Kaizens, Suggestions
- Measurement (Inspection)
- Maintenance
- Money Power
- Management

The 8 P's (Used in Service Industries)

- People
- Process
- Policies
- Procedures
- Price
- Promotion
- Place/Plant
- Product

The 4 S's (Used in Service Industries)

- Surroundings
- Suppliers

- Systems
- Skills

3.7 KEPNER-TREGOE PROBLEM ANALYSIS

3.7.1 Kepner-Tregoe (company)

Founded in 1958 by Dr. Charles Kepner and Dr. Benjamin Tregoe, Kepner-Tregoe, Inc., is a global organisation providing consulting and training services around problem solving, decision making and project execution methodologies.[11]

3.7.2 Kepner-Tregoe (technique)

Kepner-Tregoe's trademark technique, Rational Process, which is commonly referred to as the 'KT Process', is the creation of structured, systematic processes which are used to maximise the critical thinking skills of key stakeholders in a particular situation, problem (potential or real), decision or opportunity.
The Rational Processes are broken down into the following:

SITUATION APPRAISAL - the process of ensuring that priority and order are established for multiple concerns associated with a specific issue.
Example - The company's in-house built payroll system is becoming outdated and increasingly difficult to support.

PROBLEM ANALYSIS - a systematic process for finding the cause of a positive or negative deviation.
Example - The payroll system is grinding to a halt at 7am each day.

DECISION ANALYSIS - a systematic process for making a balanced choice.
Example - What is the best alternative payroll solution to fit with the company's needs?

POTENTIAL PROBLEM (OR OPPORTUNITY) ANALYSIS - a systematic process for protecting an action or a plan.
Example - Determine key risks associated with implementation of a new payroll system.

3.8 PARETO ANALYSIS

Pareto analysis is a statistical technique in decision making that is used for selection of a limited number of tasks that produce significant overall effect. It uses the Pareto principle – the idea that by doing 20% of work you can generate 80% of the advantage of doing the entire job. Or, in terms of quality improvement, a large majority of problems (80%) are produced by a few key causes (20%).

Pareto analysis is a formal technique useful where many possible courses of action are competing for one's attention. In essence, the problem-solver estimates the benefit delivered by each action, then selects a number of the most effective actions that deliver a total benefit reasonably close to the maximal possible one.

Pareto analysis is a creative way of looking at causes of problems because it helps stimulate thinking and organize thoughts. However, it can be limited by its exclusion of possibly important problems which may be small initially, but which grow with time. It should be combined with other analytical tools such as failure mode and effects analysis and fault tree analysis for example.

3.8.1 Steps to identify the important causes using Pareto analysis

- Step 1: Form a table listing the causes and their frequency as a percentage.
- Step 2: Arrange the rows in the decreasing order of importance of the causes (i.e, the most important cause first)
- Step 3: Add a cumulative percentage column to the table
- Step 4: Plot with causes on x- and cumulative percentage on y-axis
- Step 5: Join the above points to form a curve
- Step 6: Plot (on the same graph) a bar graph with causes on x- and percent frequency on y-axis
- Step 7: Draw line at 80% on y-axis parallel to x-axis. Then drop the line at the point of intersection with the curve on x-axis. This point on the x-axis separates the important causes (on the left) from the trivial ones (on the right)
- Step 8: Review the chart to ensure you are capturing at least 80% of the causes

3.9 RPR PROBLEM DIAGNOSIS

RPR is a problem diagnosis method specifically designed to determine the Root Cause of IT problems.

3.9.1 Overview

RPR (Rapid Problem Resolution) deals with failures, incorrect output and performance issues, and its particular strengths are in the diagnosis of ongoing and recurring grey problems, the method comprises of:

- Core Process, and
- Supporting Techniques

The Core Process defines a step-by-step approach to problem diagnosis and has three phases:

- Discover
  - Gather and review existing information
  - Reach an agreed understanding
- Investigate
  - Create and execute a diagnostic data capture plan
  - Analyse the results and iterate if necessary
  - Identify Root Cause
- Fix
  - Translate diagnostic data
  - Determine and implement fix
  - Confirm Root Cause addressed

The Supporting Techniques detail how the objectives of the Core Process steps are achieved, and cite examples using tools and techniques that are available in every business.

3.9.2 Limitations

RPR has some limitations and considerations, including:

- RPR deals with a single symptom at a time
- RPR is not a forensic technique and so historical data alone is rarely sufficient

- The Investigate phase requires the user to experience the problem one more time

3.9.3 History

The method was originally developed in 1990 as the Rapid Problem Resolution Method, with the first fully documented version produced in 1995. Early versions included problem management guidance but this was removed over time as the method became more closely aligned to International Technology Infrastructure Library (ITIL). RPR is now focused on Problem Diagnosis based on Root Cause Identification. Due to the highly practical nature of the Supporting Techniques and the ever changing IT landscape, Advance7 continues to develop RPR to keep it relevant to current IT environments.
Until November 2007 Advance7 made the RPR material available to its employees only, although a limited number of other IT professionals had been trained in the use of the method. In late 2007 the company announced its intention to make RPR training and material more widely available.

CHAPTER 4

BASIC ELEMENTS OF ROOT CAUSE ANALYSIS

- Materials
  - Defective raw material
  - Wrong type for job
  - Lack of raw material
- Machine / Equipment
  - Incorrect tool selection
  - Poor maintenance or design
  - Poor equipment or tool placement
  - Defective equipment or tool
- Environment
  - Orderly workplace
  - Job design or layout of work
  - Surfaces poorly maintained
  - Physical demands of the task
  - Forces of nature
- Management
  - No or poor management involvement
  - Inattention to task
  - Task hazards not guarded properly
  - Other (horseplay, inattention....)
  - Stress demands
  - Lack of Process
- Methods
  - No or poor procedures
  - Practices are not the same as written procedures
  - Poor communication
- Management system
  - Training or education lacking
  - Poor employee involvement
  - Poor recognition of hazard
  - Previously identified hazards were not eliminated
  - 4ME (Man, Machine, Materials, Method and Environment).

CHAPTER 5

ROOT CAUSE ANALYSIS AND CASUALTY INVESTIGATION IN MARITIME INDUSTRY

Investigation of accidents, casualties, or near misses is critical in prevention of future reoccurrence. In the maritime industry valuable lessons can be learned from mishaps if they are investigated properly and expeditiously; unfortunately these are becoming a rarity. Let me explain.

5.1 THE WAY INVESTIGATIONS USED TO BE DONE

If one goes back to the 1970s and earlier there was a standard format. First, there was a gathering of facts called FINDINGS OF FACTS. Each of these were substantiated by some document included or referenced. When the facts were all accumulated, the investigator used to then draw some CONCLUSIONS directly from the FACTS. And lastly RECOMMENDATIONS were made strictly upon the FACTS and CONCLUSIONS.

So basically everything was supported by something. Simple reports were typically completed within a month, whereas more complicated casualty investigations maybe took about 6-8 months. The reports were released while the casualty was still fresh in mariners' minds and was of value to the maritime community.

5.2 WHY INVESTIGATE INCIDENTS?

Maritime industries experience incidents that range from major accidents to near misses (or more appropriately, near hits). Why should these incidents be investigated? International agreements mandate it (such as the IMO "International Safety Management Code"), many flag administrations require it, and industry initiatives (such as the Oil Companies International Marine Forum's Tanker Management Self Assessment scheme) encourage it. Investigating incidents is also good business: if one can prevent recurrence and reduce the likelihood of other incidents with the same root causes, costs (human, environmental and property) associated with incidents can be eliminated.

CHAPTER 6

REPORTS AND ANALYSIS OF NON-CONFORMITIES AS DESCRIBED IN THE COMPANY'S SAFETY MANAGEMENT SYSTEM MANUAL

6.1 GENERAL

Non-conformities, accidents and hazardous occurrences reports are sent to the Company by the Master as soon as possible after the occurrence. The first report may be verbal. However, a written report must always be sent as soon as possible. [12]

Reports are sent by the Master to the responsible Managers and to the Designated Person in the following cases of incidents:

a. Accidents
b. Hazardous occurrences
c. Non-conformities

The Designated Person will analyse all reports on non-conformities and will arrange for reviews with the Senior Management at the annual Management review. Necessary corrective actions will be also discussed at the annual Management review.

6.2 RESPONSIBILITIES

All personnel, both ashore and onboard ship, are responsible for identifying and reporting non-conformities.

The Manager/Master under whose responsibility the non-conformity rests, informs other relevant Departments or personnel and initiates the required corrective action.

The Designated Person is responsible for:

a. Recording of all non-conformities reports (NCRs)

b. Evaluating each NCR to determine whether there has been a failure in the Safety Management System (SMS)
c. Ensuring that the measures taken to correct the deficiencies are effective

6.3 DEFINITIONS

6.3.1 Non-conformities

Operations which do not comply with established procedures or specifications are considered as NON-CONFORMITIES. Material breakdowns due to fair wear and tear and with no impact on work tasks shall not be regarded as non-conformities.

6.3.2 Accidents

All undesired events that result in harm to people, damage to property or loss to process are considered as ACCIDENTS.

6.3.3 Hazardous Occurrences (Near-misses)

All undesired events, which, under slightly different circumstances, could have resulted in harm to people, damage to property or loss to process, are considered as HAZARDOUS OCCURRENCES.

6.4 PROCEDURES

The following procedures should be in place in order to ensure that a non-conformity of any nature is identified and corrective action taken:

a. Recording, analysing and making decisions which have resulted in complaints from Owners, Charterers, Terminal or Port Senior Management and flag or port state competent authorities

b. Provide resources to enable corrective action to be taken when non-conformities have been identified.

c. Maintain effective communications to ensure all applicable parties are kept informed on:
   1. Corrective action taken or planned
   2. Progress of the corrective action

d. Review and update Company's procedures, when necessary

6.5 REPORTING NON-CONFORMITIES (NCRs)

All shore-based and marine personnel may report non-conformities to their respective Manager or Master, either in writing or verbally.

All non-conformities are distinguished into the following categories:

a. Shipboard non-conformities will be noted by the Master of concerned vessel and will be reported to the appropriate Manager, who in turn will evaluate the report and, where necessary will raise a NCR.

b. Shore-based non-conformities will be brought to the attention of the responsible Manager or alternatively identified by him.

c. Non-conformities identified by internal and external auditors are brought to the attention of the Designated Person.

All NCRs are finally brought to the attention of the Designated Person, who reviews and evaluates them and takes all the necessary actions.

The following three main sources may provide evidence of non-conformities:

a. Information within the Company. Such information may come from:
   - Deck and Engine log books.
   - Communications to/from vessels.
   - Voyage abstracts.
   - Inspection and maintenance reports.
   - Internal and External audit reports.
   - Port State control and Flag State Inspection reports (detentions, safety and pollution control items, drills, maintenance, crew and

vessel certificates).

- Classification Society reports.
- Loading/discharging documents.

Detentions, in particular, shall always be treated as internal non-conformities and processed accordingly.

b. The Owner or Charterer. This may be in the form of a letter of protest, complaints or claims.

c. A Third Party in general. Such information may be obtained through survey inspection reports, incident requests from another vessel or claims.

The person who reports the NCR must describe the incident in detail, give information about the possible causes, and inform the Company on the corrective actions already taken or suggested to be taken.

6.6 CORRECTIVE ACTIONS

6.6.1 Treatment

The treatment of a non-conformity depends on:

- The competent Administration and/or the classification society
- The range of severity
- The cause
- The effect
- The type

Management undertakes to correct immediately any damages or failures that affect the safety of the ship and the protection of environment.

6.6.2 Corrective actions

The Department's Manager or the Master, as appropriate, shall plan and initiate all corrective actions and follow-up to ensure that such actions have been effective. All corrective actions shall be reported to the Designated Person.

Appropriate corrective action may be:

- Revision of a procedure or operating instructions
- Issue of a new procedure or operating instructions
- Removal of a supplier or sub-contractor from the Company's approved list
- Ensuring that personnel adhere to Safety procedures
- Further Training/Education

6.6.3 Assessment of the cause

Following initial corrective action, investigation shall be made to determine the underlying cause of non-conformity and plans shall be formulated for permanent correction.

The Manager or Master concerned, should make assessment of the underlying cause of non-conformity, with assistance from the Designated Person.

All incidents, near misses or hazardous occurrences, non-conformances and defects where the underlying cause is not clear shall be investigated using the Root Cause Analysis Methodology and relevant form **RCA** (Chapter 7). The root cause may comprise of a number of contributory factors, which are interlinked or result from interacting systems or work activities.

The "**immediate cause**" is the circumstance of an event, defect or failure, which results in an immediate consequence.

The "**root cause**" is the underlying cause and may be made of a number of factors such as training, planning or lack of inspection, reporting and review.

Some accidents result from the untimely "conspiracy" of events or the effects of energized systems being operated concurrently unexpectedly.

