Safety Science 48 (2010) 950–956

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Is there a need for new theories, models and approaches to occupational accident prevention?

Jan Hovden [a,*], Eirik Albrechtsen [a,b], Ivonne A. Herrera [c]

[a] Dep. of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[b] Dep. of Safety Research, SINTEF Technology and Society, Trondheim, Norway
[c] Dep. of Production and Quality Engineering, Norwegian University of Science and Technology, Trondheim, Norway

ARTICLE INFO

Article history:
Received 19 January 2009
Received in revised form 7 May 2009
Accepted 26 June 2009

Keywords:
Accident model
Occupational accidents
Systemic accidents

ABSTRACT

This paper discusses occupational accident modelling challenges associated with a changing working life, and asks whether ideas from models developed for high-risk, complex socio-technical systems can be transformed and adapted for use in occupational accident prevention. Are occupational accidents mainly simple component failures or is a systemic approach to the phenomenon of some interest and value?

1. Introduction

The aim is to invite to a discussion about theories and models in the field of occupational accident prevention. Is the current knowledge base satisfactory, or is there a need for inspiration and approaches taken from other fields of risk research? Is there a need for radical changes, for modification of traditional approaches and knowledge bases; or do the problems of occupational accident prevention mainly amount to a question of priorities, resources and implementation of known remedial actions?

The intention is not to give clear and finite answers to these questions. Rather, the paper invites to reflections on the needs for and uses of accident models in occupational accident prevention through: (1) a brief review of established, mainstream accident models applied in this field; (2) a description of changes in working life with possible impacts on the need to rethink the paradigms for accident modelling and safety management approaches; (3) a brief review of new theoretical approaches to high-risk complex socio-technical systems; and (4) a discussion of the purposes and functions of occupational accident models in a new context which takes into account the impact of economic, political, organisational, and technological stressors on safety performance.

A delimitation: Approaches to technical risk analysis are not dealt with, and systemic models are presented only briefly and discussed solely in relation to their relevance for occupational accidents. The discussions are primarily based on today's situation in the Nordic countries both with regard to safety management practices and the associated challenges, thus defining the scope of the paper. A common basis for a Nordic framework for occupational accident prevention is described by the Finnish Institute of Occupational Health (1987).

2. Background – the established models in occupational accident prevention

Accident definitions converge in certain assumptions which describe an accident as a hazard materializing in a sudden, probabilistic event (or chains of events) with adverse consequences (injuries). Classification is used as a tool to standardise the collection and analyses of data on accidents. There are four main standard categories (Kjellén, 2000):

– *Damage/loss:* includes injuries and fatalities, material and economic losses, reputation, etc.
– *Incident:* subdivided into Type (fall, slip, explosion, etc.) and Agency (machine, vehicle, tool, etc.).
– *Hazardous condition:* covers defective tools, unsafe design, housekeeping, etc.
– *Unsafe act:* covers errors and omissions.

In addition, accidents can be categorised according to arena, i.e. where the accident happens, the type of activity involved, system characteristics, etc. The ESAW methodology for statistics on

* Corresponding author. Address: NTNU, IOT, NO 7491 Trondheim, Norway. Tel.: +47 73 59 35 07; fax: +47 73 59 31 07.
E-mail address: hovden@iot.ntnu.no (J. Hovden).

0925-7535/$ - see front matter
doi:10.1016/j.ssci.2009.06.002

accidents at work (European Commission, 2001) present a characterisation of variables which is representative for an epidemiological approach to occupational accident data and statistics; e.g. properties of the enterprise, exposure and employee, organisation and workplace, working conditions, sequence of events, and the victim. *Occupational accidents* are distinguished from other accidents by the facts that they happen in a working life context and that the main consequences are limited to injuries on the involved workers. Furthermore, the worker is often the agent as well as the victim of the injury. Injuries are classified according to the nature of the injury (cut, fracture, burns, etc.), the part of the body affected by it (head, neck, etc.), and its severity.

Most accident models and theories applied in the field of occupational accidents are still based on the ideas in Heinrich's (1931) domino model, Gibson's (1962) and Haddon's (1968) epidemiological models of energy-barriers, and are using a closed system safety mindset with mechanistic metaphors to describe the conditions, barriers and linear chains of an accident process. In the 1960s and 1970s there was typically a focus on technical faults and human errors (Kjellén and Hovden, 1993).

Competing modelling approaches evolved: (1) causal sequences similar to the domino model, e.g. ILCI (Bird and Germain, 1985), (2) descriptive models of accident processes in terms of sequentially timed events and/or phases, e.g. STEP (Benner, 1975; Hendrick and Benner, 1987), and OARU (Kjellén and Larsson, 1981), (3) system models based on a mixture of causal sequences and epidemiological models, e.g. TRIPOD, and the "Swiss cheese"model (Reason et al., 1988; Reason, 1997; Reason, 2008), (4) logical, risk analysis inspired models, e.g. the fault three based MORT method (Johnson, 1980) and the similar SMORT method (Kjellén, 2000) tailored for occupational accident investigation. In recent years technical risk analysis modelling has also been used for quantifying occupational accident risks (Ale et al., 2008). Systemic accident models are mainly within the domain of major accident risk research and will be presented in part 4. There are many ways of classifying accident models, and the grouping above is a mixture of Kjellén (2000) and Hollnagel (2004). Epidemiological models are mainly used in statistical accident reporting systems for monitoring safety (Andersson, 1991), whereas more complex models are used in in-depth accident investigations.

