Excerpt from the SINTEF-report
"Investigation methodology: Man – technology – organization"

About MTO-ANALYSIS, TRIPOD, SOL and MORT

3.1.1 MTO-ANALYSIS

The basis for the MTO-analysis is that human, organisational, and technical factors should be focused equally in an accident investigation. The method is based on HPES ("Human Performance Enhancement System") from the nuclear industry.

The MTO-analysis is based on three methods:

1. Structured analysis by use of an event- and cause-diagram.
2. Change analysis by describing how events have deviated from earlier events or common practice.
3. Barrier analysis by identifying technological and administrative barriers which have failed or are missing.

Figure 1 illustrates the MTO-analysis worksheet. The first step in an MTO-analysis is to develop the event sequence longitudinally and illustrate the event sequence in a block diagram. Then, the analyst should identify possible technical and human causes of each event and draw these vertically to the events in the diagram.

The next step is to make a change analysis, i.e. to assess how events in the accident progress have deviated from normal situation, or common practice. Normal situations and deviations are also illustrated in the diagram below.

Further, analyse which technical, human or organisational barriers[1] that have failed or was missing during the accident progress. Illustrate all missing or failed barriers below the events in the diagram.

The basic questions in the analysis are:
- What may have prevented the continuation of the accident sequence?
- What may the organisation have done in the past in order to prevent the accident?

[1] Med en barriere menes alle de systemmessige, fysiske og administrative vern som finnes i organisasjonen og på den enkelte arbeidsplass for a) å forhindre at det oppstår feil og feilhandlinger, eller b) å begrense konsekvensene av feil og feilhandlinger. Eksempler er regler og sikkerhetssystemer, låste branndører, prosedyrer, veiledninger, osv.

The last important step in the MTO-analysis is to identify and present recommendations. The recommendations should be as realistic and specific as possible, and might be technical, human or organisational.

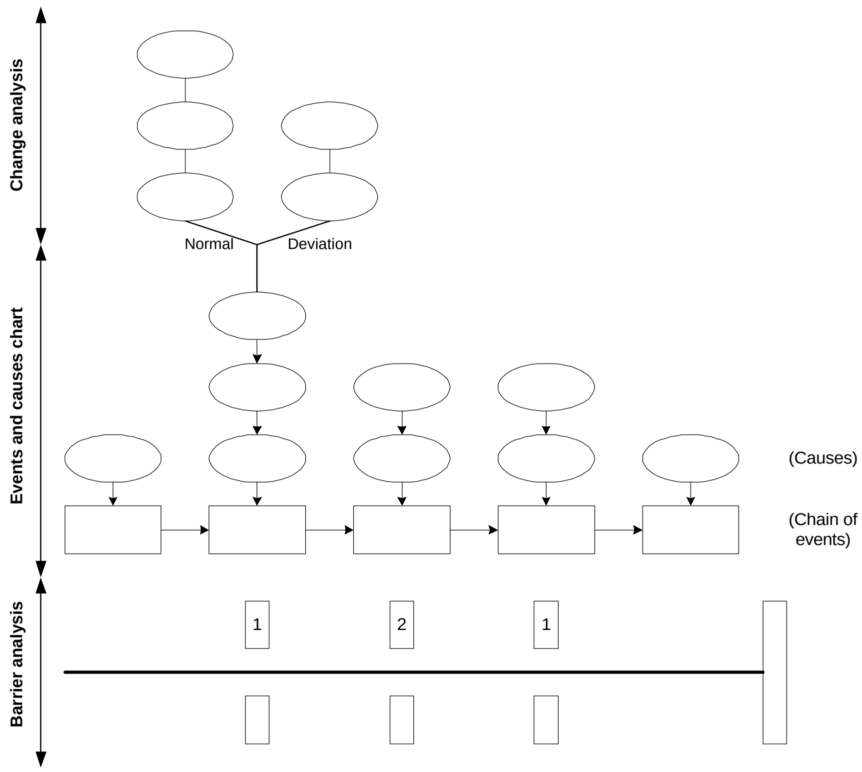

Figure 1. MTO-analysis worksheet, /28/.

