A need for new theories, models and approaches to occupational accident prevention?

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ABSTRACT
The paper discusses challenges from a changing working life on occupational accident modelling and asks if ideas from models developed for high-risk, complex socio-technical systems can be transformed and adapted to occupational accident prevention. Are occupational accidents mainly simple component failures or is a systemic approach of some interest and value?

1 INTRODUCTION

The aim of the paper 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 getting inspiration and adapting approaches from other fields of risk research? Is there a need for radical changes, modification of traditional approaches and knowledge bases, - or are the problems of occupational accident prevention mainly a question of priorities, resources and implementation?

The intention is not to give clear and finite answers to the questions raised above. The paper invites reflections on the needs and use of accident models in occupational accident prevention. This is approached by (1) presenting a brief review of established, mainstream accident models applied in this field; (2) describing changes in working life with possible impacts on needs for rethinking the paradigms for accident modelling and safety management approaches in; (3) a 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 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 just briefly presented and discussed in relation to their relevance for occupational accident and not for “system accidents”.

The scope of the paper and the basis for the discussions is mainly based on today’s situation in the Nordic countries both regarding safety management practice as well as challenges. A common fundament of a Nordic framework for occupational accident prevention is described by Saari et al. (1987).

2 BACKGROUND – THE ESTABLISHED MODELS IN OCCUPATIONAL ACCIDENT PREVENTION

Accident definitions converge to some assumptions about a hazard materializing in a sudden, probabilistic event (or chains of events) with adverse consequences (injuries). Classification is used to standardise the collection and analyses of data on accidents. Standard categories are:

- *Damage/loss:* injuries and fatalities, material and economic losses, reputation, etc.
- *Incident:* Type – fall, slip, explosion, etc. Agency – machine, vehicle, tool, etc

- *Hazardous condition:* defective tools, unsafe design, housekeeping, etc
- *Unsafe act:* errors and omissions

In addition, we can categorise accidents according to arena, - where the accident happens, type of activity, system characteristics etc.

What distinguish *occupational accidents* from other accidents is 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 nature of injury (cut, fracture, burns, etc), part of body effected (head, neck, etc), and severity.

Most accident models and theories applied in the field of occupational accidents are still based the ideas of Heinrich’s (1931) domino model and Gibson’s (1962) and Haddon’s (1968) energy models, using a closed system safety mindset, with mechanistic metaphors that describe conditions, barriers and linear causal chains of an accident process. In the 1960s and 1970s there were typically a focus on technical faults and human errors (Kjellén and Hovden, 1993). Two competing modelling approaches evolved: (1) causal sequences similar to the domino model, e.g. ILCI (Bird and Germain, 1985), TRIPOD and the “Swiss cheese”-model (Reason et al., 1988), and (2) process models in terms of sequentially timed events or phases, e.g. STEP (Benner, 1975; Hendrich and Benner, 1987), and OARU (Kjellén and Larsson, 1981).

The 1980s was the era of creative accident modelling activities, and a number of different occupational accident models were developed in the Nordic countries in addition to OARU, e.g. a Finnish model (Touminen and Saari, 1982) and a Danish model (Jørgensen, 1985). For a review of accident models, see Kjellén (2000) and Sklet (2004). As a reaction to all these efforts in accident modelling, Hovden (1984) asked the provocative question “do we need accident models?” at the yearly Nordic conference in accident research[1], and questioned the utility of these analogue models of boxes and arrows for the progress of safety science and for improved accident prevention in industry. The pessimistic conclusion was that the models were not scientific enough, not practical enough, not specific enough, and not holistic enough. Andersson’s (1991) work on the role of accidentology in occupational injury research discusses classifications of accident theories and models and revealed a cleavage between traumatology and epidemiological approaches at one end and technological and cross-disciplinary approaches at the other end. The history of accident modelling is very much about a positioning on model power between different disciplines, - technologists, psychologists, other social scientist, etc. claiming to be holistic and cross-disciplinary, combining human factors, technology and organisational aspects, - but on their own premises.

From the mid-eighties the focus changed from accident modelling to an interest in management tools for safety monitoring and safety auditing (Kjellén & Hovden, 1993). Hale and Hovden (1998) described management and culture as the third age of safety. The first age was about technical measures, the second about human factors and individual behaviour (Hale and Glendon, 1987), which was influenced by ergonomics and 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. In the same period large international companies such as DuPont became a role model for many companies by their focus on management responsibility, workers’ behaviour and safety performance indicators based on incident reporting. This review of approaches to accident modelling and prevention need to be short. But nevertheless it reveals a great variety of perspectives on accident phenomena

[1] These Nordic conferences (NOFS) has been a precursor to the WOS conferences

and preventive strategies – we see what we look for. But do these 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

The levels and layers within organisations are stressed by a number of external forces and counter forces in their coping with accident risks. The main contextual stressors influencing working life risks are: changing political climate and public awareness, market conditions and financial pressure, competence and education, and 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 micro level, "the sharp end", very little has changed in manual work tasks, - climbing a ladder at a construction site or doing maintenance work in a chemical plant has not become complex, dynamic or intractable. Or does the increased 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?