The 1980s was the era of creative occupational accident modelling activities, and a number of different occupational accident models were developed in the Nordic countries in addition to OARU, such as a Finnish model (Touminen and Saari, 1982), and a Danish one (Jørgensen, 1985). For a review of accident models, see Kjellén (2000), Leveson (2001), Sklet (2004), and Lundberg et al. (in press). As a reaction to all these efforts in accident modelling, Hovden (1984) asked provocatively, "Do we need accident models?" at the yearly Nordic conference in accident research,[1] questioning the utility of these analogue models of boxes and arrows in relation to the progress of safety science and improved accident prevention in industry. The pessimistic conclusion was that the models were not scientific enough, or practical enough, and neither were they specific enough, nor holistic enough to serve this purpose.

Andersson's (1991) work on the role of accidentology in occupational injury research discusses classifications of accident theories and models and revealed a split between traumatology and epidemiological approaches on one side, and technological and cross-disciplinary approaches on the other. The history of accident modelling is very much about a positioning on model power between different disciplines, with technologists, psychologists, other social scientists and so on claiming to be holistic and cross-disciplinary in their combining of human factors, technology and organisational aspects, while combining these according to their own biased mental models.

From the mid-eighties the focus changed from accident modelling to an interest in management tools for safety monitoring and safety auditing (Kjellén and Hovden, 1993). Hale and Hovden (1998) described management and culture as the third age of safety. The first age was preoccupied with technical measures, whereas the second focussed on human factors and individual behaviour (Hale and Glendon, 1987). The latter was influenced by ergonomics and later merged with the technological approaches. In the 1980s the socio-technical approaches based on the Tavistock School, which had a long tradition in working environment studies, influenced accident modelling. During the same period large international companies such as DuPont became role models for many companies through their focus on management responsibility, workers' behaviour, and safety performance indicators based on incident reporting.

"The three ages of safety" (Hale and Hovden, 1998) are about an expansion of perspectives on accident phenomena. The perspectives are not substituting each other, but supplement each other. Technical safety is still important, and human factor research methodological development on accident risks has – also flourished the last decades, e.g. HERMES, ATHEANA, CREAM – for a review see Hollnagel (1998). This review of approaches to accident modelling and prevention must necessarily be brief. Nevertheless, it reveals a great variety of perspectives on accident phenomena and preventive strategies: we find what we look for, and fix what we find (Lundberg et al., in press). However, do the dominant occupation accident models and approaches provide good enough understandings of current and future challenges of occupational accident prevention in a changing working life environment?

3. Changes in working life

Wilpert (2009) presents a comprehensive discussion of the impact of globalization on human work. He describes the impact of new information technologies, changing work structures in industrialized countries and changing industrial relations systems. In a report from the European Agency for Safety and Health at Work (Op de Beek and Van Heuverswyn, 2002) the changes are listed as: (1) changing industrial organizations, (2) the free market, privatization, downsizing, subcontracting, (3) technology, (4) the growing use of remote operations, homework, changes in working hours, work pace and workload, (5) changing labour market with an increase in part-time jobs, temporary work, self-employment, women in employment, the ageing of the workforce, etc. According to that report the emerging risks of the changes should be met by a dynamic safety management system emphasizing participation, leading performance measurements, communication and life-long learning.

In their process of coping with accident risks, the levels and layers within organisations are subjected to stress from a number of external forces and counter forces. The main contextual stressors influencing working life risks are changing political climate and public awareness, market conditions and financial pressures, competence and education concerns, and the fast pace of technological change (Rasmussen, 1997). Adaptation to these stressors has changed the everyday reality of work, the contents of work processes and the socio-technical systems at traditional workplaces.

At the microlevel, or "the sharp end", very little has changed in manual work tasks: climbing a ladder at a construction site or performing maintenance work in a chemical plant has not become complex, dynamic or intractable. However, does the increased

[1] These Nordic conferences (NOFS) were a precursor to the WOS conferences.

use of information and communication technologies as integral parts of manual work and the construction of new, distributed industrial organisations change the characteristics of the work in such a way that alternative approaches to accident prevention are needed?

The use of information systems creates new types of communication, improved ability to store and retrieve data and more effective information processing, and all of these factors influence the modern organisation of work (Groth, 1999). New developments in these areas create advantages such as the automation of work processes, more effective planning and communication, and improved employee availability. However, the "information revolution" also creates pitfalls such as information overload, high demand for information, and communication problems. Example No. 1 below shows an example of how information technology can influence occupational safety both positively and negatively in relation to sharp-end activities.