3.1.2 TRIPOD

Beskrivelsen av TRIPOD er basert på /10/ og /28/.

The whole research into the TRIPOD concept started in 1988 when a study that was contained in the report "TRIPOD, A principled basis for accident prevention" (/25/) was presented to Shell International Petroleum Maatschappij, Exploration and Production. The idea behind TRIPOD is that organisational failures are the main factors in accident causation. These factors are more "latent" and, when contributing to an accident, are always followed by a number of technical and human errors.

The complete TRIPOD-model[2] is illustrated in Figure 2.

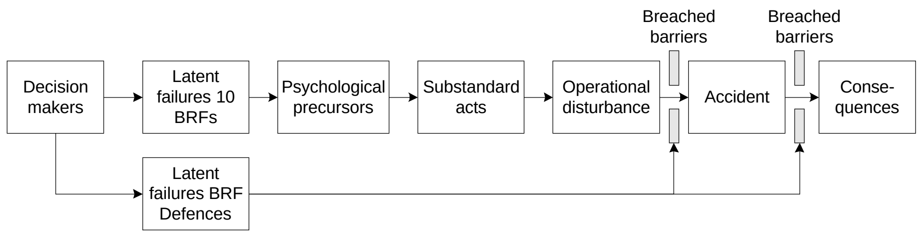

Figure 2. The complete TRIPOD model, /10/.

Substandard acts and situations do not just occur. They are generated by mechanisms acting in organisations, regardless whether there has been an accident or not. Often these mechanisms result from decisions taken at high level in the organisation. These underlying mechanisms are called Basic Risk Factors[3] (BRFs). These BRFs may generate various psychological precursors which may lead to substandard acts and situations. Examples on psychological precursors of slips, lapses and violations are time pressure, being poorly motivated or depressed. According to this model, eliminating the latent failures categorised in BRFs or reducing their impact will prevent psychological precursors, substandard acts and the operational disturbances. Furthermore, this will result in prevention of accidents.

The identified BRFs cover human, organisational and technical problems. The different Basic Risk Factors are defined in Table 2. Ten of these BRFs leading to the "operational disturbance" (the "preventive" BRFs), and one BRF is aimed at controlling the consequences once the operational disturbance has occurred (the "mitigation" BRF). There are five generic prevention BRFs (6 – 10 in Table 2) and five specific BRFs (1 – 5 in Table 2). The specific BRFs relate to latent failures that are specific for the operations to be investigated (e.g. the requirements for tools and equipment are quite different in an oil drilling environment compared to an intensive care ward in a hospital).

These 11 BRFs have been identified as a result of brainstorming, a study of audit reports, accident scenarios, a theoretical study, and a study on offshore platforms.

---

[2] The TRIPOD-model described here might be different from previously published models based on the TRIPOD theory, but this model is fully compatible with the most recent version of the accident investigation tool TRIPOD Beta described later in this chapter.

[3] These mechanisms were initially called General Failure Types (GFTs).

Table 1. The definitions of the basic risk factors (BRFs) in TRIPOD, /10/.

No	Basic Risk Factor	Abbr.	Definition
1	Design	DE	Ergonomically poor design of tools or equipment (user-unfriendly)
2	Tools and equipment	TE	Poor quality, condition, suitability or availability of materials, tools, equipment and components
3	Maintenance management	MM	No or inadequate performance of maintenance tasks and repairs
4	Housekeeping	HK	No or insufficient attention given to keeping the work floor clean or tidied up
5	Error enforcing conditions	EC	Unsuitable physical performance of maintenance tasks and repairs
6	Procedures	PR	Insufficient quality or availability of procedures, guidelines, instructions and manuals (specifications, "paperwork", use in practice)
7	Training	TR	No or insufficient competence or experience among employees (not sufficiently suited/inadequately trained)
8	Communication	CO	No or ineffective communication between the various sites, departments or employees of a company or with the official bodies
9	Incompatible goals	IG	The situation in which employees must choose between optimal working methods according to the established rules on one hand, and the pursuit of production, financial, political, social or individual goals on the other
10	Organisation	OR	Shortcomings in the organisation's structure, organisation's philosophy, organisational processes or management strategies, resulting in inadequate or ineffective management of the company
11	Defences	DF	No or insufficient protection of people, material and environment against the consequences of the operational disturbances.