Use of information systems creates new types of communication; improved ability to store and retrieve data and more effective information processing, which all influence modern organisation of work (Groth, 1999). The development creates advantages such as automation of work processes; more effective planning and communication; and improved availability of employees. But the "information revolution" also creates pitfalls such as information overload; high request of information; and communication problems. Box 1 shows an example of how information technology can influence occupational safety both positively and negatively at sharp-end activities.

Box 1: Monitoring of employees

Monitoring work performance at offshore installations

Within the Norwegian oil and gas industry, there is an ongoing transition to the concept integrated operations, i.e. 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 use of monitoring of offshore workers. This implies that operators onshore can watch offshore workers' performance by use of camera equipment and monitors. One the one hand, this creates a secure and safe environment as offshore workers have a 'watchful eye' on their performance, 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 might lead to workers feeling uncomfortable of being evaluated all time and even 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 has used manpower from the EU countries in 2007. Sectors who have traditionally had a high rate of occupational accidents top the statistics on use of foreign manpower: primary industries (58%); hotels and restaurants (49%); manufacturing; and building and construction industry (both 43%). Only half of the foreign workers were hired permanently. Swedish and Polish workers are most used foreign workers (Perduco, 2007). On the one hand side, this working immigration offers needed labour and expertise, but it also creates challenges for occupational accidents (see example in box 2), as well as working environment challenges regarding social rights.

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

Box 2: Communication problems

Language barriers creating an occupational accident

At Norwegian chemical plant, a Finish welder was hired from a contractor to stop a leakage from a pipe containing lye. Due to language problems, the Finish welder misconceived the mission and thought is was an air pipe that was to be repaired. As a consequence the welder did not wear the necessary protective equipment for the job, only mask and gloves. In the preparation of the work, the welder discovered green liquid coming out of the pipe, and then understood it was chemical liquid. In his search for the leakage, drops of lye came on his neck. He reacted to the drops by touching his neck with his gloves that had already been in contact with the lye.

Box 3: Automation

Automation of manual work

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

As part of the wave of globalization, we can see a trend of deregulation and new concepts in business administration related to profit, time and cost cutting: capital cost reduction, outsourcing, down-seizing, management, contracting, leasing, strategic alliances, joint venture/partnership, enterprises in network, lean production, just-in-time (Kanban), business process re-engineering, flexible specialization, virtual organisations, plus learning organisations, knowledge management, change management. Box 4 shows an example of complex organisation of work due to new contexts and types of organisation The question here is how occupational accident models and the safety management consider and cope with these new realities.

Box 4: Complex organisation of maintenance work

Maintenance activities in aviation

Maintenance activities in aviation are characterised of being spread over multiple locations, the tasks' complexity varies, non-optimal working environment (light, access, noise), differences in working times, downsizing and seasoning recruitment. Several programmes have been introduces to improve worker and operational safety. In aviation, there is still a need to have a more realistic approach that considers human behaviours and decision-making processes in operational contexts. A solution proposed is to monitor normal operations. This monitoring poses a challenge between approaches that decompose data into quantitative factors and those that use interpretation of qualitative data to increase the

Working life has moved from the stable industrial society to the dynamic knowledge society. Post-industrial working life can be characterised by services, handling of information and knowledge intensive work. While the industrial society was perceived as stable, the post-industrial society is dynamic: technological development, international competitions, efficiency demands and changes. This implies that post-industrial organisation of work is different from the industrial bureaucratic organisations. Some examples of changes in different types of work:

- Craft industries: in general, more mobile phones and foreign workers, automated tools replace hammers, saws etc.

- Manufacturing: increased automation (see box 3)
- Farming and fishing: less manual work, increased production volumes and energy involved
- Process and petroleum industry: increased automation, integrated operations

To sum up, technologies change, knowledge changes, organisations change, people change, values change, etc., but in occupational accident prevention do we still believe in the domino model and the iceberg metaphor - or do we not?

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 within the scope of high-risk industries and in transportation have evolved. There is some overlap between these theories, and we just want to highlight key elements and possible lessons to be learned and applied in the field of occupational accidents starting with two prominent schools addressing the organisational aspects of safety: Normal Accident Theory (NAT) and High Reliability Organisations (HRO).