6.6.3.1 Root Cause Analysis Methodology

The Root Cause Analysis comprises of an investigation into the defect, NC or incident in order to identify the factors that led to the problem.

There are a number of stages that can be implemented in the Root Cause Analysis Process:

1. Determine the significance of the event, defect or NC.
2. Deploy the "**5 WHY's**" principal:
   WHY – do we have the defect, incident of non-conformance?
   WHY – was there malfunction or poor condition?
   WHY – immediate Cause (what happened at the time)?
   WHY – underlying cause?
   WHY – was the underlying cause allowed to happen?
3. Investigate the proximate cause (being non-compliance with a Legal Requirement – such as a particular SOLAS Regulation), relating the incident.
4. Identify and investigate the "process" and "non-process" factors that may have conspired to contribute to the incident.
5. Gather relevant data and evidence.
6. Interview methods and interviewing of relevant persons.
7. Use the fault tree diagram to assist in the identification of possible contributory factors sometimes known as the "casual causes".
8. Analyze data to identify all contributory factors.
9. Develop a cause and effect analysis out of contributory factors.
10. Develop "fault tree" to help you find all possible scenarios and determine the most likely scenario.
11. Develop conclusions and produce recommendations.

Contributory factors may be made up of a number of potential causes. The findings are evaluated for significance and corrective actions recommended in order to improve the processes which were ineffective in

preventing the defect or incident for the purpose of improving procedures and preventing reoccurrence.

A Root Cause Analysis Report (Form **RCA** should be attached to the incident, non-conformities report (NCR), or defect report and given an appropriate series number).

The corrective and preventive measures shall be reviewed immediately by the Designated Person Ashore (DPA) and implemented with appropriate changes and amendments. Implementation can take place either by direct inclusion into the Safety Management System (SMS) or by inclusion in a relevant Circular for a reasonable trial period before final inclusion in the SMS. In either case corrective and preventive measures shall be audited and reviewed to assess their effectiveness and any changes made to improve the measures taken to prevent recurrence.

6.6.3.2 Training for Root Cause Analysis

The **DPA**, **Asst. DPA, Operations Manager**(s) and **Technical Manager**(s) shall be trained in the principals and methods of "Root Cause Analysis".

Training -verifiable from records - shall include Form **RCA** and methods used to:

- Define a near miss, hazardous occurrence, defect and Non-conformance.
- Investigate the immediate or proximate cause of the event, defect or Non-conformance.
- Train others to recognize and report defects and incidents.
- Initiate and conduct investigations.
- Gather information and evidence during an investigation interviewing.
- Review data.
- Establish a team or working with other personnel.
- Identify possible contributory causes.

6.6.4 Recording

All raised non-conformities are recorded using form **NCR**. The reports are numbered in sequence using separate numbering for each month in the format **mm/yy/xx**, where **xx** is a two-digit serial number and **mm** and **yy** are the month number and the last two digits of the year respectively. Each vessel and the Office have separate numbering.

The non-conformity reports are always prepared in duplicate. One copy is kept by the Designated Person in a separate file, namely the "NON-CONFORMITIES" file, while the other copy is kept by the Master or the Head of the Department concerned.

The DPA, in co-operation with the responsible department, should decide on the time limit for the completion of corrective actions. This time limit must be clearly stated on the report. If, however, it is anticipated that the set time limit will be exceeded due to objective or unforeseen reasons, it can be extended and the NCR be rescheduled accordingly.

A non-conformity remains "open" until the decided corrective actions have been applied and this has been verified accordingly. For each corrective action applied by the responsible person, the form is suitably endorsed. After verification of **all** corrective actions, the non-conformity is closed-out and the relevant form is suitably endorsed.

CHAPTER 7

ANALYSIS OF REAL CASES WITH NON-CONFORMITIES AND NEAR-MISSES

During the previous year fourteen (14) cases of Non-Conformities and Near-Misses were raised in a Shipping Company. In order to analyse each case, the form "RCA" has to be filled in, as well as a fault tree diagram, constructed. A blank form "RCA" is shown in the next page.

RCA No:		
RCA Date:		
Type of Incident:		
Incident Details:		
Immediate Cause:		
Procedures Reviewed:		
5 WHYs Process:	1 - WHY	
	2 - WHY	
	3 - WHY	
	4 - WHY	
	5 - WHY	
Analysis process:		
Contributory Causes:		
Root Cause(s):		
Recommendations:		

The fourteen cases are as follow:

1. Bad record keeping of fuel consumption and change-over procedure of low Sulphur. Old version of Oil Record Book on board. Consumption of high sulphur fuel oil in restricted area.
2. Emergency lights found inoperative during internal audit.
3. On repeated occasions obsolete forms were in use on-board company vessels instead of updated ones. This was despite corrective actions taken after each occurrence.
4. Failing to identify, report and correct vessel defects and non-conformances in timely manner, thereby causing delay in implementation of corrective actions.
5. S-VDR and Inmarsat C found out of order / Flag not advised
6. Various failures in monitoring of lub-oil analysis, including frequency of sampling, availability of results and follow-up on remedial actions when results indicate "caution" or "alert" status.
7. Maintenance and inspection of safety equipment items (life boats, fire pump, CO_2 bottles) and incorrect/insufficient implementation of existing procedures.
8. During cargo operations the crane jib fell on deck due to hoisting wire failure.
9. Poisoning of Master, all officers and crew dew to cargo hold fumigation (aluminium phosphide) entering accommodation.
10. Only one deck officer designated to carry out tank and hold inspections and there was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.
11. The new Chief Officer had only recently joined the vessel (one month ago) and he had not yet been trained up as the designated hold and tank inspector. There was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.
12. The existing multi gas detector had been supplied with the wrong accessory for remote sampling.
13. The fuel tank of the Emergency Generator was found half full.
14. It was noted that no printouts are kept for intermediate loading / discharging stages and it could not be verified that such information was readily available for all cargo operations through the ship's loading calculations software.

In the sequel the above mentioned cases are analysed:

Case No1

Bad record keeping of fuel consumption and change-over procedure of low Sulphur. Old version of Oil Record Book on-board. Consumption of high sulphur fuel oil in restricted area.

Regarding this case

From May 19th 2006, all vessels operating within SOx Emission Control Areas (SECAs) must use fuel with sulphur content that does not exceed 1,5% m/m.

These areas are:

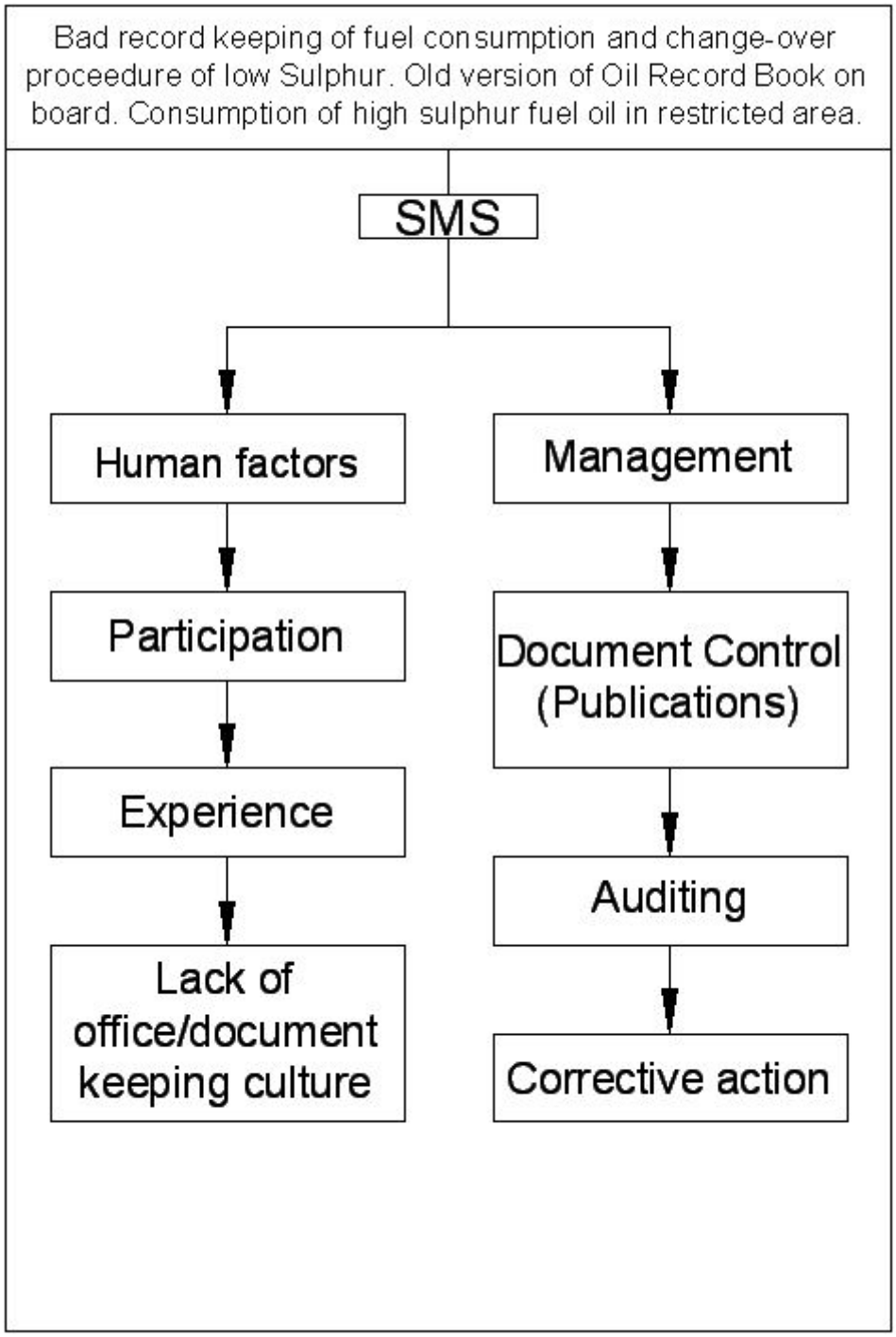
1. Baltic Sea - came into force on 19 May 2005
2. North Sea and English Channel - came into force on 11 August 2007
3. California - came into force on 1 July 2009

The sulphur content of the fuel oil received on-board shall be documented by the supplier in the Bunker Delivery Note. Each vessel shall have fuel tanks with sufficient capacity designated for the storage of low-sulphur fuel. Prior to entering a Sulphur Emission Control Area (SECA), the Chief Engineer shall verify that all necessary arrangements have been made to ensure that all machinery on-board affected by the Regulation, will be operating on low sulphur fuel (less or equal to 1.5% sulphur content) only, for the entire passage through the SECA. The volume of low sulphur fuel oils in each tank, as well as the date, time and position of the ship when any fuel changeover operation between high-sulphur fuel and low-sulphur fuel is completed, shall be duly recorded in the Marine Fuel Sulphur Record Book. Also, in order to ensure that low-sulphur fuel is not mixed with high sulphur fuel residues, vessels without dedicated low-sulphur fuel tanks should arrange fuel transfers in such a way that at least one fuel tank is stripped and drained to the maximum extent possible prior to bunkering low-sulphur fuel.

It was noted that in several vessels, the above procedures were not properly followed. Furthermore, in many cases the Oil Record Book was not filled in correctly.

It order to avoid such deficiencies in the future it is important to provide detailed instructions in the native language of the crew regarding new regulations and on how to fill in Record Books.

RCA No:		001
Type of Incident:		Non-conformity
Incident Details: Bad record keeping of fuel consumption and change-over procedure of low Sulphur. Old version of Oil Record Book on board. Consumption of high sulphur fuel oil in restricted area.		
Immediate Cause: Incomplete records in the Marine Sulphur Fuel Record Book, incorrect records of fuel quality/quantity.		
5 WHYs Process:	1 - WHY	ch. Engineer was not fully aware how to keep records in the Marine fuel Sulphur record book?
	2 - WHY	he did not read instructions properly?
	3 - WHY	the instruction how to fill the book were not translated into native language of engineer?
	4 - WHY	the other ships were not informed?
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Lack of participation, training of ch. Engineer and auditing from the office. Lack of corrective action. Lack of information from the office (not supplying new forms of oil record book)		
Root Cause(s): General lack of English language and office processing skills of individual ch. Engineers.		
Recommendations: When new record book issued it is better to provide detailed instruction in native language of crew how to fill in. Office control of supply of new publications to be improved.		


Bad record keeping of fuel consumption and change-over proceedure of low Sulphur. Old version of Oil Record Book on board. Consumption of high sulphur fuel oil in restricted area.
SMS
Human factors
Participation
Experience
Lack of office/document keeping culture
Management
Document Control (Publications)
Auditing
Corrective action

Case No2

Emergency lights found inoperative during internal audit.

