Risk factors in emergency response: a review of investigations of emergency response in Norway

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Abstract: We present a systematic review of investigations of some large incidents in Norway from 1999 to 2008. The purpose of the review is to identify factors that affect the risk level during emergency response. We found that the most important factor that increases the risk level for rescue personnel and civilians is lacking acknowledgement of risks due to lack of knowledge, causing inadequate counter measures. The most critical mistakes are made during the early stages of the response operation, before the external expertise arrives on the scene.

Keywords: emergency response; risk; decision-making; incident investigations; literature review; counterfactual reasoning.

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1 Introduction

The purpose of this study is to identify the measures that most effectively will reduce the risk level during emergency response operations. In order to address this question we have identified the most important factors that were reported to affect the risk level during emergency response operations. The identification was carried out as a systematic literature review (Kitchenham, 2004; Fink, 2009) of investigations of large potential and actual incidents in Norway from 1999 to 2008. By risk level we mean the combination of likelihood and consequence of events (Australian, 2004; ISO, 2009) that may harm valuables at stake during an emergency response operation, such as the life and health of rescue personnel and civilians, and economic values such as buildings and equipment. An emergency is an unforeseen or sudden occurrence, especially of a danger demanding immediate remedy or action (Collins, 2011). An emergency situation may for example involve an explosion at a chemical plant or a forest wildfire. Hence, when an emergency occurs an accident has already happened and human life or property may already be lost or in imminent danger.

The scope of this study is emergency response, that is, the actions taken during and after an accident to reduce casualties and damages and to minimise the impacts of an accident (Rake, 2008). We have not looked at consequences of the investigated incidents as such, but rather the *potential* for new events with negative consequences given that an incident has occurred and how decisions affect the level of new risks. The final outcome of an accident depends not only on what caused it, but also how it is handled and the decisions taken, once the incident occurs.

In decision analysis a good decision is defined as "an action we take that is logically consistent with the alternatives we perceive, the information we have, and the preferences we have" (Bratvold and Begg, 2010). The purpose of decision analysis process is to establish the quality of a decision *before* the results of the decision are known. In emergency response, however, making good decisions is difficult, due to the complexity of decision-making in the emergency domain.

Emergency response have several of the characteristics of *complex problems* (Holloway, 1979; Michalewicz et al., 2007; Phillips-Wren, 2009); a large number of factors, uncertainty, the environment changes over time and possibly conflicting objectives (e.g., the safety of rescue personnel vs. the lives of victims trapped at dangerous locations). Decision-making in the emergency domain also have additional characteristics that adds to the complexity:

- time-criticality, i.e., decisions must be made fast
- decisions require information from multiple sources
- attention-demanding and harsh conditions
- often incomplete information.

The incident commander on the scene must assess different courses of actions which may have different consequences with regard to the level of risk, i.e., the potential for new events harming values at stake.

The challenge facing the incident commander is that what constitutes a good decision is situation-dependent and often sensitive to conditions beyond decision makers' control (Drury et al., 2009b). Under the deep uncertainty (Lempert et al., 2003) that characterises emergency response a method called Robust Decision Making (RDM) is advocated (Drury et al., 2009a, 2009b; Chandrasekaran, 2005). The aim of RDM is to identify solutions that are good under most conditions, instead of seeking optimal solutions that may turn disastrous if conditions change (Drury et al., 2009a, 2009b; Chandrasekaran, 2005).

In line with the idea behind RDM, we review the investigated decisions with regard to the risks that could be estimated *given* the available knowledge at the point in time the decision was made, and not with regard to the knowledge obtained in retrospect.

The main impression from the reviewed investigations is that the emergency preparedness is good and that the emergency response on the whole is appropriate. In large response and rescue operations, however, there will always be circumstances which one finds afterwards that where not handled satisfactory and that one should learn from. Our findings indicate that:

- The most important factor that increases the risk level for rescue personnel and civilians is lacking acknowledgement of risks due to lack of knowledge, causing inadequate counter measures.
- The most critical mistakes are made during the early stages of the response and rescue operation, before the external expertise arrives on the scene.

The remainder of this paper is organised as follows. In Section 2 we present the method that we followed for conducting the review. In Section 3 we present the results of the review. Section 4 addresses the use of counterfactual reasoning in the primary studies, while Section 5 discusses the results. Threats to validity of our findings are covered in Section 6. In Section 7 we present related work, before concluding in Section 8.