Example No. 1: Monitoring work performance at offshore installations

Within the Norwegian oil and gas industry, there is an ongoing transition to the concept of integrated operations, i.e. the use of information technology and real-time data to improve decision-making processes and cooperation across disciplines and organisations. One of the implications of this development is increased monitoring of offshore workers. This implies that operators onshore can watch offshore workers' performance by use of camera equipment and monitors. On the one hand, this creates a secure and safe environment, as offshore workers' performance is monitored by a 'watchful eye', making it possible to prevent and stop unwanted actions. It also provides offshore workers with decision support from onshore experts. On the other hand, monitoring may lead to workers feeling uncomfortable at being evaluated all the time and even result in a sense of mistrust.

Globalization has also reached working life today. A study performed for the Norwegian Labour and Welfare Administration shows that one out of three Norwegian companies used manpower from the EU countries in 2007. Sectors which have traditionally had a high rate of occupational accidents top the statistics for use of foreign manpower: primary industries (58% have used foreign manpower), hotels and restaurants (49%), manufacturing, and the building and construction industry (both 43%). Half of the foreign workers were hired on temporary contracts. Swedish and Polish workers are the most widely used foreign nationality workers in Norway (Perduco, 2007). On the one hand, this work immigration provides much needed labour and expertise; but on the other hand, it also creates challenges in relation to occupational accidents (See example 2), as well as working environment challenges regarding social rights. Mearns and Yule (2009) have studied occupational safety and how globalization process affect attitudes, beliefs and behaviour of "national" workforces for multi-national companies. The study remarks that management commitment is a more important determinant of behaviour than national culture. Thus organisational issues like management and leadership emerge as important for safety performance also in a new context of working life.

As a result of the impact of information technology, globalization and a dynamic post-industrial society, work is organized in new ways. For industrial workplaces, automation is an evident change to the organizing of the work (see example 3). However, Zuboff (1988) argues that the impact of information technology is dual: it both automates and informates the organisation. It automates manual activities and it generates information about underlying productive and administrative processes, which can be used to understand, improve and plan activities. For example, an organisation is informed by access to data and information that produce new ways of achieving more effective planning, as well as faster input to safety methods and tools. The informated organisation, i.e. an organisation that utilizes the benefits of information technology, occurs in many configurations (Groth, 1999), such as car manufacturing with its tight cooperation with subcontractors based on just-in-time principles.

Example No. 2: Language barriers creating an occupational accident

At a Norwegian chemical plant, a Finnish welder was hired from a contractor to stop a leakage from a pipe containing lye. Due to language problems, the Finnish welder misconceived the mission and thought is was an air pipe that was to be repaired. As a consequence, the welder failed to wear the necessary protective equipment for the job, putting on only a mask and gloves. While preparing to fix the leak, the welder discovered that a green liquid was coming out of the pipe, and only then understood that he was dealing with a chemical liquid. During his search for the leakage, drops of lye landed on his neck. He reacted to the drops by touching his neck with his gloves, which had already been in contact with the lye.

Example No. 3: Automation of manual work

A study of occupational accidents and costs in the Norwegian furniture industry revealed that automation of the production line reduced the number of injuries, especially the cutting of fingers, but that maintenance and handling of disruptions resulted in more severe injuries, e.g. the amputation of arms.

As part of the wave of globalization, we see a trend of deregulation and new concepts in business administration related to profit, time and cost cutting. These concepts include capital cost reduction, outsourcing, downsizing, management, contracting, leasing, strategic alliances, joint venture/partnership, enterprises in network, lean production, just-in-time (Kanban), business process re-engineering, flexible specialization, and virtual organizations, plus learning organizations, knowledge management, and change management. Example No. 4 shows an example of complex organisation of work resulting from new contexts and types of organisation. The question here is how these new realities fit into occupational accident models, and how they are considered and dealt with by the safety management.

Four elements are identified in relation to subcontracting and occupational safety (Mayhew et al., 1997). The first is related to economic pressures, where occupational safety interventions are not usually perceived as good investments. The second is disorganization, leading to a fragmentation of work place where major firms produce specific safety manuals having little or no effect on subcontractors. The third is dealing with inadequate regulatory controls. Regulations primarily deal with a traditional, stable employer/employee relationship in mind and not addressing the issue of small organizations pressured by time and costs, and changing frequently work site. The increased use of outsourcing is a challenge for regulation and control. Finally, the fourth element addresses the ability of workers to organize. Self-employed workers do not normally unionize and address compensation claims. Their injuries and illness are not properly recorded. This has an implication on the visibility of subcontracting/outsourcing on occupational safety performance.

Example No. 4: Complex organisation of maintenance work
Maintenance activities in aviation are typically spread over multiple locations, the task complexity varies, the working environment is non-optimal (in terms of light, access, noise), working times differ, downsizing, increase of subcontracting and seasonal recruitment are common. Several programmes have been introduced to improve worker and operational safety. In aviation, there is still a need to take a more realistic approach; one that considers human behaviours and decision-making processes in operational contexts. A proposed solution is to monitor normal operations. This monitoring introduces the challenge of negotiating between approaches that decompose data into quantitative factors and those that use interpretation of qualitative data to increase the understanding of normal performance.

