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SAFETY ENGINEERING: TWO DIFFERENT APPROACHES

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ABSTRACT

Two totally different approaches to safety engineering are analyzed to see if they share fundamental principles or elements. Resilience engineering stresses the need for understanding normal operations, and making the systems resilient, rather than reliable. The OMT method focuses on reliability by identifying and describing human, organizational, and operational barriers. It uses standardized risk analysis methods and its central elements are modelling, multidisciplinary approach and barriers. These elements are viewed in the light of the fundamental ideas of resilience engineering. The conclusion is that though the approaches to safety engineering are totally different, some fundamental principles and central elements are shared by the two methods.

1. INTRODUCTION

Safety engineering can be defined as the study of the causes and the prevention of accidental deaths and injuries. The field of safety engineering has developed within several disciplines, and its practitioners have operated under a wide variety of position titles, job descriptions, responsibilities, and reporting levels. Safety engineering includes the identification and appraisal of accident-producing conditions and practices, and the evaluation of the severity of the accident problem. This is done by the development of accident and loss-control methods, procedures, and programs (partly adapted from (EBO, 2008)).

Safety engineering is under constant development and new methods are being developed. In recent years, several scientists have stressed the need for a different approach within safety engineering that includes studying normal performance rather than failure. This has become known as resilience engineering. In the same period, several research projects have worked to develop traditional risk assessments. This involves risk analysis as well as an evaluation of the results. Probabilistic safety assessment (PSA) is one of the terms used for a type of risk assessment. It is also referred to as quantitative risk assessment (QRA), probabilistic risk assessment (PRA), concept safety evaluation (CSE), and total risk analysis (TRA). Despite more than two decades of use and development, no convergence towards a universally accepted term has been seen (Vinnem, 2007). In this article, the term PSA refers to all the different techniques.

The project; *Risk modelling—integration of organizational, human, and technical factors* (Vinnem, 2008a) (the OMT-method) summarizes earlier projects, and includes human and organizational factors. This approach to safety engineering is totally different than resilience engineering since resilience engineering focuses on success whereas the OMT method focuses on failure. Both resilience engineering and the OMT method are taking safety engineering further by research in co-operation with the industry.

The objective of this article is to evaluate whether some central principles and elements in the generic OMT method are comparable with the main principles of resilience engineering. This is interesting to study because of the totally different approaches to safety engineering. First, the concept of resilience engineering and the OMT method is briefly described. Then the central elements of the OMT-method: *modelling*, *multidisciplinary approach,* and *barriers* are described in light of resilience engineering.

This article is limited to the oil and gas industry, and to major accidents. ‘Major accident’ in the offshore industry is often understood to be an accident sequence that is out of control and that has the potential to cause five fatalities or more. This may be, for instance, gas leaks where ignition has occurred or, in the case of structural failure, where at least local structural failure has occurred. This interpretation is in accordance with HSE’s definition (HSE, 2005).

1.1 Resilience engineering

Resilience engineering has become a concept within safety engineering: according to its followers, the term resilience engineering represents a new way of thinking about safety. According to Woods, resilience engineering is a paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success (Woods, 2006). It strongly contrasts with what is typical today—a paradigm which tabulates error as if it were a thing, followed by interventions to reduce this count. Rather than view past success as a reason to ramp down investments, resilient organizations continue to invest in anticipating the changing potential for failure because they appreciate that their knowledge of the gaps is imperfect and that their environment constantly changes. One measure of resilience is therefore the ability to create foresight—to anticipate the changing shape of risk, before failure and harm occurs (Hollnagel et al., 2006). Individuals and organizations must always adjust their performance to the current conditions; because resources and time are finite, it is inevitable that such adjustments are approximate. Success has been ascribed to the ability of groups, individuals, and organizations to anticipate the changing shape of risk before failure damage occurs (Hollnagel et al., 2006). The traditional fields of practice, such as risk analysis and probabilistic safety assessment (PSA), have been unable to provide such much needed solutions. There are several reasons for this, the most important probably being that they are firmly rooted in oversimplified accident models. Insights from research into failures in complex systems, organizational contributors to risk, and human performance, have made it clear that safety is an emergent rather than a resultant property of systems, which means that it cannot be predicted by considering only the constituent parts of a system (Hollnagel et al., 2004).