2 Research method

In order to identify which measures that may reduce risks in emergency operations, we followed a process of systematic literature review (Kitchenham, 2004; Fink, 2009). A literature review is a systematic method for collecting information to answer research questions or find out what is known about a particular topic (Fink, 2009).

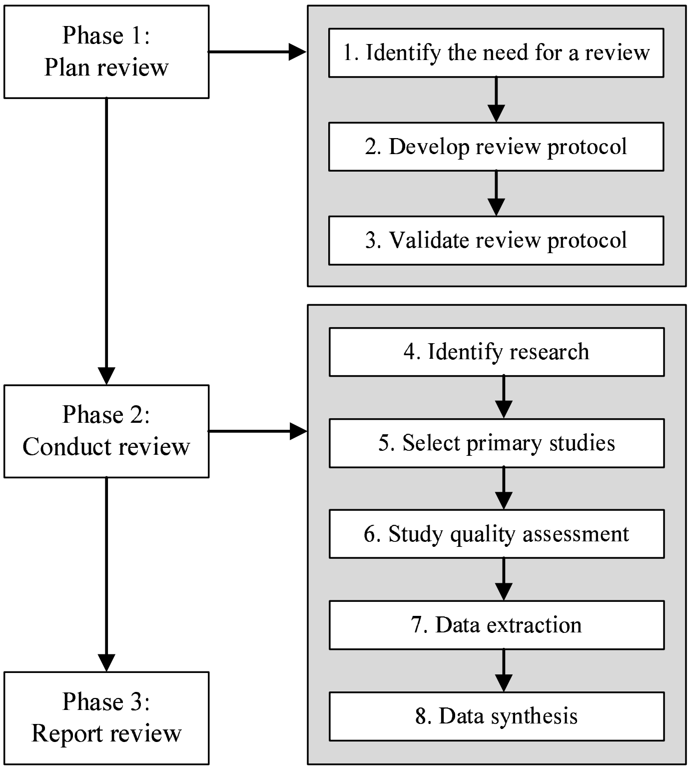
As illustrated in Figure 1 a systematic literature involves several discrete steps, which are structured into three main phases: planning the review; conducting the review and reporting the review (Kitchenham, 2004).

The remainder of Section 2 describes our instantiation of the first six steps of this process, while the final two steps are reported in Section 3.

2.1 Identify the need for a review

As mentioned the purpose of the research presented here is to identify which measures will most effectively reduce the potential for new risks related to decision making by incident commanders on-scene during emergency response. In order to map in a systematic manner the factors that affect the risk-level related to decision making by incident commanders on-scene, we identified the need for a systematic review of investigations of large potential and actual incidents focusing on this question. We are not aware of any assembled overview of investigations of emergency response and rescue operations in Norway for the purpose of comparing mistakes and shortcomings affecting the risk level. See Section 7 for a discussion of related approaches.

Figure 1 Systematic literature review process



2.2 Develop review protocol

An important aspect of a systematic literature review is to establish a protocol for the study during the planning phase. The protocol aims to minimise the bias in the study by defining in advance how the systematic review is to be conducted (Brereton et al., 2007; Kitchenham, 2004). The protocol describes the process to be followed during the review and additional information such as the research question(s) to be addressed and the criteria for selecting primary studies.

Research question

We have identified the following research question:

- Which factors have been documented to affect the risk level during emergency response in potential and actual large incidents in Norway between 1999 and 2008?

Selection criteria

As part of the planning process we decide the criteria for including and excluding primary studies in the review. This involves both deciding the criteria for selecting studies and selecting the types of incidents to include and exclude. The selection criteria are based on the research question in accordance with the guidelines of Kitchenham (2004). Thus, our main criterion for inclusion of an incident investigation is that the incident must have sufficient potential to instigate an investigation appointed by the Norwegian Government or another department of public administration.

In order to ensure that the selected studies were relevant with regard to the research questions we decided to exclude investigations of incidents that happened before 1999. There are two reasons for excluding older incident investigations: Firstly, according to representatives for the practitioners (police and fire chiefs), investigations prior to 1999 tended to discuss the rescue mission itself only summarily and focused on how to prevent future incidents instead. Secondly we assume that the rate of reforms and re-organisation of emergency planning implies that problems documented in operations more than ten years ago is less relevant than more recently documented problems.