Regarding this case

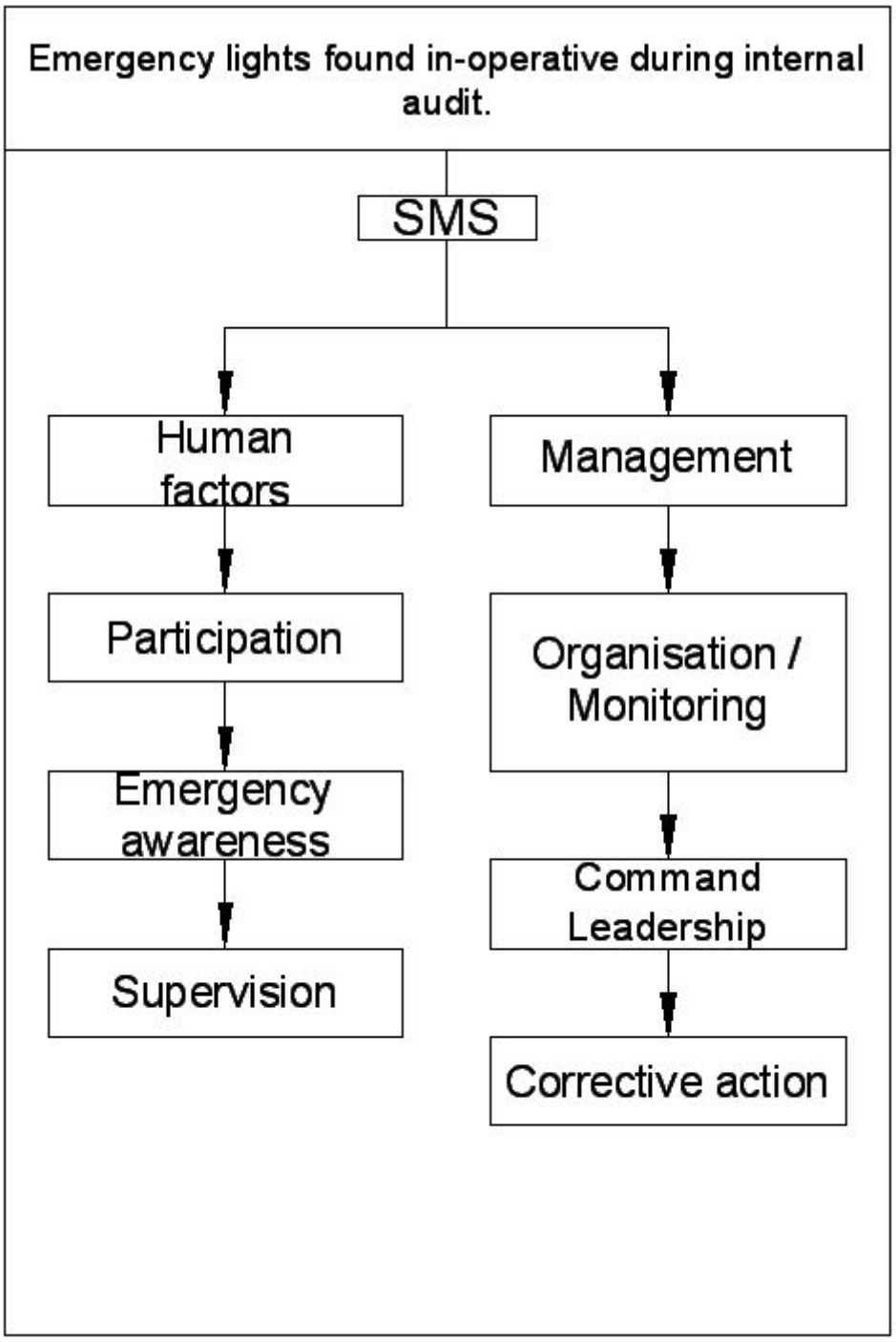
All Shipping Companies have adopted specific testing procedures for equipment and systems on-board the vessels, identified as critical, in order to ensure their functional reliability. Such systems include all emergency equipment, like:

1. Emergency steering gear
2. Emergency fire pump
3. Emergency Diesel Generators or batteries
4. Emergency air compressors
5. Emergency lights

As confirmation that such testing procedures and inspections are carried out, forms must be completed, in which all defects are reported in conjunction with their possible causes and corrective actions, if any.

As a conclusion, anyone can understand that it is unacceptable part of the emergency equipment to be found inoperative during internal an internal audit, because any defects should have been identified beforehand by the crew.

RCA No:		002
Type of Incident:		Non-conformity
Incident Details: Emergency lights found inoperative during internal audit.		
Immediate Cause: Emergency lights (Failure of some bulbs) were not tested by safety officer in operation as required.		
5 WHYs Process:	1 - WHY	emergency lights were not operational?
	2 - WHY	lights were not tested during inspection?
	3 - WHY	did senior officers not supervise quality of inspection?
	4 - WHY	lack of supervision allowed to happen?
	5 - WHY	the other ships were not informed?
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Lack of participation and supervision. Incorrect analysis of criticality. Electrician did not carry out regular inspections as described in the Safety Management System Manual.		
Root Cause(s): General Lack of the safety culture of the individual ship's officers		
Recommendations: Training for emergency awareness of safety officers to be carried out. Master of the other ships of the fleet to be informed about incident in form of Fleet circular in order to improve emergency awareness to provide crew members with information about accidents/casualties happened on merchant vessels on regular basis.		


Emergency lights found in-operative during internal audit.
SMS
Human factors
Participation
Emergency awareness
Supervision
Management
Organisation / Monitoring
Command Leadership
Corrective action

Case No3

On repeated occasions obsolete forms were in use on-board company vessels instead of updated ones. This was despite corrective actions taken after each occurrence.

Regarding this case

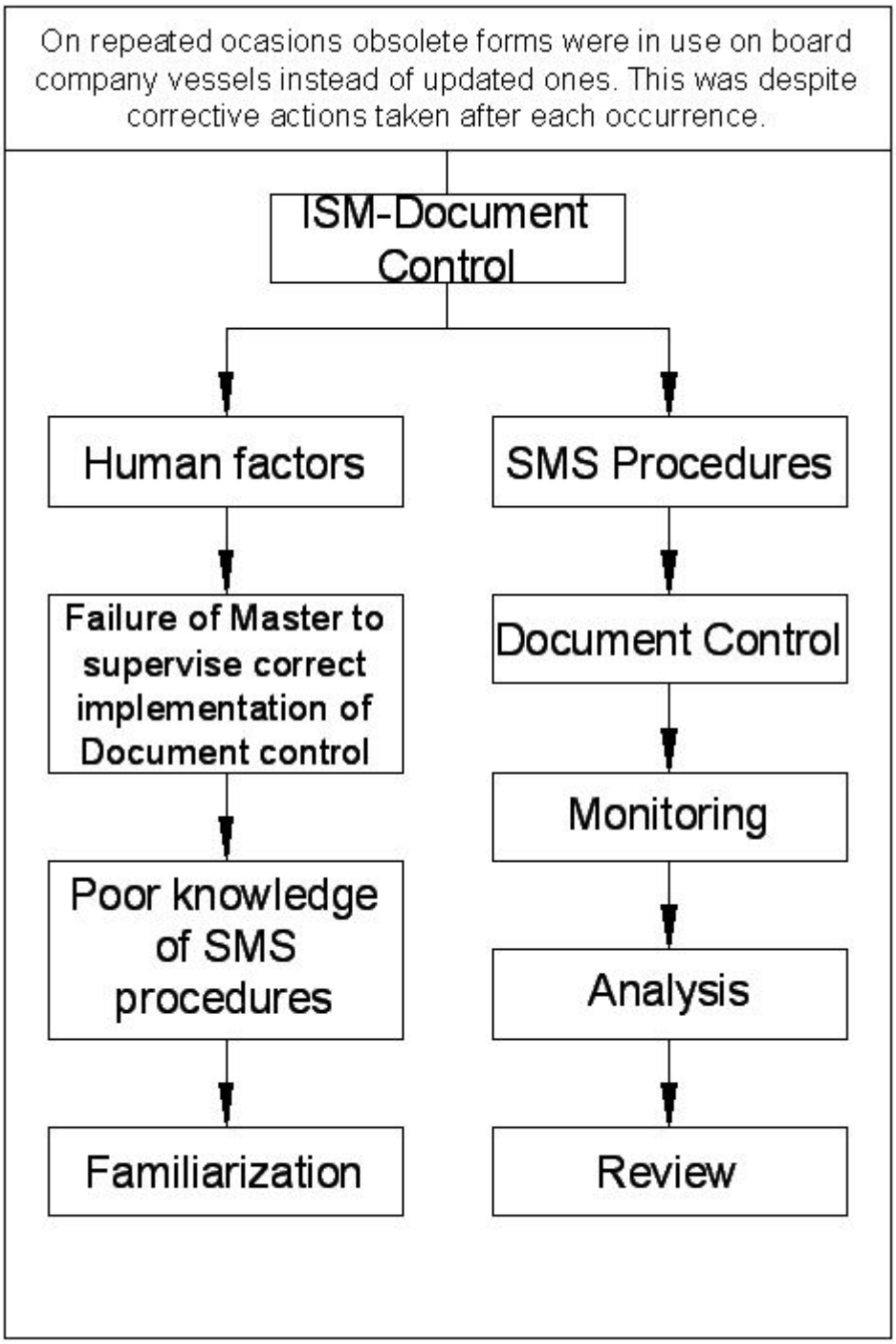
Any changes to the documented system are recorded on Amendment Record Sheets shown in the front of each copy of the Safety Management System Manual (SMSM). Modifications in the SMSM consist of revisions of manual pages and version changes of the entire manual. Modifications in Safety Management System (SMS) Forms consist of version changes only.

The master has the overall responsibility of maintaining the SMS filing system and ensuring that any amendments therein are complied with. Together with the Chief Officer they are responsible to maintain the SMS files related to deck operations, navigation, safety, training and deck maintenance.

The Chief Engineer is responsible to maintain the SMS files related to machinery operations and machinery maintenance.

All SMS forms are kept in separate files distinguished by different colours and/or numbers. The forms are divided according to the operations and procedures they cover. Changes in Forms result in replacement of modified forms, thus modifying the form's Version No. The version number and issue date are indicated on the top right of all form pages.

RCA No:		003
Type of Incident:		Non-conformity
Incident Details: . On repeated occasions obsolete forms were in use on-board company vessels instead of updated ones. This was despite corrective actions taken after each occurrence.		
Immediate Cause: New versions of forms were forwarded to vessels but Master failed to update the controlled Safety Management System Manual (SMSM) on board and/or to ensure that obsolete form was withdrawn. As a result old version kept being used.		
5 WHYs Process:	1 - WHY	old version of forms found in use
	2 - WHY	SMSM on board was not controlled effectively
	3 - WHY	Master failed to control SMSM on board
	4 - WHY	procedures for Document Control failed
	5 - WHY	office was not aware of above failure
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Masters did not realise importance of document control. Lack of training and guidance of masters. Inadequate reviews of Non Conformities /monitoring of effect of corrective actions. Failure of corrective actions to address the long tem problem dealing with the every time current symptom instead.		
Root Cause(s): Lack of clear procedures for document control on-board vessels. Insufficient monitoring/auditing.		
Recommendations: Clear relevant procedure to be included in SMSM. Awareness training of Master on the subject. Effectiveness / compliance to be audited.		


On repeated ocasions obsolete forms were in use on board company vessels instead of updated ones. This was despite corrective actions taken after each occurrence.
ISM-Document Control
Human factors
SMS Procedures
Failure of Master to supervise correct implementation of Document control
Document Control
Monitoring
Poor knowledge of SMS procedures
Analysis
Familiarization
Review

Case No4

Failing to identify, report and correct vessel defects and non-conformances in timely manner, thereby causing delay in implementation of corrective actions.

