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Merits of using a socio-technical system perspective and different industrial accident investigation methods on accidents following natural hazards – A case study on pluvial flooding of a Swedish railway tunnel 2013

Monika Rydstedt Nyman [a,b,*], Magnus Johansson [a,c]

[a] Centre for Climate and Safety, Karlstad University, Karlstad, Sweden
[b] Maintenance Division, Swedish Transport Administration, Sweden
[c] Lessons Learned Section, Swedish Civil Contingencies Agency, Karlstad, Sweden

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ABSTRACT

Functionality in infrastructure is important for a country and its societal activities. Perils such as weather dependent natural hazards cause recurrent disruptions with negative consequences for individuals, society and business. To learn lessons from past events is a key component in pro-active risk management, but the nature of society–hazards interactions is constantly increasing in complexity, which makes the task to study accident causations and impacts difficult. Assessments of the latest major accident, or disaster in some scale, have the potential to guide safety system design improvements with focus on actively decreasing vulnerabilities and strengthening resilience in an evolutionary procedure. However, practice is often guided by addressing only the most evident impacts and restricted by ownership of issues within existing sectorial responsibilities, media pressure or political moves, as opposed to evaluating experiences systematically and objectively. In this article, three different methods for industrial accident investigation are applied and their pros and cons demonstrated, within a context of extreme pluvial flooding in a railway tunnel in Sweden 2013. The outer threat that natural hazards may pose on infrastructure and related activities is not explicitly treated in such methods, where the cause of event normally is analyzed against well-known and demarcated working systems. Our bottom-up approach serve as an example on how these methods can be used and combined to unwind interrelated casual factors and find root causes across different levels in the societal hierarchy for accidents that evolve in connection with natural hazards.

1. Introduction

A functional infrastructure, with robust transport and communication, is vital for societal functions, industry and individuals [1,2]. Even if awareness is rising in general and risk reduction is highlighted both internationally and nationally [3], major accidents continue to happen. Interruptions from extreme weather induced damages influence people's daily life and their living, restrict societal functions, temporarily increase accident risks, provoke accidents and entail economic losses in both private and public sectors. Statistical synthesis of reported global disaster loss and damage data evinces increasing (logarithmic) trends [4]. Recent assessments of local outcomes of future climate change report alteration in frequency, intensity, spatial extent and duration of weather extremes [5,6,1], increasing the propensity for adverse effects of an already problematic risk factor. Conceptually, adaptive management, innovation and leadership are seen as key components in efforts to build a more robust and resilient society, along with learning and knowledge sharing from past accidents [5]. However, learning after major accidents is a complex issue with demand for system-oriented, inter-disciplinary rather than multi-disciplinary [7], approaches to study accident causation and support development of a more pro-active risk management [8].

Many learning approaches lean on investigations as a starting point [9], focusing on impacts and management with preventive purposes [10]. Investigations, follow-ups and evaluations are all mastered in the aftermath of an event and traditionally acknowledged as a way to gain, but also spread, in-depth knowledge and learning from an event [9,11]. Overall, investigations seek to achieve a better understanding of the root causes and dynamic

* Corresponding author at: Centre for Climate and Safety, Karlstad University, Karlstad, Sweden.

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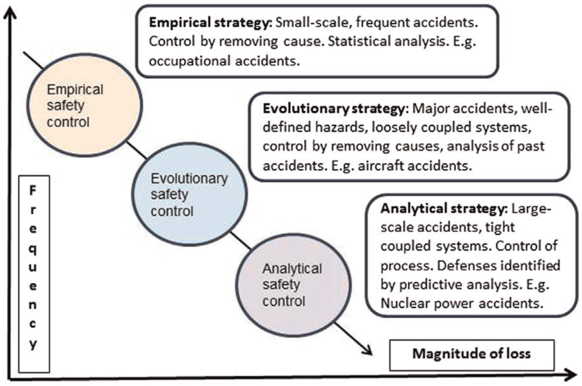

Fig. 1. Rasmussen's hazard source characteristic and risk management strategies involved with the different scale of loss magnitudes. Rasmussen [12] underlines that different types of hazards need to be dealt with different approaches of management; small-scale and frequent accidents with empirical risk management where large amount of loss data are crucial, medium scale accidents with evolutionary strategies supported by case studies, and large scale exceptional accidents where predictive analysis identify and guide suited defenses. After Rasmussen [12], the axes are logarithmic.

processes that create risks in diverse social, economic, environmental, cultural, national and local settings [7,12,10,13], making them visible for public, risk managers and policy makers.