Since our target of interest is not primarily the incident and its causes, but rather how an incident is handled once it has occurred, we also excluded investigations whose terms of reference did not include an evaluation of how the rescue operation was carried out. For example the investigation into the loss of the vessel 'Bourbon Dolphin' (NOU, 2008) was excluded as it did not include an evaluation of the rescue operation. The Tsunami in 2004 was also excluded, since it did not happen in Norway.

Data extraction and synthesis

Since the number of selected investigations was rather small, and the project had only limited resources, the review reported upon in this document was conducted by a single reviewer. To improve objectivity a pilot run was executed and reviewed by peers. The results of the data extraction are documented in Section 3.1. The extracted data are compared and synthesised as reported upon in Section 3.2.

The research question defined above is normally not directly part of the scope of the type of incident investigations we are reviewing. In order to be able to extract relevant data, we therefore identified a set of questions that we believe will contribute to illuminating the overall research question. There are three types of questions: questions addressing risks; questions addressing decision-making; and questions addressing recommendations from the investigation committee.

Questions addressing risks

1 What types of threat scenarios were documented to be present after the incident occurred?

2 What potential incidents were documented as possible outcomes of the threats?

3 What were the estimated consequences and likelihoods of the identified potential incidents?

The data extracted based on these questions were documented in tables with five columns: *Threat scenario* documenting data related to question 1; *Incident* documenting data related to question 2; *Consequence* and *Likelihood* documenting data related to question 3; and *Risk level* obtained from combining the documented consequence and likelihood values.

In order to be able to compare the risk level of potential incidents we defined common scales for consequence and likelihood values. The data extracted from the investigations had to be interpreted in terms of our predefined scale. The consequence of a risk describes the level of damage the associated unwanted event inflicts on an asset if the incident occurs.

By assets we mean the things that we want to protect. We have considered the two assets *health and safety* (of rescue personnel and civilians) and *economic values* (for example, buildings, trains, productive forest). We use a scale of five consequence levels ranging from *insignificant* to *catastrophic*. For each of the two assets we have defined the specific meaning of each consequence value. The consequence scales are given in Table 1.

Table 1 Consequence table

Consequence	*Health and safety*	*Economic values*
Insignificant	No medical treatment required	Damages up to 100.000 NOK
Minor	Injury that requires treatment	Damages from 100.000 up to 1 mill. NOK
Moderate	Moderate irreversible disability to at least one person	Damages from 1 mill up to 10 mill. NOK
Major	One or more deaths or irreversible disability	Damages from 10 mill. up to 30 mill. NOK
Catastrophic	Five or more deaths or irreversible disabilities	Damages for more than 30 mill. NOK

A likelihood is the frequency or probability of something to occur. A frequency specifies a number of occurrences within a given period of time, whereas a probability is a number ranging from 0 to 1 specifying the possibility for a scenario or an incident to occur. In a risk analysis the likelihood of a risk is often interpreted as frequency. Since we are interested in finding out the potential for risks in a given situation, we interpret likelihood as probability. For example, what is the probability of an explosion, given a fire close to a propane tank. We use a scale of five likelihood levels ranging from *unlikely* to *almost certain*. We did not map the likelihood levels to concrete values as we considered that it would be difficult to obtain concrete probability values from investigation reports. The qualitative values used to denote probability should be considered as rough estimates. In the cases were other qualitative values than the ones we have defined have been used, we show the mapping between the different values. Thus, for example the term 'imminent danger', used in the investigation of the Lillestrøm incident (NOU, 2001) is interpreted as *very likely*.

We have defined three risk levels: *low*, *medium* and *high*. The risk level for each combination of consequence and likelihood is given in the risk matrix in Table 2. We use white to represent the risk level *low*, light grey to represent *medium* and dark grey to represent *high*.