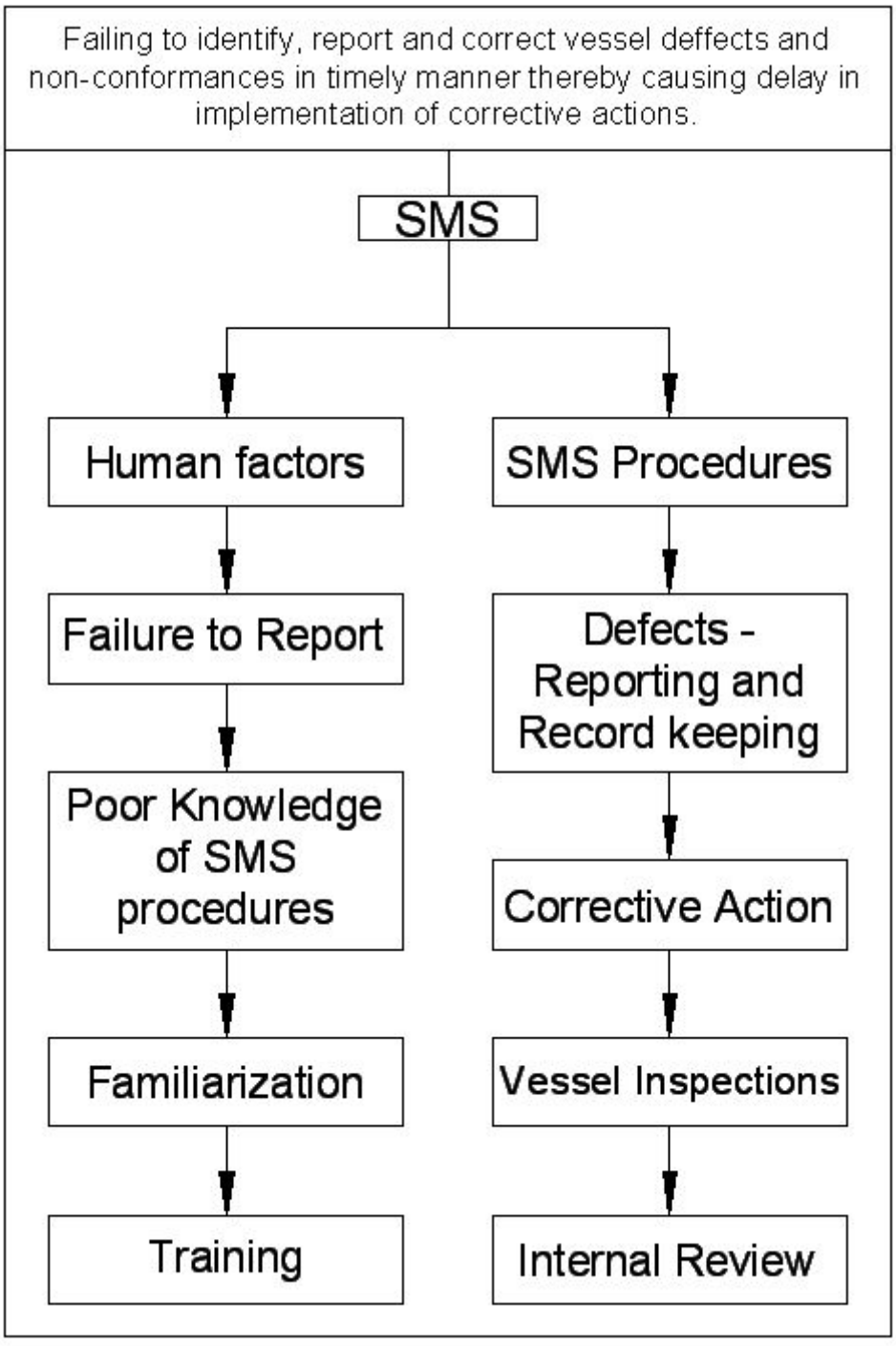
Regarding this case

The Company has established procedures for reporting defects/malfunctions observed during scheduled inspections and damages discovered during malfunctions or breakdowns of hull, machinery and equipment.
The relevant forms must be used and be immediately submitted to the responsible Technical Manager. Copy of the above form must also be kept in a separate file onboard.

Furthermore The Master shall immediately notify the Designated Person Ashore of any major defects, malfunctions or breakdowns of hull, machinery and equipment, seriously affecting the safety and health of the personnel, the ship or the pollution prevention arrangements, which cannot be repaired by the shipboard personnel.

The procedures are clear, but the Captain due to inadequate training and awareness in requirements of the company Safety Management System Manual (SMSM), was not able to identify and report defects in timely manner.

RCA No:		004
Type of Incident:		Non-conformity
Incident Details: Failing to identify, report and correct vessel defects and non-conformances in timely manner thereby causing delay in implementation of corrective actions.		
Immediate Cause: Failure by Master to insure adequate inspections of the vessel and failing to report defects using form M001		
Procedures Reviewed: Master Responsibilities 10.1, Reporting Non-compliance 5.2, Crew motivation 5.3, Masters Reviews of SMS 5.5, Maintenance Guidelines 5.4, Monitoring Effectiveness of SMS 5.5, Reporting defects/damage SMS 10.1.3.3.1, Critical Equipments 10.1.4		
5 WHYs Process:	1 - WHY	were the defects not reported?
	2 - WHY	were the defects not identified?
	3 - WHY	if defects identified were they not corrected?
	4 - WHY	was SMS procedure 10.1.3.3.1
	5 - WHY	was Master/ch. Engineer not aware of requirements of SMS and Solace?
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Lack of Comprehensive Inspection. Training of safety officers and those responsible for the maintenance of SLA/FFE and critical equipment. Inadequate record keeping. Non-compliance with SMS 10.1.3.3.1. Inadequate training and awareness of Masters in requirements of the company SMS.		
Root Cause(s): Lack of understanding of the principles of the ISM Code of the Masters. Inadequate understanding of importance of reporting and correcting defects on regular basis. Lack of appreciation of significance of Port State Control Inspections and ultimately of management of defects /NCNs.		
Recommendations: Training management, masters and chief Engineers in principals of the ISM code and implementation of the company SMS especially in the areas of maintenance and reporting. Improved internal auditing to capture onboard management failings. Longer term review of increase in frequency of vessel visits by shore Management.		


Failing to identify, report and correct vessel deffects and non-conformances in timely manner thereby causing delay in implementation of corrective actions.
SMS
Human factors
Failure to Report
Poor Knowledge of SMS procedures
Familiarization
Training
SMS Procedures
Defects - Reporting and Record keeping
Corrective Action
Vessel Inspections
Internal Review

Case No5

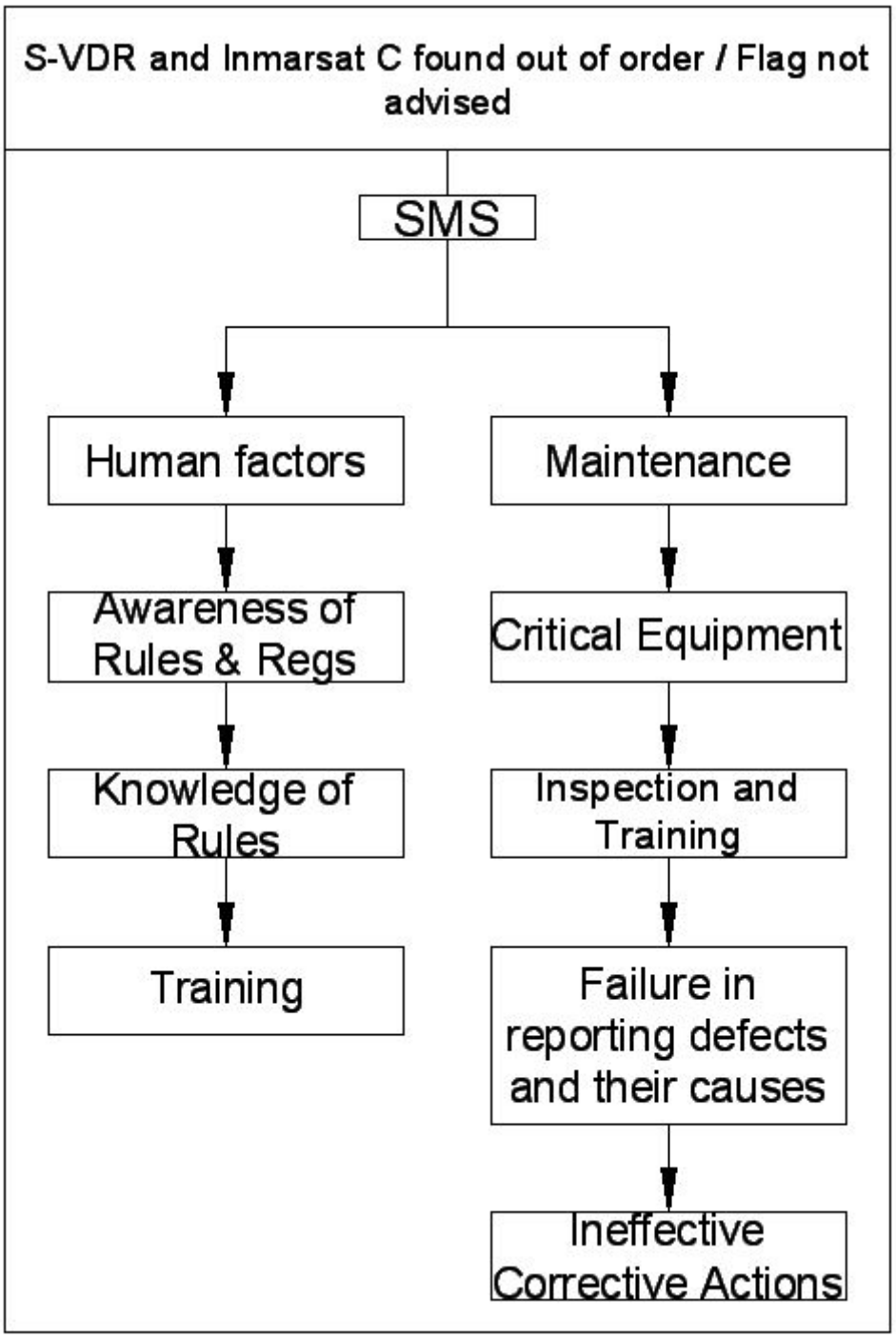
S-VDR and Inmarsat C found out of order / Flag not advised

Regarding this case

S-VDR and Inmarsat C are part of the safety equipment, therefore both devices should be checked daily for faults or errors.

Furthermore when defects or faulty items are discovered during scheduled inspections or when breakdowns occur, they must be reported through the vessel's Technical Manager to the vessel's Administration and/or Classification Society, because seaworthiness is affected.

RCA No:		005
Type of Incident:		Non-conformity
Incident Details: S-VDR and Inmarsat C found out of order / Flag not advised		
Immediate Cause: S-VDR not reported as not considered critical to safety. Was newly fitted and under makers warranty. Inmarsat C - second unit temporarily out of order - other unit still functioning and situation not considered a risk during lead up to repair.		
Procedures Reviewed: Safety Management System Manual sections 1.2.2.2, 1.2.3, 1.4, 5, 6, 8, 10, 11, 12 Nothing in particular SMS Para 10.2.3 Statutory and Class Surveys. SOLAS Ch. 1 reg 9, reg 11, ch. V reg 18, reg 20.		
5 WHYs Process:	1 - WHY	not reported to Class and of Flag?
	2 - WHY	the office not reported defects to Class/Flag?
	3 - WHY	requirements of SOLAS ch. 1 reg 11 not complied with?
	4 - WHY	not Master aware of requirement to advise Class and of Flag?
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: No company procedures for reporting defects under SOLAS ch. 1 Reg 11 of items of equipment mandatorily required for the safety equipment survey and ships radio survey certificate, noting SOLAS ch. V reg 18 and 20 and taking into consideration IMO MSC 163(78) concerning SVDRs. The Master failed to insure that Class were informed DPA did not identify requirement to report these defects. Failure to monitor and review effectiveness of SMS.		
Root Cause(s): Lack or relevant procedures and adequate of SMS audits and effective preventive action.		
Recommendations: Improvement to SMS procedures esp. 10.2.3 - Statutory & Class Surveys to include guidelines on reporting to class and defects that either erectly affect safety of the vessel and or defects of those items included in Class Survey Certificate. Company is to Provide guidance in the SMS to Master, Chief Engineers and other officers on what might constitute Class items that require reporting. Awareness training of technical Managers and DPA.		


S-VDR and Inmarsat C found out of order / Flag not advised
SMS
Human factors
Awareness of Rules & Regs
Knowledge of Rules
Training
Maintenance
Critical Equipment
Inspection and Training
Failure in reporting defects and their causes
Ineffective Corrective Actions

Case No6

Various failures in monitoring of lub-oil analysis, including frequency of sampling, availability of results and follow-up on remedial actions when results indicate "caution" or "alert" status.

Regarding this case

It has come to the attention of the company that on several occasions, oil samples for Main Engine, Auxiliary Engines, Steering Gear and Stern Tube were not landed for analysis at the required frequencies. Furthermore, it has been noted that landed samples have been lost on occasions without this being timely identified. In this respect, the Master and Chief Engineer are requested to send notifications to the Technical Department each time oil samples are landed for analysis.