1.2 The OMT-method

The project; *Risk Modelling—Integration of Organizational, Human and Technical factors* (Vinnem, 2008a) has developed a method for quantifying barrier performance reflecting organizational and operational management factors (OMT-method). The OMT method uses standardized PSA-tools like accident experience, fault trees, and event trees. These methods have according to resilience engineering been unable to provide the much needed solutions within safety engineering. The OMT-project is focusing on identifying and describing human, organizational and operational barriers for risk control by using standard methods and models and combines these in new ways. There is already extensive knowledge related to technical barriers. The objective of OMT project is to have a system, including a generic model, for assessment of the operational safety conditions with particular emphasis on how operational barriers contribute to prevention of major accidents and the effect of human and organizational factors (HOFs) on the barrier performance. These objectives are reached through a development process with the following targets (Vinnem et al., 2007):

- Identify and describe human and operational barriers for selected accident scenarios with major hazard risk potential.
- Identify those tasks that are most critical from a risk point of view, either through initiation of failures (initiating events) or failures of important barrier functions.
- Establish an overview of the factors (‘risk influencing factors’—RIFs) that influence the initiating events and the operational barrier performance, and define performance standards (PS).
- Define performance requirements (PR) for the PSs that are suitable for measuring the condition and establish methods for how to measure the status.
- Establish a system for aggregating the score of each PR into an overall indicator for operational safety condition.

Assessment of performance will involve interviews with operational personnel, in order to obtain knowledge about conditions and associated variations. Each of the RIFs is given a grade from A to F, and the results are to be factors in the risk analysis and probabilistic safety assessment (PSA).

The OMT method contributes to bridging the gap between the extensive knowledge about organizational and human factors in general, and the lack of knowledge about how to reduce the major hazard risk level. Several research and development projects form the basis for the OMT-project:

- BORA project—barrier and operational risk (Haugen, 2007)
- Activity indicator (Vinnem et al., 2004)
- Risk indicator project (Vinnem et al., 2006)
- RNNP—risk level project (PSA, 2008)
- MTO investigations by PSA

The OMT method has been used to study work operations related to offshore process plants (Vinnem, 2008b), well operations (Okstad et al., 2009) and marine operations (Skogdalen, 2009).

1.3 Safety engineering research

Safety engineering research can superficially be divided into two groups. One group points out the weaknesses with today methods, and demands totally new approaches. This will be close to argue for a paradigm shift. The other group develop further the existing methods. There are several arguments for the need for a new approach as, e.g., brought to the fore by (Leveson, 2004):

- Technology is changing faster than the engineering techniques to cope with the new technology are being created. Digital technology has created a quiet revolution in most fields of engineering, but system engineering and system safety engineering techniques have not kept pace. Digital systems introduce new 'failure modes' that are changing the nature of accidents.
- New types of hazards: The most common accident models are based on the underlying assumption that accidents are the result of an uncontrolled and undesired release of energy or interference in the normal flow of energy. Our increasing dependence on information systems is, however, creating the potential for loss of information or incorrect information that can lead to unacceptable physical, scientific, or financial losses.
- Complexity has many facets, most of which are increasing in the systems we are building, particularly interactive complexity.
- More complex relationships between humans and automation: humans are increasingly sharing control of systems with automation and moving into positions of higher-level decision making, with automation implementing the decisions. These changes are leading to new types of human error.

Another example is given in (Rasmussen, 1997), where it is explained that the stage for an accidental course of events very likely is prepared in time through the normal efforts of many actors in their respective daily work contexts, responding to the standing request to be more productive and less costly. Ultimately, a quite normal variation in somebody's behaviour can then release an accident. Had this 'root cause' been avoided by some additional safety measure, the accident would very likely be released by another cause at another point in time. In other words, an explanation of the accident in terms of events, acts, and errors is not very useful for the design of improved systems.

On the other side, there are several projects related to the further improvement of exciting methods like including human and organizational factors into PSA. Examples from the nuclear and airfare industry includes MACHINE (Embrey, 1992), WPAM (Davoudian et al., 1994), SAM (Elisabeth Paté-Cornell and Murphy, 1996), Omega Factor Model (Mosleh and Golfeiz, 1999), I-RISK (Oh et al., 1998; Papazoglou et al., 2003), ISM (Wreathall et al., 1992), ARAMIS (de Dianous and Fiévez, 2006; Delvosalle et al., 2006; Salvi et al., 2001), and Causal Modelling of Air Safety (Ale et al., 2006). With respect to PSA in the offshore industry, ORIM (Øien, 2001), BORA (Aven et al., 2006; Sklet et al., 2006), and OTS (Vinnem, 2008b; Vinnem et al., 2007) are relevant. Common among these are the following parts: (1) a set of organizational factors; (2) a link to the system risk model; (3) a set of modelling techniques; and (4) a set of measurement methods (Mohaghegh et al., 2009).