Table 2 Risk matrix

	Unlikely	*Possible*	*Likely*	*Very likely*	*Almost certain*
Insignificant					
Minor					
Moderate					
Major					
Catastrophic					

Questions addressing decision-making

4 Which decisions were documented to increase the risk level?

5 What was documented to be the reason for these decisions?

6 How were these decisions documented to affect the risk level?

The data extracted based on these questions were documented in tables with three columns: *Decision* documenting the decision documented to affect the risk level; *Reason for decision* documenting what the investigation committee judged as the reason of the decision leading to an increase in risk level, and *Effect on risk level*.

Questions addressing recommendations from the investigation committee

7 What measures were identified in order to reduce risks in future emergency response operations?

8 To what extent do the recommended measures address factors that affect the risk level?

9 Are any of the problems documented to affect risk levels not addressed adequately by recommended measures? What types of problems (if any) remain to be addressed?

Data extracted addressing question 7 are listed at the end of each section presenting the reviewed investigations. Questions 8 and 9 are discussed at a general level in Section 5.

2.3 Validate review protocol

The EMERGENCY project, one of the projects under which the research presented here was carried out, includes several scientific fora that were used in the process to scrutinise and validate the review protocol. These fora include monthly discussion meetings where university professors and Ph.D students are present, yearly meetings with international guest scientists and yearly meetings with an advisory group consisting of end-user representatives (police, Red Cross and firemen), representatives from the industry and academic researchers. Based on input in these fora on the research questions, the data extraction forms and the results of an initial pilot, some modifications were made.

In the evaluation of the research questions and extraction forms, it was pointed out that the emphasis should be on the quality of decisions, given *perceived* outcome, and not based on what actually happened. The argument behind this is that ‘good decisions’ may have ‘bad outcomes’ and vice versa. An example of this is the Lillestrøm accident where a BLEVE that would have killed a large number of people and laid Lillestrøm in ruins, was avoided more due to favourable weather conditions than good decision making.

2.4 Identify research, select primary studies and assess study quality

Since we aim to identify needs for rescue operational leaders we have not reviewed current research, but rather current practise, through the review of investigations that reports directly about experiences from emergency operations.

The Norwegian Government or other departments of public administration may appoint investigations outside legal proceedings in order to uncover the actual course of events in an extraordinary event such as a large incident (NOU, 2009). On some occasions the terms of reference of the investigation committee also encompasses an evaluation of how the response and rescue operation was carried out.

Applying the selection criteria for inclusion and exclusion of primary studies, as described in Section 2.2, we ended up with the following five investigations:

- Ålesundsutvalet. Skredulykka i Ålesund, 2008 (Ålesundsutvalet, 2008).
- NOU 2000:30 Åsta-ulykken, 4. januar 2000. Statens forvaltningstjeneste, 2000 (NOU, 2000a).
- NOU 2000:31 Hurtigbåten MS Sleipners forlis 26. november 1999. Statens forvaltningstjeneste, 2000 (NOU, 2000b).
- NOU 2001:9 Lillestrøm-ulykken 5. april 2000. Statens forvaltningstjeneste, 2001 (NOU, 2001).
- Arbeidsgruppe skogbrannberedskap. Skogbrannberedskap og håndtering av den senere tids skogbranner i Norge, 2008 (Arbeidsgruppe skogbrannberedskap, 2008).

With respect to the quality of the primary studies, we note that the appointment of investigation committees is regulated in several ways to ensure public trust in the results of a public investigation. In order to minimise bias of an investigation, the membership in publicly appointed investigation committees are regulated by the rules for legal competence in the Public Administration Act (Forvaltningsloven, 1967; NOU, 2009). Furthermore, the members of an investigation committee should have the necessary qualifications to conduct the investigation. A committee may also nominate external experts to consider specific topics where the members of the committee lack the necessary scientific competence (NOU, 2009). We consider all the identified investigations to be of sufficient quality to be included in the study, and have not found any reason to assign different weights to the primary studies. In Section 6 we discuss potential weaknesses of the primary studies that may threaten the validity of our findings.

3 Results of the review

In Section 3.1 we present the extracted data and in Section 3.2 we summarise the results presented in Section 3.1. As previously explained, we have not looked at consequences of the investigated incident as such, but rather the potential for new incidents given that an incident has occurred and how decisions affect the level of new risks. For example the decision of whether to evacuate civilians and where to deploy rescue teams in a fire, can affect the consequence of a risk. On the other hand, the decision of how and when to launch counter-measures can affect the likelihood of a risk.