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: degree of interactions and couplings. Perrow uses these two dimensions in a two-by-two table to indicate that different systems may need different ways of organising. If the system is both interactively complex and tight coupled, there is no possibility to identify unexpected events, and the system should be abandoned. In such systems, simple, trivial incidents can cascade in unpredictable ways and disastrous consequences. The changes in working life, as described above in part 3, has resulted in 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. Perrow (2007) identifies 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.

HRO researchers claim to counter Perrow’s hypothesis on high-risk, complex systems (LaPorte and Consolini, 1991). HRO is based on studies on organisations that successfully handle complex technologies. The cost of failures in these organisations is unacceptable for the society. Main characteristics for HRO’s include managing complexity through 1) continuous training, 2) use of redundancy 3) numerous sources of direct information.

Furthermore, HRO’s rarely fail even if they experience unexpected events (Weick and Sutcliffe, 2007). They re-define HRO as a mindful organisation. Organizing for high reliability requires that the organisation continuously work with anticipation and containment. A mindful organisation has the following three principles for anticipation: 1) the ability to become aware of the unexpected events through preoccupation with failures; reluctance to simplifications; 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 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 HRO conclusions are based just a few case studies which not fulfil Perrow’s definition of complex interactivity nor tight coupling (Marais, et al, 2004).

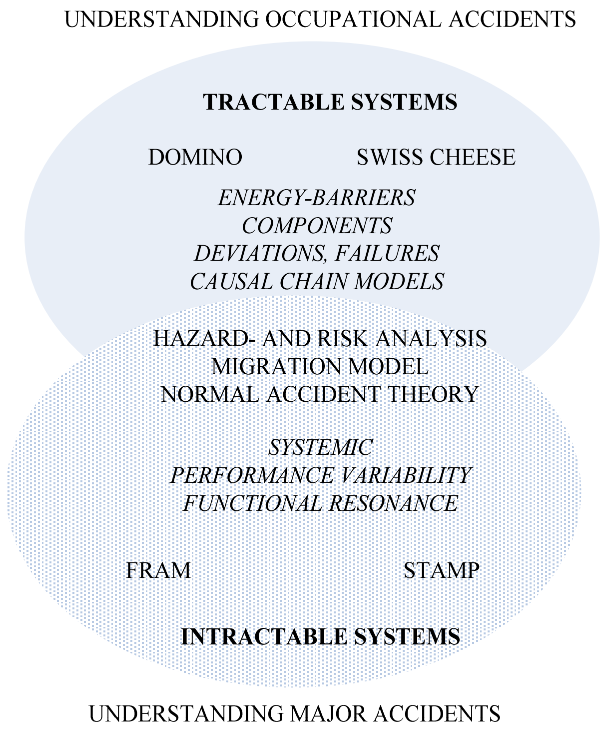
In an information processing perspective the accident is viewed as a breakdown in the flow and interpretation of information (Turner, 1978). This perspective highlights how the individuals and organisation perceive and make use of information. A key point is how information and knowledge are related to the accident and how misinformation may arise. The model includes factors like the 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, 1998).

Rasmussen (1997) directs the attention to the migration of activities towards the boundary of acceptable performance. This migration 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. A distributed decision making system is proposed to cope with the dynamics of modern organisations. He also recommended studying normal work processes rather then focusing on deviations, errors and incidents. Rosness et al. (2004) pointed 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 of 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. 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 to increase their ability to operate in a robust and flexible way.

Hollnagel et al (2006) defines 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 face of continuous stresses or major mishaps”. Premises in this definition are: 1) the increase of complexity has made the systems intractable, therefore under-specified; 2) humans are seen as an asset because people are flexible and can learn to overcome design flaws, adapt to meet demands, interpreted procedures, detect and correct when things go wrong, 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 to understand how the system as a whole dynamically adjusts and varies to continue safe operations. The focus is on the proactive side of safety management and the need to make proper adjustment for anticipation, updating of risk models and effective use of resources.



5 DISCUSSION

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

There is no simple yes or no answer to these questions. The traditional approaches may be good enough, – suited in some workplaces but not in other, and suited to understand some accidents but not others. In occupational accident prevention most problems may be solved by looking at simple, direct causes and triggering events. By such continuous work on performance improvements by deviation control the potential for reaching low injury rates is high in most industrial domains. The need for new models can therefore be considered as low in the daily work of accident reporting and surveillance. But just identifying a proximate cause as the "root cause" may lead to eliminate symptoms without much impact on reducing future accidents (Marais, et al, 2004). In order to identify systemic causes you may need to supplement with models representing alternative mindsets in order to reach "requisite imagination and fantasy" 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, the "execution" or work processes level (Hale et al., 1997), you may need very simple and rather iconic models for reporting and communication in order achieve valid information and immediate actions based on first order learning (Van Court Hare, 1967). At the meso level, "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 the context which are difficult understand by using causal system analytical models it may be helpful to look at modelling approaches based on system dynamics or more rare approaches and paradigms from anthropology, e.g. based on story telling, studying normal work processes, etc. Developments in information technology make such approaches to accident prevention more applicable.