Working life has changed along with the transformation of the stable industrial society of former times into the dynamic knowledge society of today. Post-industrial working life is characterized by provision of services, handling of information, and knowledge-intensive work. While the industrial society was perceived as stable, the post-industrial society is dynamic, with its technological development, international competitions, efficiency demands and changes. This implies that the post-industrial organisation of work is different from that of industrial bureaucratic organisations. Some examples of changes in different types of work include, by industry:

- *Craft industries*: in general, more mobile phones, more foreign workers, automated tools replace hammers and saws, etc.
- *Manufacturing*: increased automation (see Example No. 3).
- *Farming and fishing*: less manual work, increased production volumes and energy consumption.
- *Process and petroleum industry*: increased automation, integrated operations.

Types of industrial systems and context of which they operate have changed. Leveson (2004) enumerate changes on systems that are stretching the limits of current models and safety analysis techniques. Changes affecting the working life are the fast pace of technological changes, the changing nature of accidents, new types of hazards decreasing tolerance to single accidents and changing regulatory and public view on safety. Beyond these changes, work place accident prevention has also been affected by organisational changes. Even if prevention of occupational accidents is adequate, the introduction of innovations and organisational changes may have an impact in the way safety practice is carried out. Traditional firms implement changes without systematic consultation of workers. Workers in successful modern firms where major technological and organisational changes are introduced seem to be more involved in the improvement of their working condition (Harrisson and Legendre, 2003).

The world economy has been through a long period of revival which now has turned into a recession. ILO asks: "Will the financial crisis push us back in the struggle for safer and healthier workplaces?" (Al-Tuwaijri, 2009). The research literature on the effects of economic cycles on occupational safety seems scarce. But the research field of road traffic accidents tells that safety increase in recessions more than the effects of the decrease in exposure (Wilde, 1998).

To sum up, technologies, knowledge, organisations, people, values, and so on are all subject to change in a changing society. Nonetheless, when it comes to occupational accident prevention most experts and practitioners still believe in the domino model and the iceberg metaphor (Heinrich, 1931; Bird and German, 1985; Hale, 2000).

4. New approaches to safety in complex and dynamic socio-technical systems

In view of the changes briefly described above and the challenges of vulnerability in complex, dynamic socio-technical systems, theories and models have evolved in relation to the high-risk industries and in transportation. There is some overlap between these theories, and our intention here is restricted to highlighting some key elements and possible lessons to be learned and applied in the field of occupational accidents. Two prominent schools which have addressed the organisational aspects of safety are Normal Accident Theory (NAT) and High Reliability Organisation (HRO) theory.

NAT (Perrow, 1984) introduced the idea that in some systems accidents are inevitable and normal. Such system accidents involve *the unanticipated interaction of multiple failures.* NAT presents a two-dimensional typology of socio-technical systems based on degree of interaction and couplings. Perrow uses these two dimensions in a two-by-two table to indicate that different systems may need different ways of organizing. If the system is both interactively complex and tight coupled, there is no possibility for identifying unexpected events, and the system should be abandoned. In such systems, simple, trivial incidents can develop in unpredictable ways with potentially disastrous consequences. The changes in working life, as described above in part 3, have resulted in increased safety, but also increased vulnerabilities at most workplaces over the last twenty years. Therefore, it may be important to reduce interactive complexity and tight coupling in the design of workplaces. Bellamy and Geyer (1992) argue that in the new work environment there are too many tightly coupled and complex systems to be abandoned as Perrow recommend. Perrow (2007) discusses safety potential of an alternative model for organisation, the "Network of small firms". In this model the dependencies are low, with multiple sources, and single, unexpected failures will not disrupt interdependencies since other firms can change or absorb the business. The decentralized nature of small firms has positive and negative effect on safety. The small firms require good safety practice towards client requirements. On the other hand these firms have limited resources for occupational safety investments.

HRO researchers claim to counter Perrow's Normal Accident Theory (LaPorte and Consolini, 1991). HRO theory is based on studies on organisations that successfully handle complex technologies. The cost of failures in such organisations is socially unacceptable. The main characteristics of HROs include managing of complexity through: (1) continuous training, (2) use of redundancy, and (3) numerous sources of direct information. Furthermore, HROs rarely fail even if they experience unexpected events (Weick and Sutcliffe, 2007). They redefine HROs as 'mindful' organisations. Organizing for high reliability requires continuous anticipation and containment in the running of the organisation. A mindful organisation operates according to the following three principles for anticipation: (1) an ability to become aware of unexpected events through preoccupation with failures, reluctance to simplify, and sensitivity to operations; (2) commitment to resilience (involving abilities to absorb and preserve, to recover and to learn); and (3) deference to expertise (migration of decision-making to the levels were people come together to solve a problem).

Some researchers argue that the HRO approach does not contradict or falsify NAT at all because the conclusions of the HRO theory are based solely on a few case studies which do not fulfil Perrow's definition of complex interactivity or of tight coupling (Marais et al., 2004).