High-reliability theory is a organizational theory related to accident prevention and risk management (LaPorte and Consolini, 1991; Roberts and Bea, 2001). A high reliability organization (HRO) is an organization that has succeeded in avoiding major accidents in an environment where normal accidents can be expected due to risk factors and complexity. There are several characteristics related to being HRO. One is that they aggressively seek to know what they don't know (Roberts and Bea, 2001). This is an important element both related to the OMT method as well as to resilience engineering. The use of models is important in the OMT method for seeking that which is not completely known.

2. CENTRAL ELEMENTS

2.1 Modelling

Conceptual modelling is the process of formally documenting a problem domain for the purpose of understanding and communication among stakeholders. Conceptual modelling is an important part of the OMT method and can be developed using: theory (deductive), experience (codification), observation (inductive), consensus (social), synthesis (analytical), derivation (reverse inference), the goal-question-metric model, and Dromeys methodology (Moody, 2005).

Resilience engineering states the need for new models, and uses accident investigations as example. Most accident models appeal to a kind of exclusivity of the factors and activities (or how they interact) that lead up to an accident. The idea is that the organizational work (or the organizational structure that exists) preceding an accident is somehow fundamentally or at least identifiably different from that which is not followed by an accident. Thus, accidents require their own set of models if people want to gain predictive leverage. Accident models are about understanding accidents, and presumably about predicting them before they happen. But if success and failure stem from the same source, then accident models are either useless, or as useless (or useful) as equally good models of success would be. According to resilience engineering the problem is that we do not have many good models of operational success, or even of normal work that does not lead to trouble (Dekker, 2006).

Accepting a specific model not only has consequences for how accidents are understood, but also for how resilience is seen. In a simple linear model, resilience is the same as being impervious to specific causes; using the domino analogy, the pieces either cannot fall or are so far apart that the fall of one cannot affect its neighbours. In a complex linear model, resilience is the ability to maintain effective barriers that can withstand the impact of harmful agents and the erosion that is a result of latent conditions. In both cases the transition from a safe to an unsafe state is tantamount to the failure of some component or subsystem and resilience is the ability to endure harmful influences. In contrast to that, a systemic model adopts a functional point of view in which resilience is an organization's ability to efficiently adjust to harmful influences rather than shun or resist them. An unsafe state may arise because system adjustments are insufficient or inappropriate rather than because something fails. In this view, failure is the flip side of success, and therefore a normal phenomenon. Resilience engineering devotes effort to make observable the organization's model of how it creates safety, in order to see when the model is in need of revision (Woods, 2006).

The idea behind the OMT method and models is that by modelling normal operations and their potential for hazardous situations that are constrained by barriers, one has a model that both shows the way to success just as much as to failure. The models in the OMT method show how the barriers and RIFs influence each other and thereby how flexible one may be, while still remaining within the field of safe operations. In addition to generic risk models, there are also risk influence diagrams and sequentially timed events plotting (STEP)-diagrams. The OMT method uses models that are theory- and experience-based to illustrate in what way good practice in the form of barriers can ensure safe operations. These models are largely the same as those used previously in the field of risk analysis, but combined and structured in a new way. Common risk analysis taxonomy contains a large number of expressions like risk modelling, cause and consequence modelling, stochastic modelling, system models, and probability models. In general, a model is a simplified representation of a selected aspect of a complex reality.

Models applied within risk analysis are mathematical models and enable predictions of future properties of defined systems to be made. Descriptions of uncertainty related to the quantities at a low system level are transformed into uncertainty measures of overall outcomes by means of models representing causal coherence in the system studied. In risk analyses, like the OMT-method, the extent to which potential undesirable consequences threaten the performance of a given activity is quantified by constructing and analyzing a model. The model constitutes a simplified representation of the real system, reflecting the causal relations that produce the events focussed on by the decision-makers. The complexity of the model is governed by several factors, such as the complexity of the system, the knowledge about the system that is available to the risk analysis team, the amount of information the decision-makers consider a sufficient basis for making the decision in question, and the resources available to the analysis team. The conception of 'model uncertainty' is commonly related to deviations of the simplified representation in a model from the real world it represents. When analyzing complex systems in real life, compliance of the properties of the system being analyzed with the model assumptions never exists in an absolute sense. In most cases, the question is rather whether the model can be accepted in spite of reality's infringing one or more of the conditions underlying the model (Nilsen and Aven, 2003).

The OMT method earlier used linear models but is now testing the use of Bayesian thinking, where the focus is on so-called observable quantities, that is, quantities expressing states of the 'world' or nature, which are unknown at the time of the analysis but will (or could) become known in the future; these quantities are predicted in the risk analysis and probability is used as a measure of uncertainty related to the true values of these quantities. The emphasis on these principles gives a framework which is easy to understand and use in a decision-making context (Aven and Kvaløy, 2002).