This notification should include:

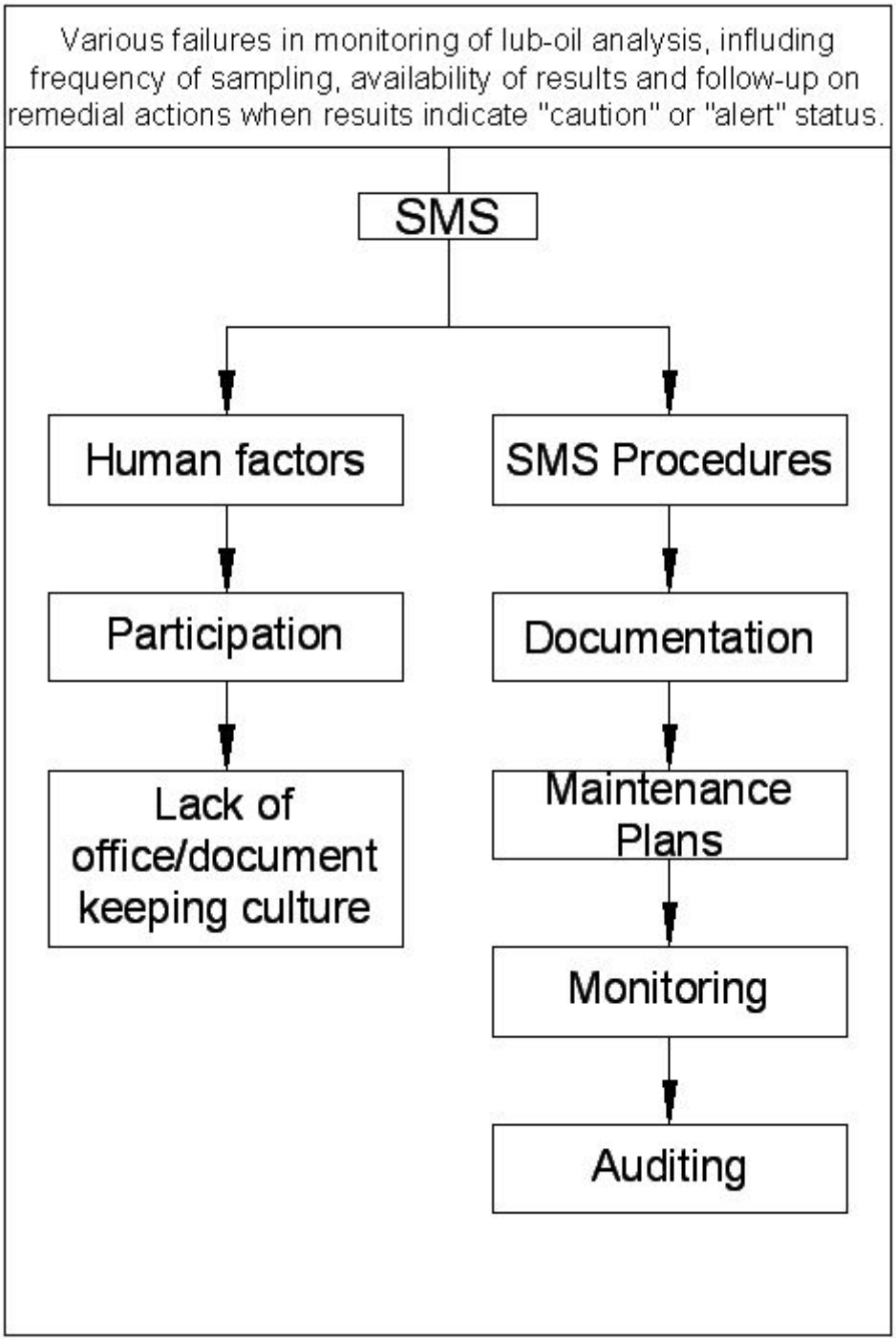
i. the date when samples were landed,
ii. the place (port) where landed, and
iii. equipment from which samples were taken.

Samples should be collected according to the following schedule:

1. Main Engine: every 3 months, samples before and after purifier.
2. Diesel Generators: every 3 months, unless the oil of the generators was changed recently. Oil changes to be reported in the remarks section of the engine log abstract.
3. Steering gear and Stern tube: every 6 months

In order to follow this time schedule the company setup an automated reminder system to monitor due dates for analysis (and track dates coming overdue) and issue appropriate reminders for the vessels and the Technical Department. Office personnel should check for availability of results on the basis of submittal dates of samples and forward results to the vessels and the technical department with reminder to co-ordinate in follow-up actions when this is required by the results.

RCA No:		006
Type of Incident:		Non-conformity
Incident Details: Various failures in monitoring of lub-oil analysis, including frequency of sampling, availability of results and follow-up on remedial actions when results indicate "caution" or "alert" status.		
Immediate Cause: Existing procedures not properly followed.		
Procedures Reviewed: SMS documentation or relevant procedure in paragraphs 10.1.2.4, 10.2.2.7		
5 WHYs Process:	1 - WHY	sampling frequencies not followed?
	2 - WHY	analysis results not monitored?
	3 - WHY	no follow-up when remedial actions required?
	4 - WHY	no means for taking samples provided?
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Poor control of supply of sampling kits, inconvenient trading schedule (including long voyages or remote ports), poor co-operation from port agents.		
Root Cause(s): Lack of proper monitoring of sampling frequencies. Lack of monitoring of results. Lack of provision of resources required to perform requested task (availability of sampling kits)		
Recommendations: To setup an automated reminder system to monitor due dates for analysis (and track dates coming overdue) and issue appropriate reminders for the vessels and the Tech. dept. To assign office personnel to check for availability of results on the basis of submittal dates of samples and forward results to the vessels and the technical dept. with reminder to co-ordinate in follow-up actions when this is required by the results. To setup a procedure for monitoring availability to sufficient sampling kits on board and request replenishment when used-up.		


Various failures in monitoring of lub-oil analysis, influding frequency of sampling, availability of results and follow-up on remedial actions when resuits indicate "caution" or "alert" status.
SMS
Human factors
Participation
Lack of office/document keeping culture
SMS Procedures
Documentation
Maintenance Plans
Monitoring
Auditing

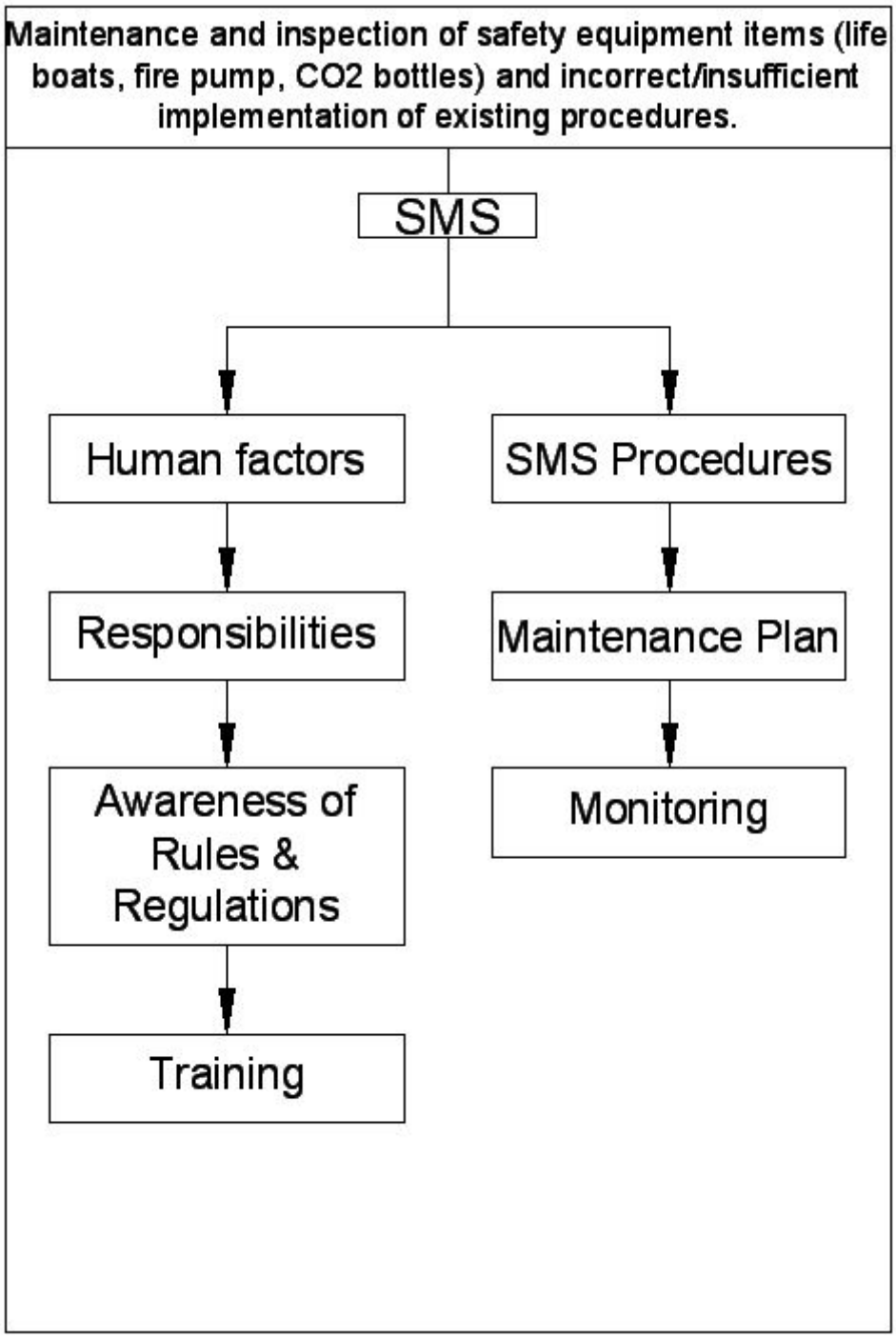
Case No7

Maintenance and inspection of safety equipment items (life boats, fire pump, CO_2 bottles) and incorrect/insufficient implementation of existing procedures.

Regarding this case

The ship's Safety Officer (in many shipping companies is the third officer) who is working under the Master, is responsible for ensuring that regular inspections and tests of all shipboard Safety and Environment Protection equipment onboard are carried out and that crew follow the emergency drills and onboard training.
Furthermore he is responsible to record the test date and condition of such equipment on the relevant Card enclosed in the aforementioned manual duly signed and dated by both the Master and Chief Officer. Any defect will be also reported in accordance with the relevant procedures explained in this company's safety Management System Manual.

RCA No:		007
Type of Incident:		Non-conformity
Incident Details: Maintenance and inspection of safety equipment items (life boats, fire pump, CO_2 bottles) and incorrect/insufficient implementation of existing procedures.		
Immediate Cause: Failure by Master and other responsible officers to report defects and ensure proper follow-up.		
5 WHYs Process:	1 - WHY	the maintenance was ineffective?
	2 - WHY	the inspection regime was ineffective?
	3 - WHY	there were no defect reports?
	4 - WHY	there were no corrective actions?
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Inadequate understanding of the importance of reporting defects. Insufficient company procedures to monitor routine check lists completed on board.		
Root Cause(s): Providing insufficient of inaccurate information of shipboard reports.		
Recommendations: Training of Master and responsible officers in the areas of maintenance and reporting. Improve onboard supervision of safety officer. Evaluate quality of reports by reviewing observed vessel condition during attendances against submitted reports. Possible increase of attending frequency.		


Maintenance and inspection of safety equipment items (life boats, fire pump, CO2 bottles) and incorrect/insufficient implementation of existing procedures.
SMS
Human factors
Responsibilities
Awareness of Rules & Regulations
Training
SMS Procedures
Maintenance Plan
Monitoring