3.1 Data extraction: investigated incidents

In this section we summarise the findings from the five selected investigations.

3.1.1 Ålesund landslide

On March 26, 2008, part of a cliff in Ålesund, Norway, broke loose and slid, demolishing the lower two floors of an apartment building in Fjelltunvegen 31 and pushing part of the building into the street. Five people died. The remaining 15 residents of the apartment building were rescued from the building or got out by themselves.

The Ministry of Local Government and Regional Development appointed a committee to investigate into the incident at May 9, 2008 (Ålesundsutvalet, 2008). The mandate of the investigation committee included evaluating how the rescue operation was carried through. A major issue for the committee, in the evaluation of the rescue operation, was whether the actions that were carried out during the rescue operation were appropriate and justifiable, both with regard to the choice of actions and whether the actions was carried out at the right time and were adequately proportioned. This question was considered both with regard to the knowledge that the rescue team had at the time, and the knowledge obtained in retrospect.

A 3-ton propane tank, buried in front of the apartment building, caught fire during the rescue operation. The investigation report identifies the following risks related to the leaking propane tank:

- Overheating of the tank might have caused a Boiling Liquid Expanding Vapour Explosion (BLEVE). A BLEVE occurs when a tank containing pressurised liquid ruptures due to overheating in connection to a fire. According to the investigation report the shock wave from a BLEVE together with the heat could have laid large areas in ruins.
- The heating load on the apartment building caused by burning propane could lead to further collapse of the building.
- Since propane is heaver than air, leaked propane might have gathered in the lower areas of the building. Mixed with the right amount of air (2–1% propane) this would become an explosive mix.

In order to be able to place the potential risks described above in the risk matrix defined in Table 2 we need to map the expected outcomes and likelihoods to the scales defined in Section 2.2. The investigation report describes a BLEVE as a 'very dramatic event' (Ålesundsutvalet, 2008, p.119). We have chosen to interpret "very dramatic event" as an event with consequence *catastrophic*. The reason for this is that at the time the risk of a BLEVE was present, there were still people in the surrounding buildings. Thus a BLEVE would most likely have lead to the loss of more lives. The investigation report includes no estimation of the consequence of the event that the building collapsed further. However, when this risk was present both rescue personnel and surviving residents was still inside the building. We have therefore assigned this event the consequence *catastrophic*. The investigation report documents that the Incident management considered that a gas explosion could have 'dramatic consequences' (Ålesundsutvalet, 2008, p.124). Again we interpret 'dramatic consequences' as '*catastrophic*'.

The fire chief, who was responsible for assessing the risks related to the propane tank, was advised by The Directorate for Civil Protection and Emergency Planning (DSB) and Statoil Norge that the likelihood of a BLEVE was 'very small' (Ålesundsutvalet, 2008, p.31). We interpret 'very small' as *unlikely*. At the time of the rescue operation the Incident management did not have sufficient information to assess the likelihood of a gas explosion or further collapse of the building. We have therefore said that the likelihood of these events are somewhere in the interval ranging from *unlikely* to *almost certain*.

The identified risk are summarised in Table 3. The incident BLEVE has been assigned the risk value *medium*, in accordance with the risk matrix defined in Table 2. The other two incidents are assigned intervals ranging from *medium* to *high*, since their likelihoods ranges from *unlikely* to *almost certain*.

Table 3 Risks related to the Ålesund landslide

Threat scenario	*Potential incident*	*Consequence*	*Likelihood*	*Risk level*
Overheating of leaking propane tank	BLEVE	Catastrophic	Unlikely	Medium
Overheating of building due to BLEVE	Further collapse of building	Catastrophic	[Unlikely, Almost certain]	[Medium, High]
Leakage of propane gas	Gas explosion	Catastrophic	[Unlikely, Almost certain]	[Medium, High]

Due to the potential risk of a gas explosion it was decided to evacuate nearly 500 residents from nearby buildings. However, the evacuation was not carried through until after the surviving residents had been rescued from the collapsed building. The investigation committee observes that

> "In this phase (i.e., the first hours after the land slide (authors comment)) it seems like the need to rescue survivors overshadowed the risk caused by the gas leakage, compared to later dispositions that were carried through on the basis of the leakage." (Ålesundsutvalet, 2008, p.129)

The overall conclusion of the investigating committee was that the incident where handled in a good way and that no more people could have been saved. However, the investigation committee states that

> "Given such reasoning (reasoning concerning the risk of a gas explosion (authors comment)) the evacuation should have been carried through much earlier, and one should have taken further precautions in the early stage." (Ålesundsutvalet, 2008, p.124)

Based on this statement we identified *No evacuations of civilians in early phase* as a decision that affected the risks related to the Ålesund landslide. Based on the descriptions in the investigation report we document the reason for this decision as *Reactive crisis management. No risk assessment in the early stage*, see Table 4.