TRIPOD Beta

The TRIPOD Beta-tool is a computer-based instrument that provides the user with a tree-like overview of the accident that was investigated. It is a menu driven tool that will guide the investigator through the process of making an electronic representation of the accident. TRIPOD Beta is distributed by Tripod Solutions (for more information, see /34/).

TRIPOD Beta-tool merges two different models, the HEMP ("The Hazard and Effects Management Process") model and the TRIPOD model. The merge has resulted in an incident causation model that differs conceptually from the original TRIPOD model. The HEMP model is presented in Figure 3.

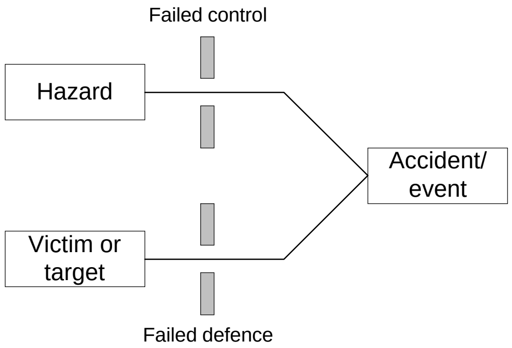

Figure 3. "Accident mechanism" according to HEMP, /10/.

The TRIPOD Beta accident causation model is presented in Figure 4. This string is used to identify the causes that lead to the breaching of the controls and defences presented in the HEMP model.

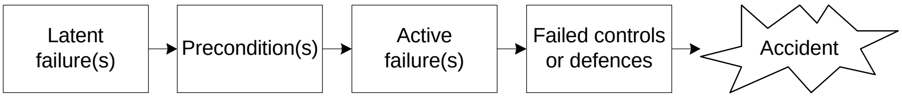

Figure 4. TRIPOD Beta Accident Causation Model, /10/.

Although the model presented in Figure 4 looks like the original TRIPOD model, its components and assumptions are different. In the Beta-model the defences and controls are directly linked to unsafe acts, preconditions and latent failures. Unsafe acts include how the barriers were breached and the latent failures why the barriers were breached.

An example of a TRIPOD Beta accident analysis is shown in Figure 5.