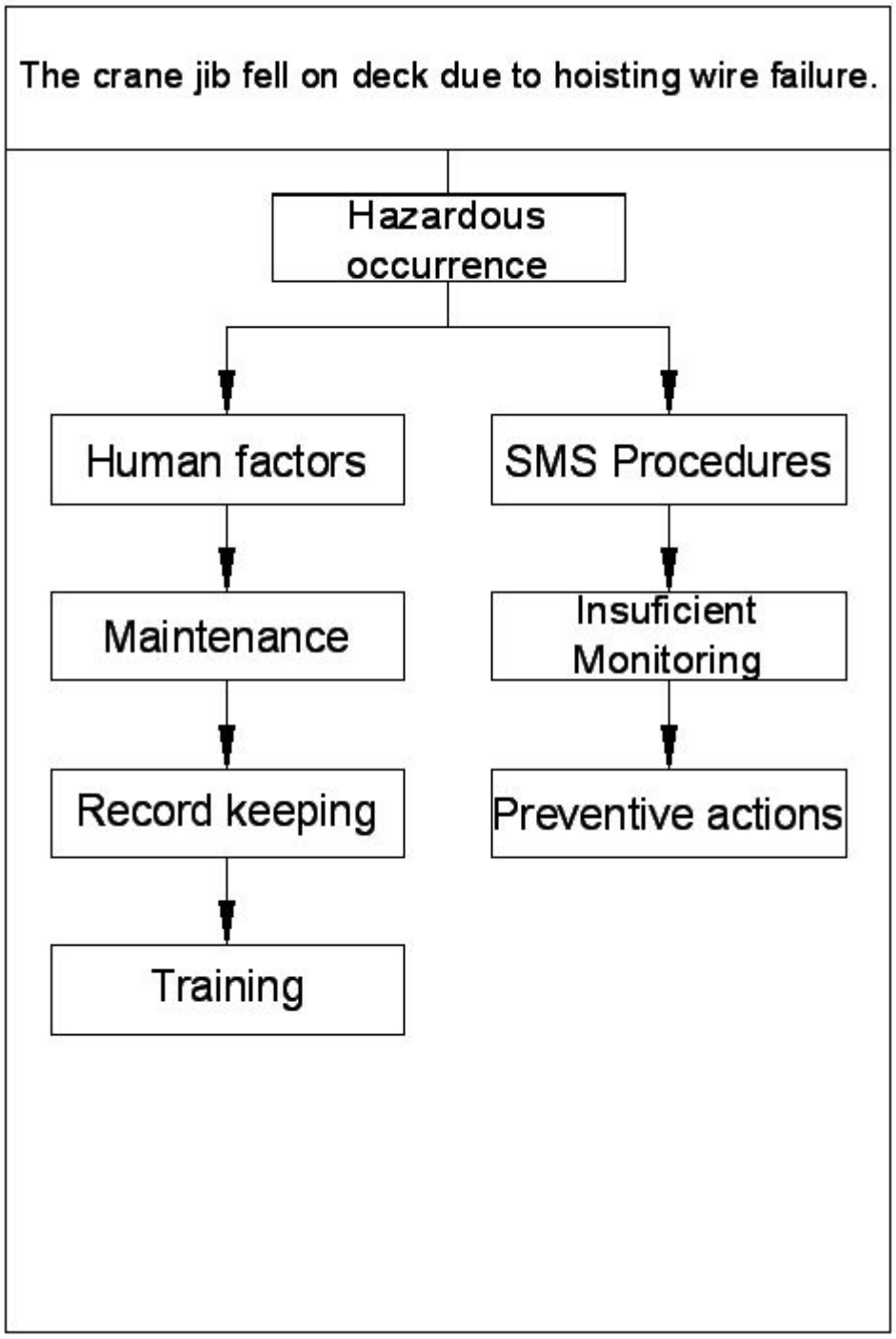
Case No8

During cargo operations the crane jib fell on deck due to hoisting wire failure.

Regarding this case

The investigation revealed that the hoisting wire was not in good condition although greasing schedules had been maintained. In order to deal with this problem specific instructions were given to all fleet vessels, suggesting that all crane wires shall be changed after five years of the installation date regardless of operating hours. Appropriate records must be kept and timely requisitions made in order to ensure that this procedure is adhered to.

RCA No:		008
Type of Incident:		Hazardous Occurrence
Incident Details: During cargo operations the crane jib fell on deck due to hoisting wire failure.		
Immediate Cause: Fortunately there were no injuries and the crane sustained minor damage. Lack of analysis of reporting incidents with objective to improve safety.		
5 WHYs Process:	1 - WHY	the incident was not formally investigated although internally reported?
	2 - WHY	corrective/preventive actions not properly documented?
	3 - WHY	management did not disclose relevant information to concerned parties?
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: The investigation revealed that the hoisting wire was not in good condition although greasing schedules had been maintained. Insufficient monitoring and follow-up on corrective/preventive actions. Poor co-operation between responsible departments.		
Root Cause(s): Incomplete instructions in relevant SMS procedures.		
Recommendations: All crane wires shall be changed after five years of the installation date regardless of operating hours. Appropriate records must be kept and timely requisitions made in order to ensure that this procedure is adhered to.		


The crane jib fell on deck due to hoisting wire failure.
Hazardous occurrence
Human factors
SMS Procedures
Maintenance
Insuficient Monitoring
Record keeping
Preventive actions
Training

Case No9

Poisoning of Master, all officers and crew dew to cargo hold fumigation (aluminium phosphide) entering accommodation.

Regarding this case

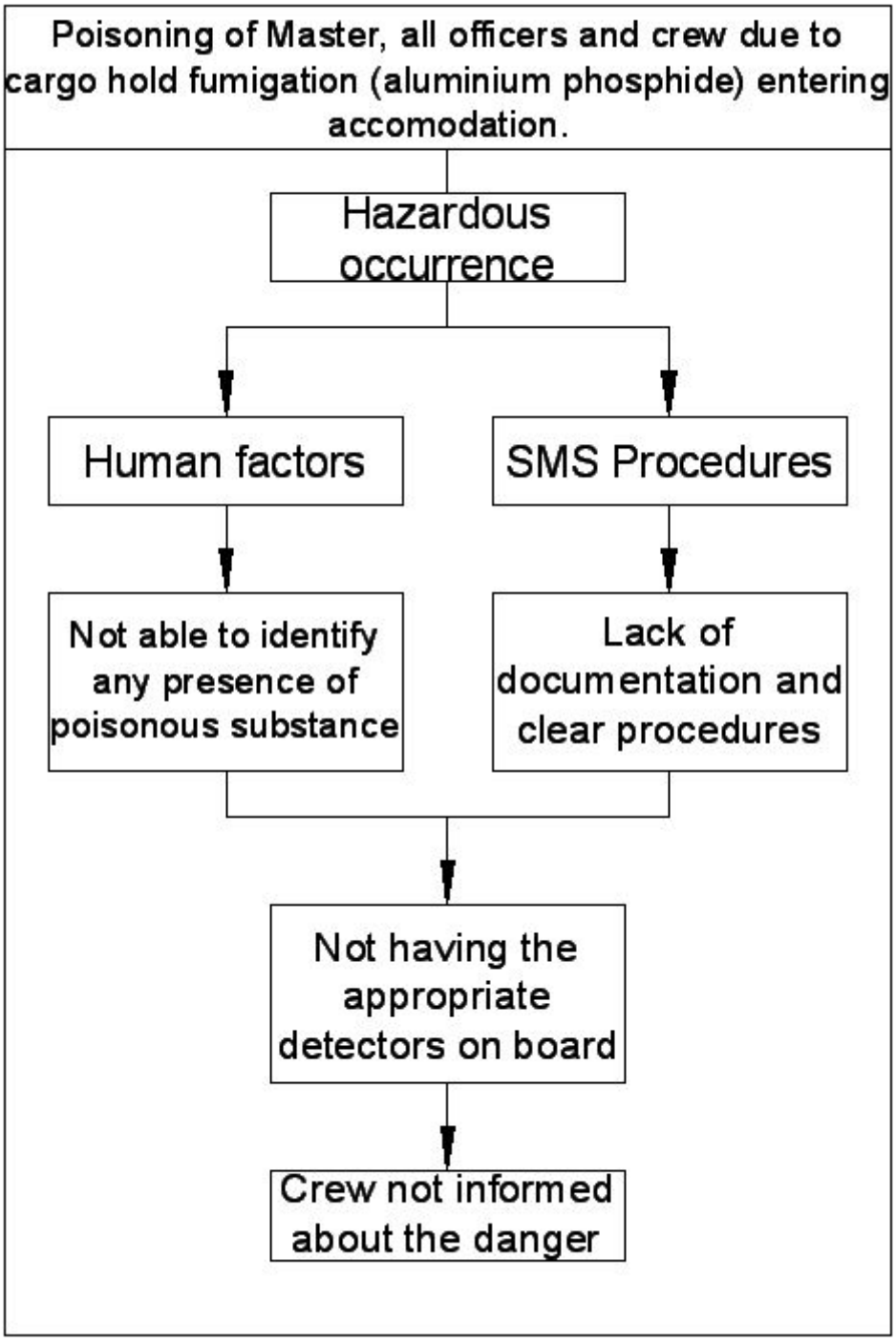
Aluminum Phosphide is a chemical that reacts with moisture to release the fumigant, phosphine, or hydrogen phosphide. The aluminum phosphide fumigant formulation contains approximately 55 percent aluminum phosphide and 45 percent inert ingredients to regulate the release of the fumigant and suppress flammability. Inert ingredients may include ammonium carbonate, ammonium bicarbonate, urea, and paraffin. It reacts with moisture in the air to produce phosphine (hydrogen phosphide), which is highly toxic to all forms of animal and human life.
Phosphine is a colorless, odorless gas.

Symptoms of exposure to phosphine are:

1. Slight or mild poisoning which produces a feeling of fatigue, ringing in the ears, nausea, pressure in the chest, and uneasiness. All of these symptoms will normally disappear when the person is removed to fresh air.
2. Moderate exposure that leads to general fatigue, nausea, gastro-intestinal symptoms accompanied by vomiting, stomach ache, diarrhea, disturbance of equilibrium, strong pains in the chest, and difficulty in breathing.
3. Exposure to very high concentrations which rapidly produces strong difficulty in breathing, bluish-purple skin color, difficulty in walking or reaching, subnormal blood oxygen content, unconsciousness, and death. Death can be immediate or may be delayed until several days later.

If a member of the crew experience any of the symptoms previously described, he should be immediately removed to fresh air and a physician should be contacted as soon as possible.

RCA No:		009
Type of Incident:		Hazardous Occurrence
Incident Details: Poisoning of Master, all officers and crew dew to cargo hold fumigation (aluminium phosphide) entering accommodation.		
Immediate Cause: Master reported all crew with medium degree of poisoning. Lack of analysis of reporting incidents with objective to improve safety.		
5 WHYs Process:	1 - WHY	the incident was not formally investigated although internally reported?
	2 - WHY	corrective/preventive actions not properly documented?
	3 - WHY	management did not disclose relevant information to concerned parties?
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Since the holds were sealed and had been hose tested recently we can only assume that a quantity of fumigant remained by the cargo holds, undetected by the crew, causing the poisoning. Insufficient monitoring and follow-up on corrective/preventive actions. Poor co-operation between responsible departments.		
Root Cause(s): Incomplete instructions in relevant SMS procedures.		
Recommendations: When carrying fumigated cargo, the fumigators are requested to provide the vessel with appropriate detectors and that living quarters adjacent to the cargo holds are regularly monitored (using these detectors) in order to identify any presence of poisonous substance for min two days after fumigation. All crew must be properly informed of the fumigant hazardous properties and symptoms of poisoning.		


Poisoning of Master, all officers and crew due to cargo hold fumigation (aluminium phosphide) entering accomodation.
Hazardous occurrence
Human factors
SMS Procedures
Not able to identify any presence of poisonous substance
Lack of documentation and clear procedures
Not having the appropriate detectors on board
Crew not informed about the danger

Case No10

Only one Deck Officer designated to carry out tank and hold inspections and there was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.

Regarding cases No10 and No11

Cargo holds and ballast tanks should be inspected in greater detail, according to the following procedure:

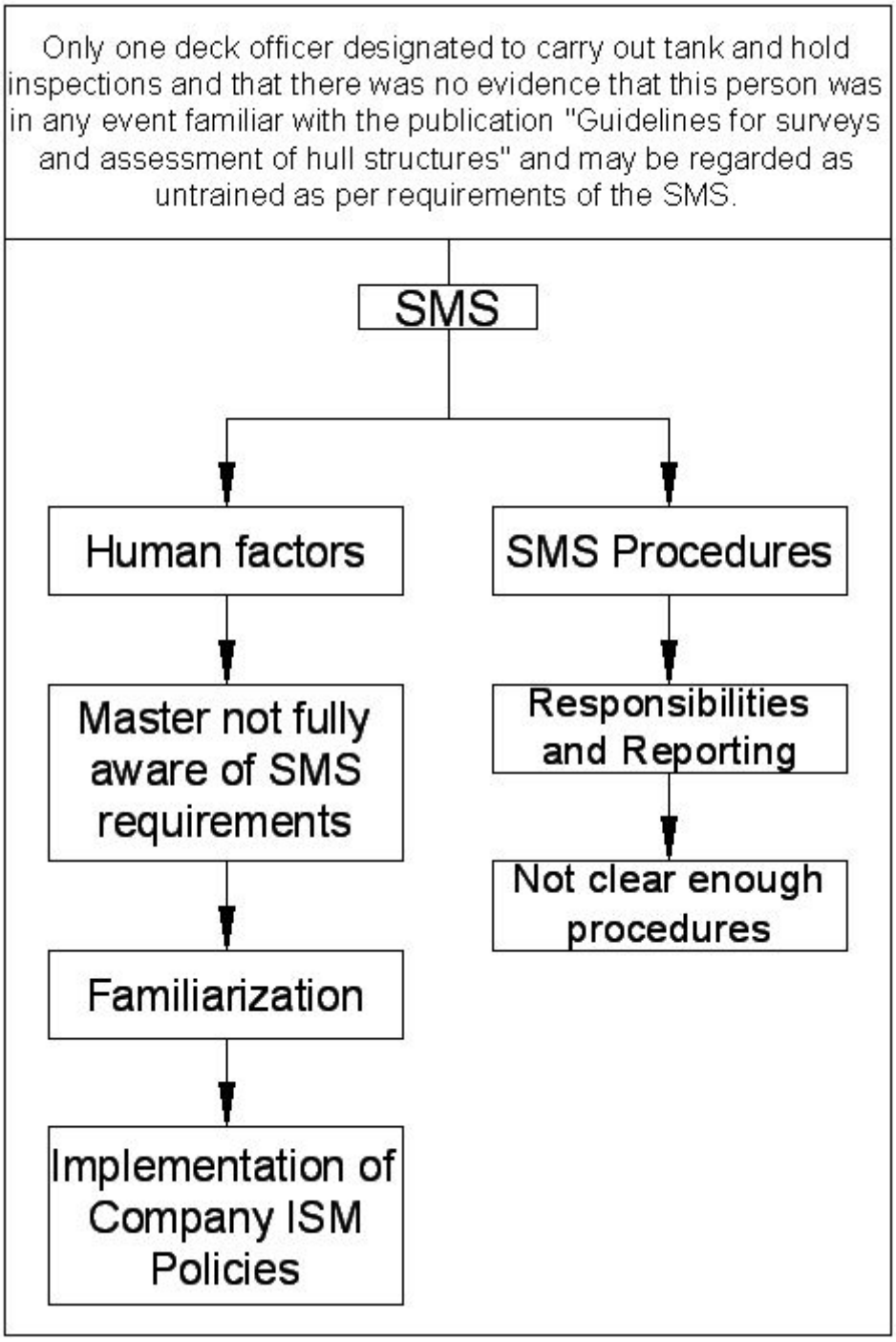
One (1) cargo hold is to be inspected during every ballast voyage with duration of 5 days or longer.