Table 4 Decision affecting risks related to the Ålesund landslide

Decision	*Reason for decision*	*Effect on risk level*
No evacuation of civilians in early phase	Reactive crisis management. No risk assessment in the early stage	Increased consequence of potential gas explosion

If a gas explosion had happened in the early stage of the rescue operation, before neighbouring residents were evacuated, the consequences of the explosion would obviously have been much larger than if the residents had been evacuated right away. Hence, we document the effect upon the risk level of the faulty decision as *Increased consequence of potential gas explosion.*

Recommendations from the investigation committee addressing risk reduction:

- the establishment of a national register of specialist resources that can be drafted and assist in large complex rescue operations
- effective transport of specialist resources to the scene of the accident
- improved education of fire fighters in areas where the competence of the fire service is crucial in handling complex events that has potentially large consequences.

3.1.2 The Åsta accident

The Åsta accident was a railway accident that occurred on January 4, 2000 at Åsta in Åmot, south of Rena in Østerdalen, Norway. A train from Trondheim collided with a local train from Hamar on Rørosbanen resulting in an explosive fire. 19 people were killed. Between four and eight of these died in the subsequent fire.

The day after the incident it was decided to appoint an investigation committee that was independent of the Norwegian National Rail Administration and Norwegian State Railways (NSB) (NOU, 2000a). The mandate of the investigation committee included evaluating how the rescue operation was carried through.

Immediately after the collision, a fire started in the collision area. There was a risk that the fire should spread to the foremost train carriage of the southbound train (carriage number 3), where several passengers were trapped. According to the investigation committee, as many as nine passengers in this carriage, may still have been alive after the collision. When the local fire brigade arrived at the incident ground they immediately started an effort to extinguish the fire and prevent it from spreading to carriage number 3. The local fire brigade also summoned help from a larger fire brigade in a larger neighbour municipality, who arrived on the scene 35 minutes after the collision. However, the combined effort of the two fire brigades were not enough to prevent the fire from spreading to carriage number 3 or extinguish it in time to save the trapped passengers. Table 5 shows the identified risk.

Table 5 Risks related to the Åsta accident

Threat scenario	*Potential incident*	*Consequence*	*Likelihood*	*Risk level*
Fire spreads to carriage number 3	Civilian deaths	Catastrophic	[Unlikely, Almost certain]	[Medium, High]

The investigation committee concluded that the two fire brigades did everything within their power to extinguish the fire, given the available resources. The committee observed that it would have required resources and water supply far beyond what was available in the area, in order to extinguish the fire while passengers who survived the collision still were alive. However, the committee did note that it would have been beneficial if the larger fire brigade had been requested for assistance immediately after the emergency call was received by the local fire brigade. The committee concluded that the somewhat late call for assistance was no fault of the local fire brigade, but rather was due to the way the fire brigades where organised, with responsibility for handling fires being the responsibility of the municipality where the fire occurred. Hence, there were not identified any decisions that affected the risk level during the rescue operation.

Recommendations from the investigation committee addressing risk reduction:

- coordinate fire services in inter-communal fire services.

3.1.3 The loss of MS Sleipner

On November 26, 1999, during bad weather the passenger catamaran Sleipner collided with a rock, just north of the town of Haugesund on its way to Bergen. The ship sank and 16 of the 85 passengers died.

The Ministry of Local Government and Regional Development appointed a committee to investigate into the incident on December 1, 1999 (NOU, 2000b). The mandate of the investigation committee included evaluating how the rescue operation was carried through.

At 19:08 Sleipner crashed into the rock called Store Bloksen. After some time the nose broke off and the boat went off the rock. The immediate risk was then that the boat should sink before the help arrived and that passengers and crew drowned, see Table 6.