In a wider perspective of societal practice, different risk management strategies have evolved for different hazard categories. There lies an inverse relation between the frequency of certain accidents and the magnitude of losses [14] behind those strategies, stretching from being mostly empirical, via evolutionary, to analytical [12] (Fig. 1). Epidemiological studies of the very large number of data from daily, small-scale, accidents, registered at hospitals, local rescue services, etc., constitute a solid knowledge base for empirically based safety control and preventive activities [8,12]. Learning from the past is here the key to the present risk management. At the other end, concerning industrial installations like nuclear power or hydroelectricity plants, the risk acceptance of failures are so low that their design and safety measures cannot be based on empirical grounds from past accidents. Instead, an analytical approach with system design assumptions predicted from models of the processes and the hazards involved, must be applied [8,12].

Major accidents or small to medium-size disasters, following natural or quasi-natural [15] hazards, imply numerous accidents over wide areas during a short time span, which have the implication and necessity to focus on selected parts of an event for investigation and learning, to be justifiable from a practical time and resource point of view. Usually the selection is event specific and guided by, and limited to, the most severe impacts reported and their direct and indirect consequences, observed mistakes in coping and/or consequences that were unexpected in some sense and therefore of special interest among responsible actors/authorities. In this category, analyses of the latest accident guide system design improvements, focusing on removal of causes of this particular accident and thereby decreasing vulnerabilities and improving resilience in an evolutionary procedure [12], while awaiting the next peril to cause stresses on society. This evolutionary strategy for improved safety has earlier been exemplified with accidents such as hotel fires, aircraft accidents and train collisions [12], but fits also rather well with post-response and rebuilding strategies used in many countries worldwide after natural hazards with impacts of “alarm-clock” type.

There is seldom one single cause to be found behind accidents, regardless if they are related to natural, technological or man-made hazards. Instead most accidents are complex and involve multiple, interrelated, casual factors [7,12,10]. The dynamic and rapid development of transport systems and just-in time delivery schemes have entailed more coupled and complex systems, where safety and risk management increasingly have turned into socio-technical control problems across different levels in the societal hierarchy [8,12]. Rasmussen [12] argues that risk management in the present complex and dynamic society, with stresses from the fast technological change, requires a “system-oriented approach based on functional abstraction rather than structural decomposition”. A similar way of thinking can be found in the Pressure and Release (PAR) model by Wisner et al. [13], where people's vulnerability analytically is related to social processes and underlying root causes that may be remote in both time and space from the disaster event itself. In addition, the same search for fundamental causes in a broad, multi-disciplinary and comprehensive perspective builds the Forensic Investigations of Disasters (FORIN) method, developed within the program of Integrated Research on Disaster Risk (IRDR) [7,11]. None of these approaches searches for guilt or culpability primarily, but rather provides a broader understanding of the meaning of environmental, political, economic and social contexts on different levels in creating local vulnerabilities and accident outcomes.

Industrial accident investigation methods are also designed for learning and future prevention at first hand, and hence in comparison with forensic (criminal) investigation methods of the police different in design, data capture, analysis and resulting actions. Alexander [16] encourage a more active use and integration of organizational learning theory and industrial accident investigation methods as a way forward to improve lessons learning after disasters, in the strive to build more resilient societies. This implies application of such methods in other scales and system contexts, and a balancing act methodologically where functional abstraction and structural decomposition are complementary.

In this study, three different well-established accident investigation methods (Fault Tree Analysis; Man-Technology-Organization (MTO); and Accident Mapping (AcciMap)) are applied on a case where extreme rainfall in 2013 in Söderhamn, Sweden, suddenly implied flooding of a railway tunnel, among many other reported damages. The investigation scale and strategy is analogous with the evolutionary procedure in a loosely coupled system [12]. Overall, the many different existing methods for accident investigation [10], originally developed for industrial safety work, and often with strict demand on well-defined system definitions and data sorting rules, have different areas of application, as well as diverse pros and cons. A combination of some selected methods is normally required to achieve an, at least moderately, comprehensive picture of major accidents [8,10]. Our approach serve as an example on how such methods can be used and combined to find root causes and unwind interrelated casual factors for accidents that evolve during natural hazard events. With three methodologies applied on one case, it will be possible to see how these methods have different perspectives and outcomes. It enables to pinpoint strengths and weaknesses in methods applied in the context of intense rainfall and pluvial flooding.

2. Methodology and material

2.1. Data collection and analysis

Data collection contains previous risk analysis done before building the tunnel, which lay as ground for an understanding of previous decisions within planning and projection [17]. The former Swedish Road Administration [*Vägverket*] and Railway Administration [*Banverket*] made a joint project for the tunnel and the highway E4-which was drawn parallel to the railroad and the