In an information processing perspective, the accident is viewed as a breakdown in the flow and interpretation of information

(Turner, 1978). This perspective highlights how the individuals and the organisation perceive and make use of information. A key point is to establish how information and knowledge are related to the accident and how misinformation may arise. The model includes factors such as wrong interpretation of signals, information ambiguities, disregard for rules and instructions, and overconfidence and organisational arrogance. A response to this perspective was the description of how organisations treat information in a (1) pathological, (2) bureaucratic, and (3) generative way (Westrum, 1993). This also became a basis for classifying and ranking safety cultures (Reason, 1997).

Rasmussen (1997) directs the attention to the migration of activities towards the boundary of acceptable performance – a migration which is influenced by the pressure towards cost-effectiveness in an aggressive and competitive market. He argues that it is feasible to provide the necessary decision support to operators, and proposes a distributed decision-making system in order to cope with the dynamics of modern organisations. He also recommends studying normal work processes rather then focusing on deviations, errors and incidents. Rosness et al. (2004) point out that in the migration model, regulations and procedures keep the actors within the boundary of safe operation and prevent conflicts between activities when decision-making is distributed.

From the classical definition of safety as freedom from unacceptable risk, through safety seen as a dynamic non-event (HRO), to the ability to predict, plan and act to sustain continuous safe operation, the Resilience Engineering school presents an alternative or supplementing perspective, claiming that instead of focusing on failures, error counting and decomposition, we should address the capabilities to cope with the unforeseen. The ambition is to "engineer" tools or processes that help organisations increase their ability to operate in a robust and flexible way.

Hollnagel et al. (2006) define resilience engineering as the "intrinsic ability of an organisation (or system) to adjust its functioning prior to or following changes and disturbances to continue working in the face of continuous stresses or major mishaps". The premises of this definition are the following: (1) the increase of complexity has made the systems intractable, and therefore under-specified; (2) people are seen as an asset because they are flexible and can learn to overcome design flaws, they can adapt to meet demands, interpret procedures, detect and correct when things go wrong, and use "requisite imagination" (Westrum, 1993) to cope with the unexpected; and (3) systems balance efficiency and thoroughness to meet demands. Hence resilience engineering encompasses research on successes and failures in socio-technical systems, organisational contributions and human performance. A systemic view is encouraged in order to understand how the system as a whole dynamically adjusts and varies for the sake of continuing safe operations. The focus is on the proactive side of safety management and the need to make proper adjustments in terms of anticipation, updating of risk models and effective use of resources.

People, organizations and technology are under continuous change. Do these changes represent a growing complexity in the working life? As a parallel to Perrow's description of complexity and tight coupling, Hollnagel (2008) proposes the concepts "tractable" and "intractable": a system, or a process, is tractable if the principles of functioning are known, if descriptions are simple and with few details, and most importantly if the system does not change while it is being described. Contrary, a system or a process is intractable if the principles of functioning are only partly known or even unknown, if descriptions are elaborated with many details, and if the system may change before the description is completed". Accident models and theories provide different "glasses" that will influence the way we look for, understand, analyse and provide recommendations.

5. Discussion

Can theories from the domain of high-risk complex and advanced socio-technical systems such as the ones advocated by Perrow, Rasmussen, Weick, Hollnagel and others contribute to better understandings and practices in relation to preventing traditional and often seemingly simple and trivial occupational accidents? Do they have something substantial to add to this area, or do they represent a different world of risk problems?

These questions cannot be answered with a simple yes or no. The traditional approaches may be good enough; suited to some workplaces but not to others, and suited to understanding some accidents but not others. In occupational accident prevention most problems may be solved by looking at simple, direct causes and triggering events. In most industrial domains, there is a high potential for achieving low injury rates through continuous work to improve performance through deviation control. Saari (2001) states that humans tend to underestimate known risks and overvalue new risks. Still falls cause a large proportion of fatalities at workplaces, but are old and well known.

The need for new models can therefore be considered as low in the daily work of accident reporting and surveillance. Merely identifying a proximate cause as the "root cause" may, however, lead to the elimination of symptoms without much impact on the prospect of reducing future accidents (Marais et al., 2004; Leveson, 2004). In order to identify systemic causes, one may need to supplement with models representing alternative mindsets in order to spark the imagination and creativity required to solve the accident risk problem.

The use of accident models can be discussed in a framework of learning loops at different levels (Freitag and Hale, 1997). At the sharp end, i.e. the "execution" or work processes level (Hale et al., 1997), very simple and rather iconic models for reporting and communication may be needed in order to achieve valid information and immediate actions based on first order learning (van Court Hare, 1967). At the meso level, i.e. "planning" by safety professionals, more advanced analogue models such as TRIPOD, ILCI, etc., may be appropriate for second order learning by monitoring and auditing. For emerging events related to new technologies and changes in a context which are difficult to understand and specify, it may be helpful to look at modelling approaches based on system dynamics, or at more rare approaches and paradigms from anthropology, e.g. ones that are based on story telling and text mining, studying of normal work processes, etc. Developments in information technology make such approaches to accident prevention more applicable.