2.2 Barriers

In the OMT-method, modelling of safety barriers is a central part. Safety barriers are defined as physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents. The means may range from a single technical unit or human actions, to a complex socio-technical system. It is useful to distinguish between barrier functions and barrier systems. Barrier functions describe the function of preventing the realization of a threat, or of reducing damage potential. Barrier systems describe a set of MTO related actions that will provide the planned barrier function. If the barrier system is functioning, the barrier function is performed (Sklet, 2005). 'Barrier' does also play a part in resilience engineering. Barriers are an effective means against known risks, a way to prevent unwanted events from taking place and to protect against their consequences. Yet barrier design must not become entirely reactive, since in that case safety will become a game of constant fire fighting or catching up. Safety cannot genuinely be improved only by looking to the past and taking precautions against the accidents that have happened. Safety must also look to the future. It must be proactive, although that requires taking a risk—the unwanted outcome being that nothing untoward happens and that the investment therefore is not matched by tangible results (Hollnagel, 2008).

Effective barriers normally rely on a mixture of barrier systems, with the possible exception of some physical barrier systems. Several barriers may also be used together to increase the robustness, not least for safety-critical applications. Typical examples are the use of defense-in-depth. Having more than one level of barriers obviously reduce the probability that an accident will happen, although it can never completely eliminate it. As an overriding concern, it is important to be able to assess the vulnerability of the barriers that are put in place as well as how they may fail—singly or in combination. System design and risk assessment do that by identifying how barriers may, potentially, fail, i.e., what the weaknesses of the system are (Hollnagel, 2008).

The barriers that are surveyed in the OMT method are, to a large extent, barriers that are crucial for the system to function as well as for avoiding failure. The human and organizational barriers are defined in six performance standards (PSs).

Table 1. PS in OMT-method

Work practice	The complexity of the given task, how easy is it to make mistakes, best practice/normal practice, check lists and procedures, silent deviations, control activities
Competence	Training, education—both general and specific, courses, system knowledge, etc.
Communication	Communication between stakeholders in the process of plan, act, check and do
Management	Labour management, supervision, dedication to safety, clear and precise delegation of responsibilities and roles, change management
Documentation	Data based support systems, accessibility and quality of technical information, work permit system, safety job analysis, procedures (quality and accessibility)
Work schedule aspects	Time pressure, work load, stress, working environment, exhaustion (shift work), tools and spare parts, complexity of processes, man-machine-interface, ergonomics

By doing barrier-analysis in the OMT-method, one ensures knowledge about the latitude for safe operations. The OMT method does, to a large extent, focus on barriers that are flexible.

2.3 Multidisciplinary approach

Both the OMT method and resilience engineering emphasize the need for a multidisciplinary approach within safety engineering. According to Wreathall, there are seven themes in highly resilient organizations (Hollnagel et al., 2006):

Top-level commitment: Top management recognizes the human performance concerns and tries to address them, infusing the organization with a sense of the significance of human performance, providing continuous and extensive follow-through to actions related to human performance, and being seen to value human performance both in word and deed.

Just culture: Supports the reporting of issues up throughout the organization, yet not tolerating culpable behaviours. Without a just culture, the willingness of the workers to report problems will be much diminished, thereby limiting the ability of the organization to learn about weaknesses in its current defences.

Learning culture: A shorthand version of this theme is 'How much does the organization respond to events with denial versus repair or true reform?'

Awareness: Data gathering that provides management with insights about what is going on regarding the quality of human performance at the plant, the extent to which it is a problem, and the current state of the defences.

Preparedness: 'Being ahead' of the problems in human performance. The organization actively anticipates problems and prepares for them.

Flexibility: This is the ability of the organization to adapt to new or complex problems in a way that maximizes its ability to solve the problem without disrupting overall functionality. It requires that people at the working level (particularly first-level supervisors) are able to make important decisions without having to unnecessarily wait for management instructions.

Opacity: The organization is aware of the boundaries and knows how close it is to 'the edge' in terms of degraded defences and barriers.

As seen in Table 2, the multidisciplinary principles are all covered by different performance standards (Table 1) in the OMT-method.