Table 6 Risk related to the loss of Sleipner

Threat scenario	*Potential incident*	*Consequence*	*Likelihood*	*Risk level*
Boat sinks before help arrives	Civilian deaths	Catastrophic	[Unlikely, Almost certain]	[Medium, High]

Immediately after the crash, Sleipner notified the authorities of the accident via Rogaland Radio which was relayed to the Joint rescue coordination centre for the South of Norway. Rogaland Radio transmitted a Mayday and vessels that were within 30–40 minutes of the incident area where requested to approach the shipwreck. A Sea King rescue helicopter was also requested. The rescue helicopter arrived on the scene at 20 : 10.

The boat sank about 35 minutes after it hit the rock. 69 persons where rescued from the sea alive, by the assisting vessels and the helicopter. 16 persons drowned.

The investigation committee found several problems with the evacuation programme and fleet arrangement at the boat. They were also critical of how the captain and crew handled the incident. In this paper, however, we only focus upon the findings regarding the official rescue operation. Some problems that were discussed were:

1 difficulties with the communication

2 sub-optimal placement of the survivor reception centre; and most importantly

3 late arrival of the rescue helicopter.

(1) and (2) were not found to have any bearing on the outcome of the incident. With regard to the late arrival of the rescue helicopter the investigation committee states that

> "It is not possible to say for certain whether a 15 minute reaction time would have reduced the extent of the injuries of the loss of Sleipner, but it is clear that this would have meant that the helicopter would have left Sola airport 23 minutes earlier." (NOU, 2000b, p.221)

At the time of the Sleipner incident the minimum reaction time of rescue helicopters was 1 hour. Hence, the late arrival of the rescue helicopter was a structural problem and not due to any incorrect decisions by the incident management. The investigation committee made the following recommendation to reduce risks:

- reducing reaction time of rescue helicopter to 15 minutes.

3.1.4 The Lillestrøm accident

A goods train with two propane tanks collided with another train at Lillestrøm station on the night before Wednesday April 5, 2000. The two propane tanks were damaged and propane leaked out. After a short time, the propane ignited. The situation was critical and came very close to a BLEVE that would have killed a large number of people and laid Lillestrøm in ruins. About 2000 people were evacuated from the danger zone estimated at 1000 metres from the tanks.

At the time of the Lillestrøm incident the investigation into the Åsta incident, described in Section 3.1.2 was still going on. On April 14, 2000 the mandate of the investigation committee was extended to include the Lillestrøm train accident (NOU, 2001). The mandate of the investigation committee included evaluating how the rescue operation was carried through.

The investigation committee concluded that the efforts of the rescue service prevented the Lillestrøm accident from developing into a catastrophe that would have had enormous consequences. Good emergency preparedness, access to suitable equipment and a good supply of water prevented an accident on a very large scale. But, the margins were small: Computations conducted by ComputIT on assignment by the investigation committee show that if the wind had been stronger, or the temperature higher, a BLEVE would most likely have occurred before the point in time when the rescue personnel started cooling of the tanks.

The investigation committee stated that there was an 'imminent danger' of a BLEVE (NOU, 2001, p.107). We have interpreted 'imminent danger' as *very likely*. We assign the consequence *catastrophic* to the event that a BLEVE occurs, as the expected outcome of a BLEVE fulfils the definition of *catastrophic* in Table 1. The incident BLEVE has been assigned the risk value *high*, in accordance with the risk matrix defined in Table 7.

Table 7 Risk related to the Lillestrøm accident

Threat scenario	*Potential incident*	*Consequence*	*Likelihood*	*Risk level*
Burning propane	BLEVE	Catastrophic	Very likely	High

The investigation committee notes that the incident management did not have the necessary knowledge to assess the risk level in the early stage of the rescue operation. As a consequence of this, measures to reduce the risk level, such as evacuation of civilians were launched too late. The total extent of the risks was not properly understood until external expertise arrived to assist the incident management. Table 8 summarises the decisions that affected the risk level during the emergency response.

Recommendations from the investigation committee addressing risk reduction:

- the Liquefied Petroleum Gas (LPG) of Scandinavia establishes a joint strike force for accidents involving LPG with good access to fast transport of persons and equipment

- the authorities and the LPG industry together develops a training program that makes the fire service better equipped to consider counter measures in connection with accidents that can lead to a BLEVE.