At the level of "structure" or strategic management, an important question is to distinguish events that tell us to make fundamental changes in the safety management system or the regulatory regime from those that tell us to try harder to implement the systems and preventive measures we have (Hale, 1997). Important tasks at this level are *change analysis* related to impacts on safety from changes in technology, organisation and work processes and to consider remedial actions within a framework of cost-benefit for the company and regulatory constrains by government. For these tasks the basic ideas of resilience engineering seems appropriate. "Resilience" has become a popular buzzword in many research areas. It seems to represent a feeling of an answer to the threats and uncertainties of the fast pace of changes in modern society. The ongoing developments in the field of "resilience engineering" are promising for needs in strategic occupational accident risk management, but the field is still immature regarding practical and applicable tools for the industry.

Accident models affect the way people think about safety, how they identify and analyse risk factors and 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 are based on failures regardless of whether the consequence is major or minor, e.g. Lost Time Injury (LTI) and pre-assumptions about an iceberg metaphor of the relationship between unsafe acts, injuries and fatalities (Heinrich, 1931; Hale, 2000). Sequential models, e.g. the Swiss cheese model (Reason et al., 1988), have an underlying idea that actions at "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 e.g. barriers, maintenance error, failure to control hot work, etc. (Hopkins, 2007).

Recently, two systemic models have been introduced: The Functional Resonance Accident Model (FRAM) (Hollnagel, 2004) where failures and successes are result of adaptations to cope with complexity, and the Systems-Theoretic Accident Model and Processes (STAMP) (Leveson, 2007).These models may inspire to a more creative search for alternative and proactive (leading) safety performance indicators.

The accident models applied guide the choice of performance indicators. Herrera and Hovden (2008) defines 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* calculated risk has changed. In FRAM the idea of causality changes to emergence, where a combination of factors in a given context can produce an unexpected outcome. At sharp-end level leading indicators are e.g. overtime, seasoning recruitment, quality of training, and adequate feedback from reporting, sick leave percentage, how risk management processes are systematically integrated in the activities (use of safe job analysis), interpretation and update of procedures. At the organisational level (Wreathall, 2001) suggests leading indicators related to management commitment, awareness, preparedness, flexibility.

Do we need models that are more flexible in adaptation and tailoring to specific work contexts and local needs? If yes, that will reveal a need for developing taxonomies of types of workplaces, relevant features of the socio-technical systems, the phenomenology of incidents and energy involved, etc. 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 basis for defining the contents of the taxonomies. This is huge research challenge - which we leave for further research.

There are many reasons for discussing the need for accident models:

- Create a common understanding of accident phenomena by a shared simplified representation of accidents occurring in real life
- Help structuring and communicating risk problems
- Give a basis for inter-subjectivity, preventing personal biases regarding accident causation and opens for wider range of preventive measures
- Guide investigations regarding data collection and accident analyses
- Help analysing 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 guidance on proper and effective remedial actions.

6 IMPLICATIONS AND CONCLUSIONS

Organisations today are stressed by a number of dynamic factors in their environment, e.g. technological changes, globalization and market conditions. Modern socio-technical systems can be 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 mainly remained unchanged, but there are some changes at this level as well: e.g. automation of manual work; more foreign workers; and use of information systems to coordinate work and communicate effectively.

The question addressed in this paper is whether new theories from other fields of risk research are fruitful for occupational accident prevention. There is no straightforward answer to this question. The need for new models and approaches seem to be low for understanding direct causes for occupational accidents in daily work at the sharp end. The basic energy-barrier model of Gibson (1961) 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 the post-industrial society, theories, models and approaches to high-risk complex socio-technical systems have potential of enriching occupational safety management activities such as learning and accident models (understanding root causes), planning (expect and respond to the unexpected) and change analysis.

Normal accident theory, the theory of high reliability organisations and resilience engineering have all been developed within and used in a 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 invite to consider whether new models and approaches can supplement and improve current occupational accident approaches.

Based on the arguments presented in the paper, we invite to discussions and further research on development of new tools to the occupational safety management toolkit, e.g. leading indicators, understanding of normal operations, accident models and accident investigation.

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