At the level of "structure" or strategic management, it is important to distinguish events that suggest that fundamental changes are needed in the safety management system or the regulatory regime from those that suggest that greater efforts are needed with respect to implementing the systems and preventive measures already in place (Hale, 1997). Important tasks at this level are to conduct a *change analysis* related to impacts on safety caused by changes in technology, organisation and work processes, and to consider remedial actions within a framework of cost-benefit for the company and regulatory constrains imposed by the government. For these tasks the basic ideas of resilience engineering seem appropriate. "Resilience" has become a popular buzzword in many research areas. It seems to inspire a feeling that it represents an answer to the threats and uncertainties associated with the fast-paced changes of modern society. The ongoing developments in the field of "resilience engineering" are promising in relation to needs in strategic occupational accident risk management, but the field is still immature with regard to practical and applicable tools for the industry.

Accident models affect the way people think about safety, how they identify and analyse risk factors, and how they measure performance. Accident models can be used in both reactive and proactive safety management. Many models are based on an idea of causality. Accidents are thus the result of technical failures, human errors or organisational problems. Most applied performance indicators do not take into account whether the consequences of failures are major or minor, e.g. Lost Time Injury (LTI), and are build on pre-assumptions based on an iceberg metaphor for the relationship between unsafe acts, injuries and fatalities (Heinrich, 1931; Hale, 2000). Many models, e.g. the Swiss cheese model (Reason et al., 1988), have an underlying idea that actions at the "sharp end" are influenced by conditions set at the "blunt end". The measurement of performance is based on the status or effectiveness of the risk control systems, such as barriers, maintenance error, failure to control hot work, etc. (Hopkins, 2007).

Recently, two systemic models have been introduced, namely the Functional Resonance Accident Model (FRAM) (Hollnagel, 2004), where failures and successes are the result of adaptations to cope with complexity; and the Systems-Theoretic Accident Model and Processes (STAMP) (Leveson, 2004). These models may inspire a more creative search for alternative and proactive (leading) safety performance indicators.

The accident model applied guide the choice of performance indicators and gives a reference point from which they can be interpreted (Hollnagel, 2008). Herrera and Hovden (2008) define leading indicators as precursors that when observed, imply the occurrence of a subsequent event that has an impact on safety and performance. Leading indicators are indicators that change *before* a change has occurred in the calculated risk. In FRAM the idea of causality is replaced by emergence, whereby a combination of factors in a given context can produce an unexpected outcome. At sharp-end level, leading indicators are factors such as overtime, seasonal recruitment, and the quality of training, adequate feedback from reporting, sick leave levels, how risk management processes are systematically integrated into normal activities (use of safe job analysis), and interpretation and update of procedures. At the organisational level, Wreathall (2001) suggests leading indicators related to management commitment, awareness, preparedness, and flexibility.

Is there a need for models that are more flexible in the sense that they can be adapted and tailored to specific work contexts and local needs? If yes, it reveals a need to develop taxonomies of types of workplaces, relevant features of the socio-technical systems, the phenomenology of incidents and energy involved and so on, merged with a categorisation of main accident theories, models and approaches to accident prevention. This task may be approached by developing a representative list of accident scenarios as a basis for defining the contents of the taxonomies. This is huge research challenge – a challenge which we leave for further research to address.

There are many reasons for discussing the need for accident models, namely to:

- Create a common understanding of accident phenomena through a shared simplified representation of real-life accidents.
- Help structure and communicate risk problems.
- Give a basis for inter-subjectivity, thus preventing personal biases regarding accident causation and providing an opening for a wider range of preventive measures.
- Guide investigations regarding data collection and accident analyses.
- Help analyse interrelations between factors and conditions.
- Different accident models highlight different aspects of processes, conditions and causes.

Therefore, *many* different and competing models are welcome as they highlight different aspects of the risk problem (Kjellén, 2000). They are simplified representations of real-life accidents, not right or wrong, and should be evaluated on their applicability in different risk arenas and on the guidance they can offer in terms of proper and effective remedial actions.

6. Implications and conclusions

Organisations today are under stress from a number of dynamic factors in their environment, such as technological changes, globalization, and market conditions. Modern socio-technical systems are characterized by increased complexity and coupling, and are as a consequence increasingly intractable (Hollnagel, 2008). However, it can be argued that working life at the sharp end has remained largely unaltered, although some changes have occurred at this level as well. Examples of such changes include automation of manual work, the increased use of migrant workers and multicultural challenges at workplaces, and new use of information technology to coordinate work and to communicate effectively. The question addressed is whether new theories from other fields of risk research can play a constructive role in occupational accident prevention. There is no straightforward answer to this question. There seems to be little need for new models and approaches for the sake of understanding the direct causes of occupational accidents in daily work at the sharp end. For this purpose, Gibson's (1961) basic energy-barrier model and Haddon's (1968) 10 strategies for loss prevention will never be outdated.

However, as a result of the changes at higher levels than the sharp end in post-industrial society, theories, models and approaches to high-risk complex socio-technical systems have the potential of enriching occupational safety management activities such as learning from accident models (understanding root causes), planning (expecting and responding to the unexpected) and change analysis.

Normal accident theory, the theory of high reliability organisations, and resilience engineering have all been developed and used within the context of complex high-risk socio-technical systems. Theories from such risk research domains are nevertheless important contributors to discourses on occupational safety management approaches, as they represent an invitation to consider whether new models and approaches can supplement and improve current approaches to this subject area.