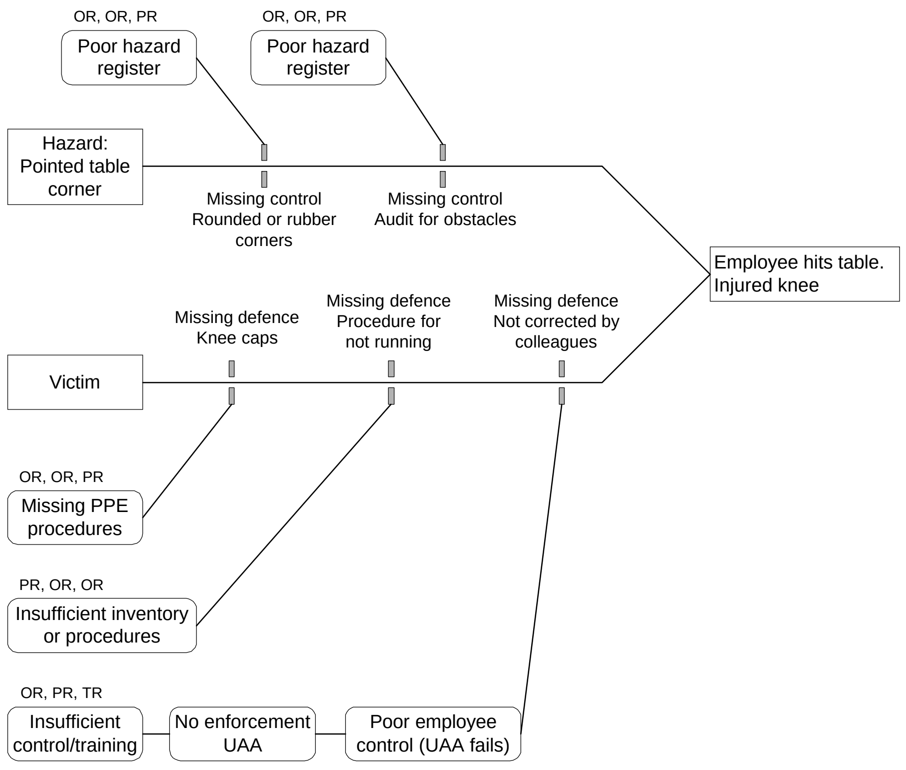

Figure 5. Example on a TRIPOD Beta analysis, /10/.

3.1.3 SOL ("Safety through Organizational Learning")

SOL develops the concept of event analysis in a set of standardised process steps. A set of three specific instruments is aimed to support the process of event analysis, to ensure its standardised conduct while at the same time mobilising expert knowledge and creativity of the analysis which can be compared to a backward oriented problem solving process:

1. Guideline for the description of the situation
2. Guideline for the identification of contributing factors
3. Guideline for the reporting of the event (not further described in this report).

Guideline for Description of the Situation
As soon as possible after an event occurred the whole event must be described, i.e. recording what happened. The description aims at separating the process of information gathering and interpreting this information. Similar to the STEP method the event is broken down into a sequence of event-parts i.e. single actions of different actors (man or machine), event building blocks, and no contributing factors should be identified at this stage.

The STEP-method was developed by Hendrick and Benner, /13/, and the following description is copied from, /28/. Hendrick and Benner proposed a systematic process for accident investigation based on multi-linear event sequences and a process view of the accident phenomena.

STEP builds on four concepts:

1. Neither the accident nor its investigation is a single linear chain or sequence of events. Rather, several activities take place at the same time.
2. The event Building Block format for data is used to develop the accident description in a worksheet. A building block describes one event, i.e. one actor performing one action.
3. Events flow logically during a process. Arrows in the STEP worksheet illustrate the flow.
4. Both productive and accident processes are similar and can be understood using similar investigation procedures. They both involve actors and actions, and both are capable of being repeated once they are understood.

With the process concept, a specific accident begins with the action that started the transformation from the described process to an accident process, and ends with the last connected harmful event of that accident process.

The STEP worksheet provides a systematic way to organise the building blocks into a comprehensive, multi-linear description of the accident process. The STEP worksheet is simply a matrix, with rows and columns. There is one row in the worksheet for each actor. The columns are labelled differently, with marks or numbers along a time line across the top of the worksheet, as shown in Figure 6. The time scale does not need to be drawn on a linear scale, the main point of the time line is to keep events in order, i.e., how they relate to each other in terms of time.

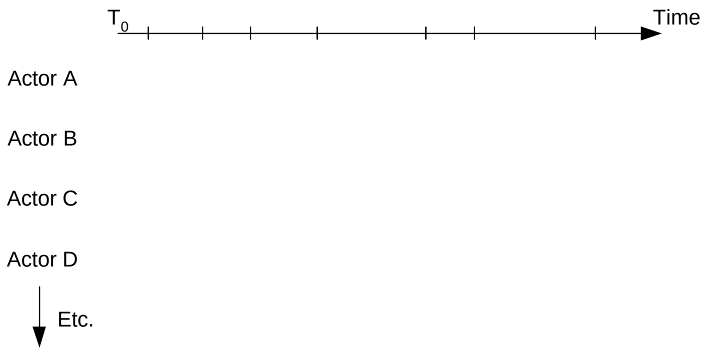

Figure 6. STEP worksheet, /29/.

An event is one actor performing one action. An actor is a person or an item that directly influences the flow of events constituting the accident process. Actors can be involved in two types of changes, adaptive changes or initiating changes. They can either change reactively to sustain dynamic balance or they can introduce changes to which other actors must adapt. An action is something done by the actor. It may be physical and observable, or it may be mental if the actor is a person. An action is something that the actor does and must be stated in the active voice.

In SOL, an accidental event is determined by a sequence of singular actions by different actors (maybe a person or a technical component) between a starting point and an end point. The starting point is defined as the first alarm or the first perceived deviation from a warranted course of action. The end point is defined as the recovering of a safe system state.