Two (2) ballast tanks are to be inspected during every loaded voyage with duration of 5 days or longer.

The condition of each inspected compartment must be reported. Reports can be supported by photos covering all areas of the compartment, with additional close-ups of suspect areas.

Furthermore at least two Officers, one of whom shall be the Chief Officer, should be assigned to carry out these inspections and prepare the reports. These officers should familiarize themselves with the available on board “Guidelines for Surveys, Assessment and Repair of Hull Structures”. This training should be recorded and shall be repeated at each employment, regardless of previous services on board the same or similar vessels. The reports are prepared in duplicate. Original remains on board while a copy is sent to the Technical department.

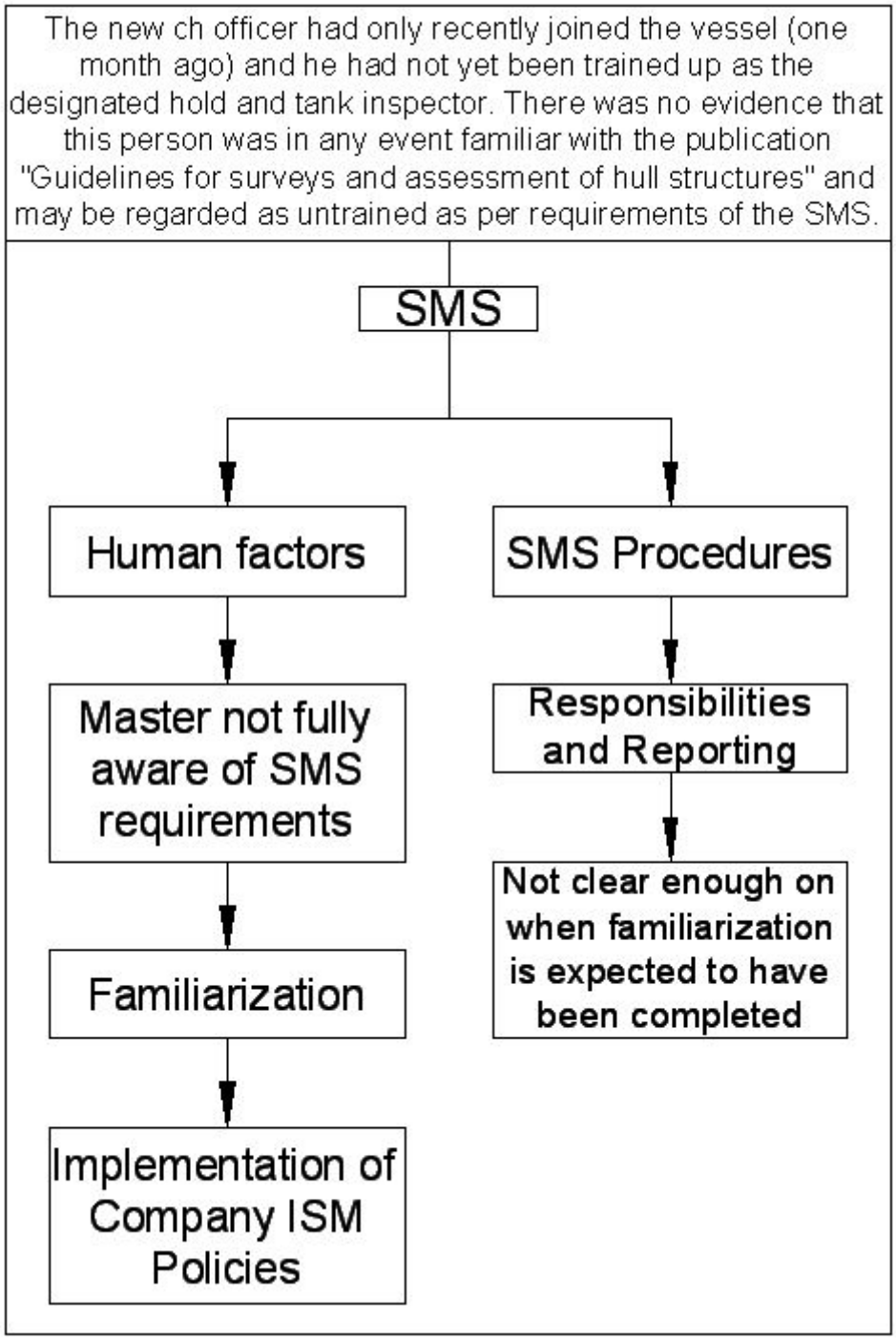
RCA No:		010
Type of Incident:		Non-conformity
Incident Details: Only one deck officer designated to carry out tank and hold inspections and there was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.		
Immediate Cause: Failure of the Master to designate a second deck officer as tank and hold inspector due to lack of familiarity with the company requirements.		
Procedures Reviewed: SMS procedure 10.2.6.1.2 (inspection of cargo holds and ballast tanks) and 10.2.6.1.3 responsibilities and reporting.		
5 WHYs Process:	1 - WHY	was a second deck officer not allocated?
	2 - WHY	was an officer who had been designated as a tank and hold inspector not been trained?
	3 - WHY	are the SMS procedures not clear enough on the subject of designation and familiarisation?
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Failure of Masters to familiarise themselves with the relevant SMS procedures.		
Root Cause(s): Effective failure of SMS.		
Recommendations: The procedure should clarify that the Master should designate two such officers as tank and hold inspectors, one of which is the ch. officer. Company to improve auditing methods so as to identify areas of non implementation of SMS.		


Only one deck officer designated to carry out tank and hold inspections and that there was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.
SMS
Human factors
SMS Procedures
Master not fully aware of SMS requirements
Responsibilities and Reporting
Not clear enough procedures
Familiarization
Implementation of Company ISM Policies

Case No11

The new Chief Officer had only recently joined the vessel (one month ago) and he had not yet been trained up as the designated hold and tank inspector. There was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.

RCA No:		011
Type of Incident:		Non-conformity
Incident Details: The new Chief Officer had only recently joined the vessel (one month ago) and he had not yet been trained up as the designated hold and tank inspector. There was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.		
Immediate Cause: Failure of the Master to train the Chief Officer in a short time period as tank and hold inspector due to lack of familiarity with the company requirements.		
Procedures Reviewed: SMS procedure 10.2.6.1.2 (inspection of cargo holds and ballast tanks) and 10.2.6.1.3 responsibilities and reporting.		
5 WHYs Process:	1 - WHY	was the Ch. officer not immediately allocated and familiarised at the time of signing on?
	2 - WHY	are the SMS procedures not clear enough on the subject of designation and familiarisation?
	3 - WHY	
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Failure of Masters to familiarise themselves with the relevant SMS procedures.		
Root Cause(s): Effective failure of SMS.		
Recommendations: The procedure should clarify that the Master should train the Chief Officer in a short time period. Company to improve auditing methods so as to identify areas of non implementation of Safety Management System (SMS).		


The new ch officer had only recently joined the vessel (one month ago) and he had not yet been trained up as the designated hold and tank inspector. There was no evidence that this person was in any event familiar with the publication "Guidelines for surveys and assessment of hull structures" and may be regarded as untrained as per requirements of the SMS.
SMS
Human factors
SMS Procedures
Master not fully aware of SMS requirements
Responsibilities and Reporting
Not clear enough on when familiarization is expected to have been completed
Familiarization
Implementation of Company ISM Policies

Case No12

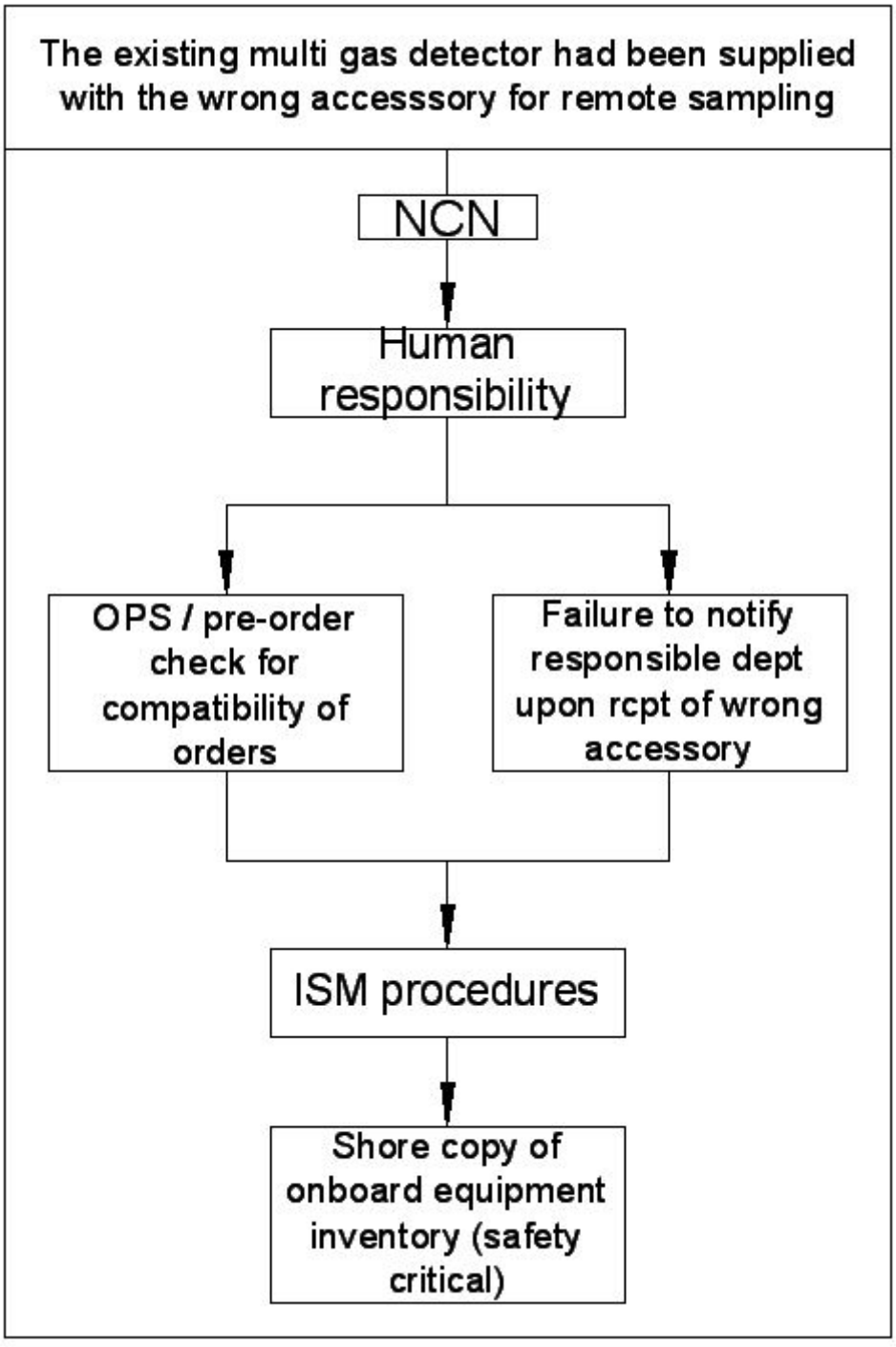
The existing multi gas detector had been supplied with the wrong accessory for remote sampling.