Based on these arguments presented, there is a need for further discussions and research on the development of new tools to be added to the occupational safety management toolkit. Examples of areas to be explored are leading indicators, mapping and understanding normal operations (work as actually performed), improvements of accident models and approaches to accident investigation.

References

Ale, B.J.M., Baksteen, L.J., Bellamy, L.J., Bloemhof, L., Gossens, L., Hale, A., Mud, M.L., Oh, J.I.H., Papazoglou, I.A., Post, J., Whiston, J.Y., 2008. Quantifying occupational risk: the development of an occupational risk model. Safety Science 46 (2), 176–185.

Al-Tuwaijri, S., 2009. Will the financial crisis push us back in the struggle for safer and healthier workplaces? ILO Global Job Crisis Observatory Note. <http://www.ilo.org/public/english/support/lib/financialcrisis/featurestories/story12.htm>.

Andersson, R., 1991. The role of accidentology. Arguments for a scientific approach. Doctoral Dissertation, Arbete och Hälsa 17

Bellamy, L. J., Geyer, T. A. W. 1992. In: (ed Williams, J. C.,) Organisational, Management and Human Factors in Quantified Risk Assessment. HSE Contract Research Report No. 33/1992. <http://www.hse.gov.uk/research/crr_pdf/1992/crr92033.pdf>.

Benner, L., 1975. Accident investigations. Multilinear events sequencing methods. Journal of Safety Research 7 (2), 67–73.

Bird, F.E., Germain, G.L., 1985. Practical Loss Control Leadership. Inst. Publ. Division of International Loss Control Institute, Atlanta, Georgia.

European Commission, 2001. European Statistics on Accidents at Work (ESAW). Methodology. DG Employment and Social Affairs, UNIT D-5. Health, Safety and Hygiene at Work. Brussels. <http://osha.europa.eu/en/publications>.

Finnish Institute of Occupational Health, 1987. Successful Accident Prevention. Recommendations and Ideas Field Tested in the Nordic Countries. Review 12. Finish Institute of Occupational Health, Helsinki.

Freitag, M., Hale, A.R., 1997. Structure of event analysis From Accidents to Organisational Learning. In: Hale, A.R. et al. (Eds.), After the Event. Pergamon, Oxford.

Gibson, J.J., 1961. The contribution of experimental psychology to the formulation of the problem of safety – a brief for basic research. In: Behavioral Approaches to Accident Research. Association for the Aid of Crippled Children, New York, pp. 77–89.

Groth, L., 1999. Future Organizational Design. The Scope for the IT-based Enterprise. John Wiley, Chichester.

Haddon, W., 1968. The changing approach to epidemiology, prevention and amelioration of trauma. American Journal of Public Health 58 (8), 1431–1438.

Hale, A.R., 1997. Introduction: The goals of event analysis. In: Hale, A.R. (Ed.), After the Event. From Accidents to Organisational Learning. Pergamon, Oxford.

Hale, A., 2000. Conditions of occurrence of major and minor accidents. 2me séance du séminaire Le risque de défaillance et son contrõle par les individus et les organisations, Gif sur Yvette.

Hale, A.R., Glendon, I., 1987. Individual Behaviour in the Control of Danger. Elsevier, Amsterdam.

Hale, A.R., Hovden, J., 1998. Management and culture: the third age of safety. A review of approaches to organizational aspects of safety, health and environment. In: Feyer, A.M., Williamson, A. (Eds.), Occupational Injury. Risk Prevention and Intervention. Taylor & Francis, London.

Hale, A.R., Bellamy, L.J., Gildenmund, F., Heming, B.H., Kriwan, B., 1997. Dynamic modelling of safety management. In: Presented at ESREL'97.

Hare, V.C., 1967. System Analysis: A Diagnostic Approach. Harcourt Brace & World, New York.

Harrisson, D., Legendre, C., 2003. Technological innovations, organizational change and workplace accident prevention. Safety Science 41, 319–338.

Heinrich, H.W., 1931. Industrial Accident Prevention. McGraw-Hill, New York.

Hendrick, K., Benner, L., 1987. Investigating Accidents with STEP. M. Dekker, New York.

Herrera, I.A., Hovden, J., 2008. Leading indicators applied to maintenance in the framework of resilience engineering: a conceptual approach. In: Proceedings of the third Symposium on Resilience Engineering.

Hollnagel, E., 1998. Cognitive Reliability and Error Analysis Method (CREAM). Elsevier Science Inc., New York.

Hollnagel, E., 2004. Barrier and Accident Prevention. Ashgate, Hampshire, England.

Hollnagel, E., 2008. The Changing Nature of Risks. Ecole des Mines de Paris, Sophia Antipolis, France.

Hollnagel, E., Woods, D.D., Leveson, N., 2006. Resilience Engineering. Concepts and Precepts. Ashgate, Aldershot.

Hopkins, A., 2007. Thinking about Process Safety Indicators. In: Presented at the Oil and Gas Industry Conference, Manchester, England, November 2007.