Guideline for the Identification of Contributing Factors (CFs)

This guideline carries the analysts through the single steps of an event analysis in a certain sequence. It provides the standardisation of the analysis process. Every single action (representing an “event building block”) identified in the description of the situation should be analysed by asking the question "why". Each event building block is located within a time-actor diagram. This graphic charting of the single building blocks of the event is completed by identifying contributing factors. Every contributing factor is complemented by adding further contributing factors. The contributing factors are related to five subsystems shown in Figure 7. Thus, a graphic chart is developed which represents the event and all contributing factors in their whole complexity.

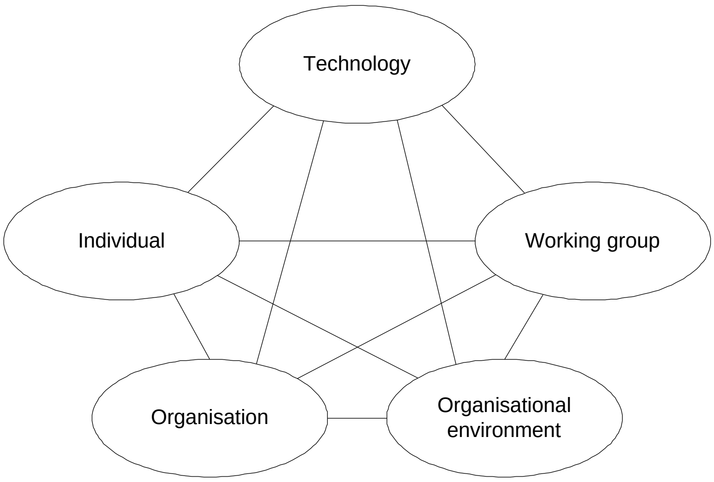

Figure 7. Socio-technical system model of event genesis, /37/.

SOL differentiates *directly* contributing factors from *indirectly* contributing ones. Six factors are deemed to be *directly contributing* in terms of their direct and immediate contribution to the genesis of an event:

A Information
B Communication
C Working conditions
D Personal performance
E Violation
F Technical components.

Indirectly CFs are seen to be factors which are temporally and spatially somewhat more distant from the actual event evolution but nevertheless often crucial for the event. A list of 19 contributing factors[4] was collated to assist the search for CFs:

1. Information
2. Communication
3. Working conditions
4. Personal performance
5. Violation
6. Operation scheduling

[4] Five of the CFs (e.g. Information and Communication) may be directly, as well as indirectly CFs.

7. Responsibility
8. Control and supervision
9. Group influence
10. Rules, procedures and documents
11. Qualification
12. Training
13. Organisation and management
14. Feedback of experience
15. Safety principles
16. Quality management
17. Maintenance
18. Regulatory and consulting bodies
19. Environmental influence.

All possible contributing factors are transferred into general questions, e.g. the factor “working conditions” is transferred into the question “Could there have been an influence of the working conditions on the operator performance?” Thus, the aid contains general questions related to possible contributing factors for each of the five subsystems and thus ensures the comprehensiveness of the analysis. These questions serve as a support of the problem solving process of the team by giving them an idea of how certain factors could have contributed to the occurrence of the event.

3.1.4 MORT

In MORT, accidents are defined as unplanned events that produce harm or damage, that is, losses. Losses occur when a harmful agent comes into contact with a person or asset. This contact can occur either because of a failure of prevention or, as an unfortunate but acceptable outcome of a risk that has been properly assessed and acted-on (a so-called "assumed risk"). MORT analysis always evaluates the "failure" route before considering the "assumed risk" hypothesis.

In MORT analysis, most of the effort is directed at identifying problems in the control of a work/process and deficiencies in the protective barriers associated with it. These problems are then analysed for their origins in planning, design, policy, etc. To use MORT, we must first *identify key episodes in the sequence of events.* Each episode can be characterised as:

- a vulnerable target exposed to –
- an agent of harm in the –
- absence of adequate barriers.