Regarding this case

Entering and working in closed spaces like cargo holds, tanks and void spaces can be dangerous. Oxygen may have been absorbed, or CO2 or other toxic gases may have diluted the atmosphere. Prior to entering such spaces and during work, monitoring of gases is of the utmost importance for workers´ safety. For this purpose ships need appropriate portable gas detection instruments catered to their vessel and cargo.

Without the correct accessories, like the aspirator hoses and probes the equipment would be unfit for remote sampling.

RCA No:		012
Type of Incident:		Non-conformity
Incident Details: The existing multi gas detector had been supplied with the wrong accessory for remote sampling.		
Immediate Cause: The equipment was unfit for sampling cargo holds in line with the BC Code requirements.		
5 WHYs Process:	1 - WHY	the accessory for remote sampling was wrong?
	2 - WHY	nobody checked it?
	3 - WHY	nobody informed the OPS?
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: The crew failed to identify the problem and inform the company.		
Root Cause(s): Lack of proper monitoring of onboard equipment inventory.		
Recommendations: Requisition to be sent to Operations dept. for replacement of incompatible accessory. Accessory to be replaced prior to loading of cargo that requires atmosphere readings to be taken.		


The existing multi gas detector had been supplied with the wrong accesssory for remote sampling
NCN
Human responsibility
OPS / pre-order check for compatibility of orders
Failure to notify responsible dept upon rcpt of wrong accessory
ISM procedures
Shore copy of onboard equipment inventory (safety critical)

Case No13

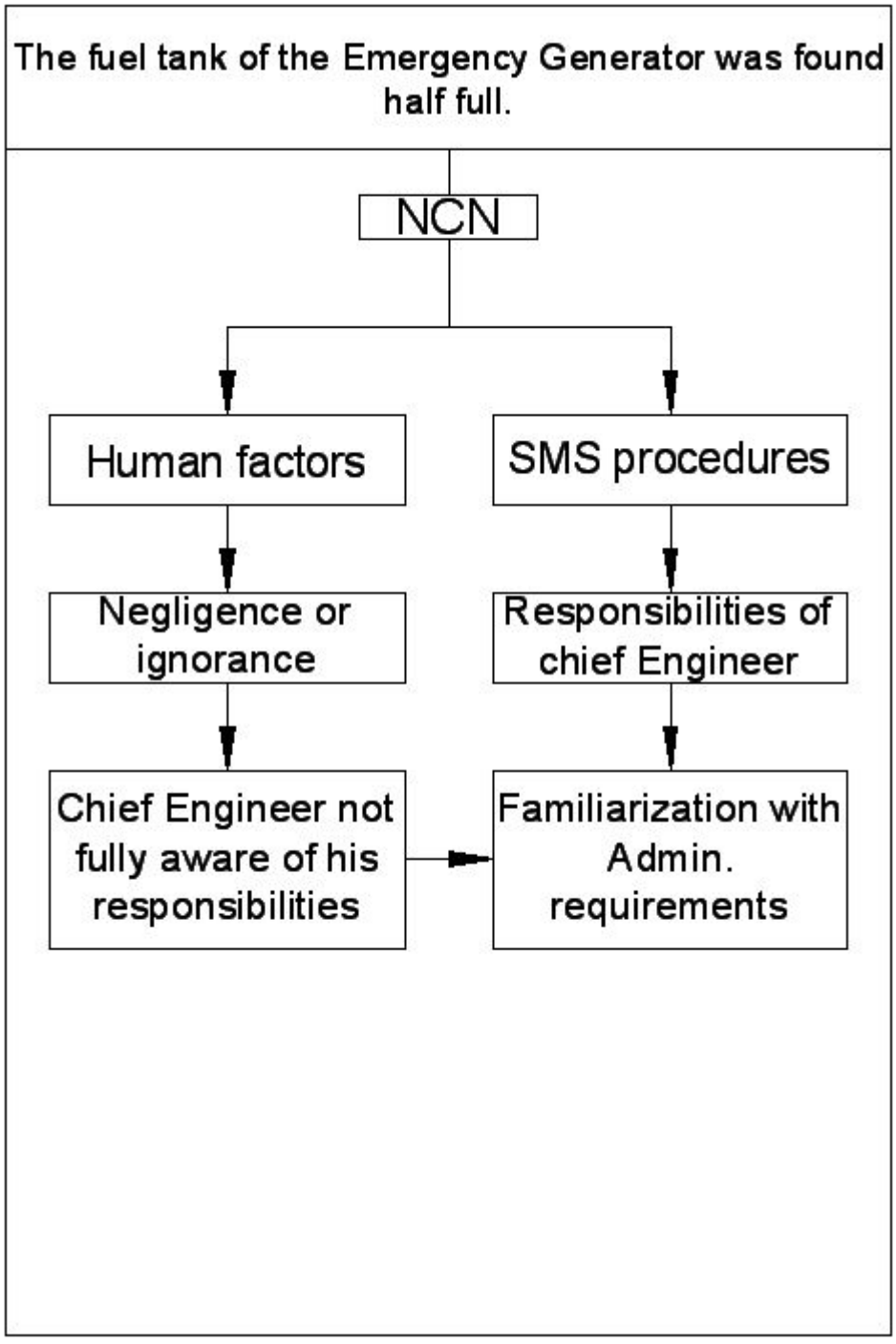
The fuel tank of the Emergency Generator was found half full.

Regarding this case

As described before in Case No2, all equipment and systems on-board the vessels, identified as critical, should be regularly tested and maintained in a good working condition.

In this case we can assume that after several tests of the Emergency Generator, the fuel was consumed and the Chief Engineer, who is responsible for the emergency equipment, did not keep the tank full.

RCA No:		013
Type of Incident:		Non-conformity
Incident Details: The fuel tank of the Emergency Generator was found half full.		
Immediate Cause: The E.G. would work for the half time in case of a drill or an emergency.		
5 WHYs Process:	1 - WHY	the Ch. Engineer didn't fill up the tank?
	2 - WHY	he was not aware of his responsibilities?
	3 - WHY	he was not familiarized with the SMS procedures?
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: The Ch. Engineer was not fully aware of his responsibilities.		
Root Cause(s): Familiarization of Ch. Engineer.		
Recommendations: Emergency Generator fuel tank to be kept full at all times. A sign to be posted by the tank, written in the working language of the crew.		


The fuel tank of the Emergency Generator was found half full.
NCN
Human factors
SMS procedures
Negligence or ignorance
Responsibilities of chief Engineer
Chief Engineer not fully aware of his responsibilities
Familiarization with Admin. requirements

Case No14

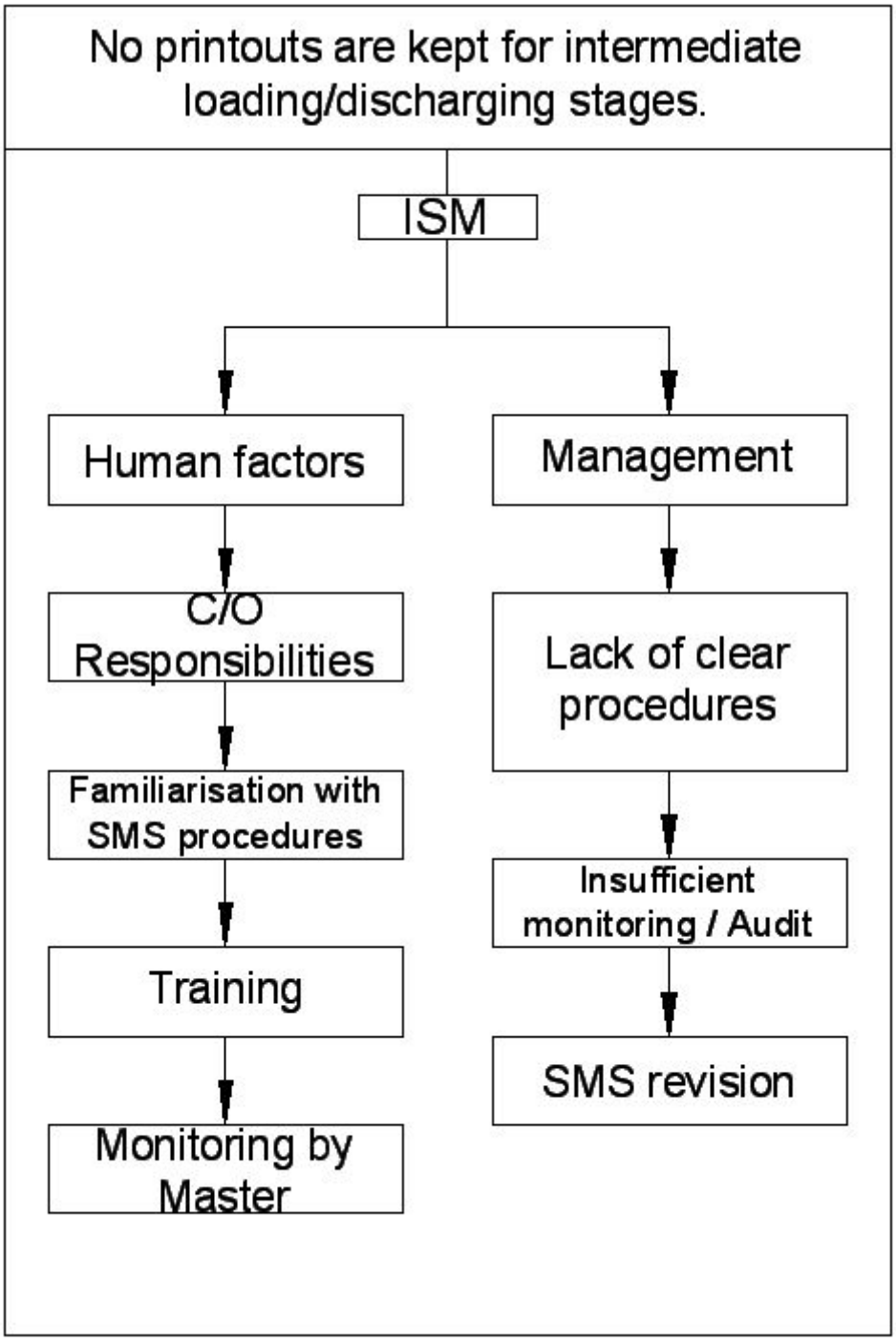
It was noted that no printouts are kept for intermediate loading / discharging stages and it could not be verified that such information was readily available for all cargo operations through the ship's loading calculations software.

Regarding this case

Bulk carriers must be handled with care in port as well as at sea. Ships' Officers responsible for cargo operations become key partners for ship safety, because the lives of seafarers depend on careful cargo handling.

The ship's loading calculations software provides a mean to calculate the shear forces and bending moments in any load or ballast condition and to assess these against the assigned maximum permissible values. Therefore intermediate loading and discharging stages are also very important, in order to minimize the risks of over-stressing the hull structure, something that can lead to catastrophic failure.

RCA No:		014
Type of Incident:		Non-conformity
Incident Details: It was noted that no printouts are kept for intermediate loading / discharging stages and it could not be verified that such information was readily available for all cargo operations through the ship's loading calculations software.		
Immediate Cause: Incomplete records for intermediate loading / discharging stages.		
5 WHYs Process:	1 - WHY	the C/O not fully aware of his responsibilities?
	2 - WHY	he didn't know the correct procedure?
	3 - WHY	the Master didn't monitor his records in order to identify any problems?
	4 - WHY	
	5 - WHY	
Analysis process: Fault Tree Diagram - See Attached		
Contributory Causes: Lack of training of C/O. Lack of clear procedures.		
Root Cause(s): Familiarisation with SMS procedures.		
Recommendations: Procedures to be submitted in the company as evidence.		


No printouts are kept for intermediate loading/discharging stages.
ISM
Human factors
Management
C/O Responsibilities
Lack of clear procedures
Familiarisation with SMS procedures
Insufficient monitoring / Audit
Training
SMS revision
Monitoring by Master

CHAPTER 8

SUMMARY and RECOMENDATIONS

The basic reason for investigating and reporting the causes of occurrences is to enable the identification of corrective actions adequate to prevent recurrence protect the health and safety of the public, the workers, and the environment.

To make it simple, ROOT CAUSE ANALYSIS is just a process where you keep asking WHY until you get to the root of the matter. It is peeling away the layers until you reach the heart of the problem/issue (generally this is about 5 layers of WHY's). Most important is the follow-up. It does little good to identify the problem and do nothing about it! Another benefit of learning the ROOT CAUSE ANALYSIS process is that it can be applied to problem solving not just casualty analysis. [13]

From the analysis of the fourteen cases, some points are important to be mentioned as recomendations:

1. Adequate training and guidance of Masters and Chief Engineers should be made by the office.
2. It is better to provide detailed instructions in the native language of the crew.
3. Masters of the other ships of the fleet should be informed about incidents in order to prevent reoccurance.
4. It is important to have clear proceduresin the Company's Safety Management System Manual.
5. Masters Should understand the importance of reporting defects and incidents.

CHAPTER 9

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