Table 2. Seven themes of RE and PS in OMT method

Resilient organization (Hollnagel et al., 2006)	**Performance standards in the OMT method (Vinnem, 2008b)**
Top-level commitment	Management, communication, documentation, work schedule aspects
Just culture	Documentation, management, work practice,
Learning culture	Documentation, management, work schedule aspects
Awareness	Documentation, competence, management, work practice
Preparedness	Documentation, competence, management, work practice
Flexibility	Work practice, competence, communication, management, work schedule aspects
Opacity	Management, work practice

3. DISCUSSION

According to resilience engineering, traditional safety management assume that performance conditions can be completely specified, but in fact performance conditions are always underspecified (Hollnagel et al., 2006). The OMT method does not state that the model is a 'true' simplification of the real world, but that using that model is a technique for describing connections and a useful tool for risk control and risk communication. Both methods share the view that in some very safe systems, incident reporting no longer works well, as it makes a number of questionable assumptions that no longer seem to be valid. The most common assumption is linked to the iceberg theory, and has proven its weaknesses. Even so, when there is a strong link between precursor incidents and the possibility of major accidents, like for example the reported number of gas leaks, and the potential for major hazard. Modelling of the link between root causes, precursor incident and potential consequences can be a powerful tool for better understanding and further improvements. Even simple models like fail trees, event trees, cause and effect and 'bow-ties' can be important tools to understand the potential in an incident and how human and organizational factors influence in the sequence.

In the OMT-method, models are used to give a simplified description of a physical system intended to capture the essential aspects of the system in a sufficiently simple form to enable the mathematics to be solved. The models require approximation techniques to be used. It can be argued that complexity cannot be quantified and assessed by risk analysis. If risk analysis is to be understood in terms of some kind of true risk equation such arguments makes sense, but in practice models require approximation techniques to be used, and will never be exactly soluble. The models used in the OMT method will never be complete. They can be useful in a risk management context, and in resilience engineering management. The OMT method is about revising risk models, as pointed out as needed by the believers in resilience engineering. Even though the OMT method includes technical, human, and organizational factors, it will only be an element in risk management as part of safety engineering. By combining different modelling techniques, the OMT method can give a more holistic and functional description of a system.

The development of models involves the trading off of complexity (to provide a satisfactory representation of the system under study) against the simplicity (required for making an analysis feasible). Despite the simplifications and inaccuracies necessarily introduced in this process, the results from the analysis of models can make a valuable contribution to the informational basis of decision-making as part of safety engineering.

Both resilience engineering and the OMT method recognise that new knowledge is needed to further improve safety. They both point out the need for multidisciplinary understanding. The ability to succeed under varying conditions can only be understood by analyzing organizational, human, and technical barriers; their interfaces and influence; and their summation as being dynamic and complex. Major hazards risk potential is the central element in the OMT method and not occupational accident or less severe accidents. This is an important difference in comparison to several other methods that also focus on human and organizational factors. Control over major hazards forms the basis for the method, and a pilot study showed that the results would have been different if one had also included general safety culture and occupational accidents (Vinnem et al., 2007). Experience from several large accidents—for example, Longford (Hopkins, 2000) and Texas City (Baker et al., 2007)—has also shown that a focus on occupational accidents does not necessarily reduce the risk of large accidents. This view is shared by the viewpoint of resilience engineering that disapproves of the metaphors that inspire and justify incident reporting (e.g., the 'iceberg', the 'Swiss cheese'). These models assume that there is a linear progress of breakdowns (a domino effect) that either gets stopped somewhere (constituting an incident) or not (creating an accident).

It can be questioned whether resilience engineering is a new paradigm within safety research, meaning that it contributes new conceptual world-views that consist of formal theories, classic experiments, and trusted methods within safety research. If so, it is interesting to see that using 'old' methods, as in the OMT-method, one has very much the same elements. Both methods do stress the need for a more holistic view, where human and organizational factors are included, and by this they share a principal. This demands a more multidisciplinary approach to safety engineering, leading to closer collaboration between different branches of the sciences.

4. CONCLUSION

The OMT method is based on the idea that by combining existing knowledge on a multidisciplinary level, further improvement can be achieved. The existing safety models need adjustments and new combinations based on multidisciplinary knowledge, and thereby it is not about a new paradigm within safety. In the OMT method research related to barriers and modelling is central. As shown earlier, barriers and modelling are also important elements in resilience engineering, and it is the use of these elements, and not the elements themselves that are problematic. Modelling is an effective tool, but it has to be used in the right context, and its weaknesses also have to be addressed. It is the same with barriers. The OMT method does to a large extent focus on barriers that are flexible. An organization that scores well on the performance standards will probably also be well prepared to cope with new hazards, and in that way be resilient. The OMT method and resilience engineering share the principle that new knowledge is needed for further improvement within safety engineering. The approach for achieving this knowledge is different but central elements as modelling, barriers and multidisciplinary approach are shared.

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