MORT analysis can be applied to one or more of the episodes identified; it is a choice to make in the light of the circumstances particular to the investigation. To identify these key episodes, we have to undertake a barrier analysis (or "Energy Trace and Barrier Analysis"; ETBA). Barrier analysis allows MORT analysis to be focused; it is very difficult to use MORT, even in a superficial way, without it. The MORT process is rather like a dialogue between the generic questions of MORT and the situation that we are investigating. The analyst acts as the interpreter between MORT and the situation. The questions in MORT are asked in a particular sequence, one that is designed to clarifying the facts surrounding the incident. Even so, not every question posed by MORT will be relevant on all occasions.

Getting acquainted with MORT is essentially about becoming familiar with the principal questions in the manual. The chart itself then acts as a prompt list allowing us to concentrate on the issues revealed through the process. It is important to make notes as we go, just as it would be if we were conducting an interview. In practice, MORT analysts make brief notes on the MORT chart - enough to capture the issues that arise and their assessment of them. To make this process easier to review, it is customary to colour-code the chart as the investigation proceeds:

- red, where a problem is found;
- green, where a relevant issue is judged to have been satisfactory, and;
- blue, to indicate that an issue is relevant, but have not enough information to assess it properly.

In addition, issues presented by MORT that are judged to be irrelevant, should be crossed-out to show that we have considered them.

In Figure 8 the relationship between the "Controls & barriers" in ETBA and the main elements in the MORT Tree, /21/, is shown. These are the "MTO factors" emphasised in the MORT Tree.

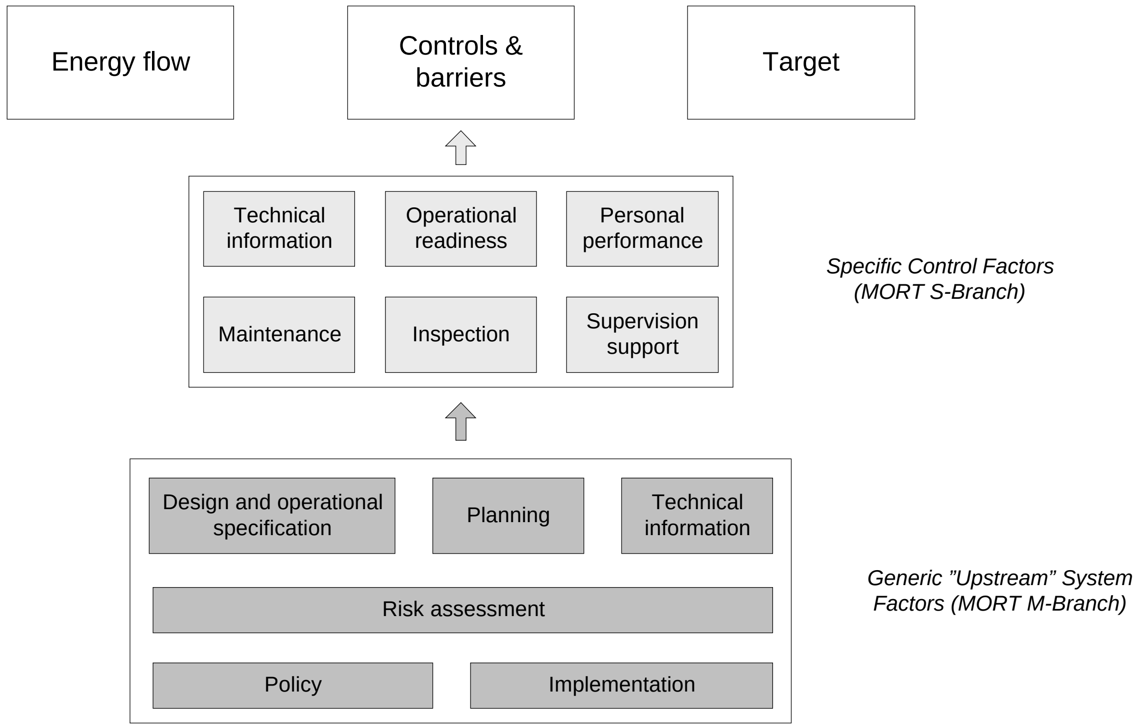

Figure 8. The relationship between Energy Trace and Barrier Analysis and the MORT concept, /17/.