Hovden, J., 1984. Behøver vi ulykkesmodeller? Fordeler og ulemper ved ulike modeller. In Norwegian [Do we need accident models?] In Fjärde Nordiska Olycksfallsforskningsseminariet, Technical Research Centre, Symposium, 55, Espoo.

Johnson, W.G., 1980. MORT Safety Assurance System. Marcel Dekker, New York.

Jørgensen, K., 1985. Forskning om arbejdsulykker. In Danish. [Reserach on occupational accidents]. In Hovden, J. et al. (Eds.), nordiske konferanse for ulykkesforskere. 5. SINTEF, Trondheim.

Kjellén, U., 2000. Prevention of Accidents Through Experience Feedback. Taylor & Francis, London.

Kjellén, U., Hovden, J., 1993. Reducing risks by deviation control – a retrospection into a research strategy. Safety Science 16, 417–438.

Kjellén, U., Larsson, T.J., 1981. Investigation accidents and reducing risks – a dynamic approach. Journal of Occupational Accidents 3, 129–140.

LaPorte, T.R., Consolini, P.M., 1991. Working in practice but not in theory: theoretical challenges of high-reliability organizations. Journal of Public Administration Research and Theory 1, 19–47.

Leveson, N., 2001. Evaluating Accident Models using Recent Aerospace Accidents, Technical Report, MIT Dept. of Aeronautics and Astronautics. <http://sunnyday.mit.edu/accidents>.

Leveson, N., 2004. A new accident model for engineering safer systems. Safety Science 42, 237–270.

Lundberg, J., Rollenhagen, C., Hollnagel, E., in press. What-you-look-for-is-what-you-find – the consequences of underlying accident models in eight accident investigation manuals. Safety Science. doi:10.1016/j.ssci.2009.01.004.

Marais, K., Dulac, N., Leveson, N., 2004. Beyond normal accidents and high reliability organizations: the need for an alternative approach to safety in complex systems. In: Engineering Systems Division Symposium. MIT, Cambridge, MA.

Mayhew, C., Quinlan, M., Ferris, R., 1997. The effects of subcontracting/outsourcing on occupational health and safety: survey evidence from four Australian industries. Safety Science 25 (1–3), 163–178.

Mearns, K., Yule, S., 2009. The role of national culture in determine safety performance. Challenges for the global oil and gas industry. Safety Science 47, 777–785.

Op de Beeck, R., van Heuverswyn, K., 2002. New Trends in Accident Prevention Due to the Changing World of Work. Report, European Agency for Safety and Health at Work, Bilbao. <http://osha.europa.eu/en/publications/reports/208>.

Perduco, 2007. En bedriftsundersøkelse om arbeidskraft. Utarbeidet for NAV-EURES. [A company survey on manpower, the Norwegian Labour and Welfare Administration]. <www.nav.no/binary?id=805394484&download=true> in Norwegian.

Perrow, C., 1984. Normal accidents. In: Living with High-Risk Technologies. Princeton University Press, Princeton, NJ.

Perrow, C., 2007. The Next Catastrophe: Reducing our Vulnerabilities to Natural, Industrial, and Terrorist Disasters. Princeton University Press, Princeton, NJ.

Rasmussen, J., 1997. Risk management in a dynamic society: a modelling problem. Safety Science 27 (2–3), 183–213.

Reason, J., 1997. Managing the Risks of Organizational Accidents. Ashgate, Aldershot.

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

Reason, J.T., Shotton, R., Wagenaar, W.A., Hudson, P.T.W., Groeneweg, J., 1988. TRIPOD: A Principle Basis for Safer Operations. Report for Shell International, Univ. of Manchester and Univ. of Leiden.

Rosness, R. Guttomersen, G., Steiro, T., Tinmannsvik, R, Herrera, I.A., 2004. Organisational Accidents and Resilient Organisations: Five Perspectives. SINTEF Report STF38 A 04403, Trondheim, Norway.

Saari, J., 2001. Accident Prevention Today. Magazine of the European Agency for Safety and Health at Work, No. 4, 2001.

Sklet, S., 2004. Comparison of some selected methods for accident investigation. Journal of Hazardous Materials 11 (1–3), 29–37.

Touminen, R., Saari, J., 1982. A model for analysis of accidents and its application. Journal of Occupational Accidents 4, 263–273.

Turner, B.A., 1978. Man-made Disasters. Wykeham, London.

Weick, K.E., Sutcliffe, K.M., 2007. Managing the Unexpected: Resilient Performance in an Age of Uncertainty. Jossey-Bass, San Francisco, CA.

Westrum, R., 1993. Cultures with requisite imagination. In: Wise, J.A. et al. (Eds.), Verification and Validation in Complex Man–Machine Systems. Springer, New York.

Wilde, G.J.S., 1998. Risk homeostasis theory: an overview. Injury Prevention 4, 89–91.

Wilpert, B., 2009. Impact of globalization on human work. Safety Science 47, 727–732.

Wreathall, J., 2001. Final Report on Leading Indicators of Human Performance. US Department of Energy Washington, DC, EPRI, Palo Alto.

Zuboff, S., 1988. In the Age of the Smart Machine. The Future of Work and Power. Basic Books, New York.