•

Referanser

/1/ Aven T., Hauge S., Sklet S., Vinnem J.-E.: *Operational risk analysis. Total analysis for physical and non-physical barriers.* H2.1 Methodology for Analysis of HOF Factors, Draft 0, Rev. 0, Preventor report no. 200254-04, 2004.

/2/ Bento, J.-P.: *Menneske – Teknologi – Organisasjon. Veiledning for gjennomføring av MTO-analyser*. Kurskompendium for Oljedirektoratet. November 2001.

/3/ Bellamy, L.J., Papazoglou, I.A., Hale, A.R., Aneziris, O.N., Ale, B.J.M., Morris, M.I., Oh, J.I.H: *I-RISK Development of an Integrated Technical and Management Risk Control and Monitoring Methodology for Managing and Quantifying On-Site and Off-Site Risks*. Main Report. Contract No. ENVA-CT96-0243, September 1999.

/4/ Bird, F.E., Germain, G.L.: *Practical Loss Control Leadership.* International Loss Control Institute. Georgia, USA, 1990.

/5/ Davoudian, K., Wu, J.-S., Apostolakis, G.: Incorporating organisational factors into risk assessment through the analysis of work processes. *Reliability Engineering and System Safety*, 1994, 45, pp. 85-105.

/6/ Edwards, E.: *Man and Machine: Systems for Safety*. Loughborough University of Technology, 1972.

/7/ Embrey, D.E., Humphreys, P., Rosa, E.A., Kirwan B., Rea, K.: *SLIM-MAUD: An approach to assessing human error probabilities using structured expert judgment.* NUREG/CR-3518, Department of Energy, USA, 1984.

/8/ Frei, R., Kingston, J., Koorneef, F., Schallier, P.: *Investigation tools in context.* Presentation at JRC/ ESReDA seminaret "Safety Investigation of Accidents". Petten, Nederland, 12-13 May, 2003.

/9/ Gibson, H., Basra, G., Kirwan, B.: *Development of the CORE-DATA database.* University of Birmingham, UK, Paper dated 23.04.98.

/10/ Groeneweg, J.: *Controlling the controllable. The management of safety*. Fourth edition. DSWO Press, Leiden University, The Netherlands, 1998.

/11/ Haddon,W.: The basic strategies for reducing damage from hazards of all kinds. *Hazard Prevention*, September/October, 1980, pp. 8-12.

/12/ Harms-Ringdahl, L.: *Safety analysis - Principles and practice in occupational safety.* Taylor & Francis, London, 2001. Nettadresser: http://www.irisk.se/english/booksa.htm; http://www.irisk.se/engpubl/lhresr03.pdf

/13/ Hendrick, K., Benner, L. Jr.: *Investigating accidents with STEP*. ISBN 0-8247-7510-4, Marcel Dekker, 1987.

/14/ Hollnagel, E.: *Cognitive Reliability and Error Analysis Method, CREAM*. ISBN 0-08-0428487, Elsevier, 1998.

/15/ Jørgensen, K.: *En taxonomi for Arbejdsulykker. En systematisk beskrivelse af årsagssammenhænge.* Rapport BYG.DTU R-027, ISBN 87-7877-086-6. Danmarks Tekniske Universitet, 2002. Nettadresse: http://www.byg.dtu.dk/publications/rapporter/R-027.pdf

/16/ Kingston, J., Nertney, R., Frei, R., Schallier, P., Koornneef, F.: *Barrier Analysis Analysed in MORT Perspective.* In Spitzer, C., Schmocker, U., Dang V.N. (eds): Probabilistic Safety Assessment and Management, PSAM7 – ESREL'04, Springer, June 14 – 18, Berlin, 2004.

/17/ Kingston. J.: *Barrier Analysis Analysed in MORT Perspective.* Presentation at PSAM7 – ESREL'04, June 14 – 18, Berlin, 2004.

/18/ Kjellén, U., Tinmannsvik, R.K., Ulleberg, T., Olsen, P.E., Saxvik, B.: *SMORT – Sikkerhetsanalyse av industriell organisasjon*, Offshore-versjon. Yrkeslitteratur, 1987.
/19/ Kviseth Tinmannsvik, R.: *Systematisk HMS-arbeid i SMB. Internt tilsyn.* ISBN 82-14-00433-0, SINTEF 1997.
/20/ NRI - Noordwijk Risk Initiative Foundation: Nettadresse: http://www.nri.eu.com
/21/ NRI - Noordwijk Risk Initiative Foundation: *MORT User's Manual. Generic Edition.* ISBN 90-77284-01-X, NRI-1, 2002. Nettadresse: http://www.nri.eu.com
/22/ Paradies, M., Unger, L.: *TapRooT. The System for Root Cause Analysis, Problem Investigation, and Proactive Improvement.* System Improvements, Inc., Knoxville, USA, 2000.
/23/ Rasmussen, J.: Risk Management in a Dynamic Society: A Modelling Problem. *Safety Science*, 27 (2/3), 1997, pp. 183-213.
/24/ Reason, J.: *Managing the Risks of Organizational Accidents*. ISBN 1 84014 105 0, Ashgate, 1997.
/25/ Reason, J. et al.: *TRIPOD, A principled basis for accident prevention*. 1988.
/26/ Rollenhagen, C.: *Att utreda olycksfall: Teori och praktik*. ISBN 91-44-04243-4. Studentlitteratur, Lund, 2003.
/27/ Samarbeid for Sikkerhet (SfS): Seminar om barrierer, 4. februar 2004. www.samarbeidforsikkerhet.no
/28/ Sklet, S.: *Comparison of some selected methods for accident investigation.* Presentasjon ved JRC/ ESReDA seminaret "Safety Investigation of Accidents". Petten, Nederland, 12-13 May, 2003.
/29/ Sklet, S.: *Methods for accident investigation*. ROSS (NTNU) 200208, ISBN 82-7706-181-1, NTNU, Trondheim, 2002.
/30/ Sklet, S., Hauge S.: *Reflections on the concept of safety barriers*. In Spitzer, C., Schmocker, U., Dang V.N. (eds): Probabilistic Safety Assessment and Management 2004, Vol 1. pp. 94-99, ISBN 1-85233-827-X, Springer. PSAM 7 - ESREL '04, June 14 - 18, Berlin.
/31/ Sklet, S., Hauge S.: *Safety barriers to prevent release of hydrocarbons during production of oil and gas.* DRAFT SINTEF-rapport STF38 A04419, ISBN 82-14-02735-7, Trondheim, 2004.
/32/ Svedung, I., Rasmussen, J.: Graphic representation of accident scenarios: mapping system structure and the causation of accidents. *Safety Science* 40, pp. 397-417, 2002.
/33/ Swain, A.D., Guttmann, H.E.: *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications.* Final Report, NUREG/CR-1278, SAND80-0200, US NRC, 1983.
/34/ Tripod Solutions: Tripod Brochure 2004. *Organisational Risk Management. Controlling Human Error.* Nederland, 2004. Nettadresse: http://www.tripodsolutions.net/GetBlob.aspx?TableName=News&ColumnName=PDF&RecordID=60ef1b27-b3e1-4565-b118-afef1e3778c5
/35/ Valvisto, T., Harms-Ringdahl, L., Kirchsteiger, C., Røed-Larsen, S.: *Accident Investigation Practices. Results from a European enquiry.* ESReDA Safety Series. ISBN 82 515 0301 9. ESReDA, 2003.
/36/ Visser, J.P.: *Developments in HSE management in oil and gas exploration and production.* In Hale, A.R. & Baram, M. (Eds.) Safety management: the challenge of organisational change. Pergamon, Oxford, 1998.
/37/ Wilpert, B., Fahlbruch, B.: *SOL – Safety through Organizational Learning. A Computer assisted Event Analysis Methodology.* The Bieleschweig Workshops on System Engineering: http://www.rvs.uni-bielefeld.de/Bieleschweig/Fahlbruch_Miller_SOL-Handout.pdf (udatert).