Table 8 Decisions affecting risks related to the Lillestrøm accident

Decision	*Reason for decision*	*Effect on risk level*
No evacuation of civilians in early phase	Underestimation of risks due to lack of knowledge	Increased consequence of BLEVE
Placement of the Command post at scene of accident	Underestimation of risks due to lack of knowledge	Increased consequence of BLEVE
Inefficient cooling of tanks in early phase	Insufficient knowledge	Increased likelihood of BLEVE
Slow restart of cooling after failed extinguishing attempts	Underestimation of risks due to lack of knowledge	Increased likelihood of BLEVE

3.1.5 Froland forest fire

The forest fire in the Froland municipality in June 2008 lasted from June 9 to June 22, 2008. This was the largest forest fire in Norway in modern history, with a total of 22 cabins and 2–3 sheds burned to the ground and 19 km^2 forest lost. Strong wind caused the fire in Froland to re-ignite after it was considered to be under control. The largest part of the damage occurred after it re-ignited the second time (11 km^2). The total cost related to the Froland forest fire is estimated to about 48 million NOK (23 mill. for extinguishing the fire + 25 mill. in insurance money) (Brunvatne, Det Kongelige Landbruks- og Matdepartement, 2011).

In the aftermath of the Froland forest fire a working group was appointed to review the forest fire preparedness and the handling of recent forest fires (Arbeidsgruppe skogbrannberedskap, 2008). The mandate of the working group included reviewing relevant experiences from forest fires, with a particular emphasis on the Froland forest fire.

The working group stated the following about the handling of the Froland fire:

> "The Froland fire is an example of the importance of recognising and understanding the potential forest fire hazard and the development of the fire at an early stage and scale the response accordingly. With such an understanding the effort to control the burned areas could have been organised and carried through in such a way that the fire was not given the opportunity to re-ignite on the second day." (Arbeidsgruppe skogbrannberedskap, 2008, p.19)

Hence, according to the working group there was a potential risk for re-ignition of the fire that was not acknowledged by the fire chief in charge of the operation to extinguish the fire. Based on the estimated total cost of the forest fire, and the amount of forested areas that where lost after the fire reignited, we estimate the consequence of the potential new event (loss of more productive wood) to be *major*, according to the scale defined in Table 1. As we understand the comments by the working group there was sufficient information available in the early stage of the operation to realise the potential of such an event. Hence, we assign the likelihood *likely* to the related risks, see Table 9. Table 10 summarises the decisions affecting the risk level during the operation to extinguish the Froland forest fire.

These are the recommendations from the investigation committee addressing risk reduction:

- introduce Incident Command System (ICS) for the Norwegian fire service
- organise regional courses in extinguishing forest fires
- establish national support teams as an aid for the incident command in fires.

Table 9 Risk related to the Froland forest fire

Threat scenario	*Potential incident*	*Consequence*	*Likelihood*	*Risk level*
Re-ignition of fire	Loss of more productive wood	Major	Likely	High
Re-ignition of fire	Costly extinguishing operation	Major	Likely	High

Table 10 Decisions affecting risks related to the Froland forest fire

Decision	*Reason for decision*	*Effect on risk level*
Inadequate mop-up	Lacking acknowledgement of the potential for spreading of the fire due to lack of knowledge and training	Increased likelihood of re-ignition of the fire

3.2 Data synthesis

Based on the results from the investigations we identify the following categories of faults related to decision making during emergency response operations that contributes to an increased risk level:

- counter measures are launched too late
- counter measures are inadequate
- counter measures are terminated too early.

The two main reasons for the faulty decision identified as:

- risks not assessed or taken into account
- risks are underestimated.

Table 11 summarises the findings from the five investigations documented above.

Table 11 Summary of findings

Incident	*Decision*	*Reason for decision*	*Effect on risk level*
Ålesund	Counter measures are launched too late	Risks not assessed or taken into account	Increased consequence of potential risk
Åsta	None	None	None
Sleipner	None	None	None
Lillestrøm	Counter measures are launched too late	Underestimation of risks due to lack of knowledge	Increased consequence of potential risk
Lillestrøm	Counter measures are inadequate	Underestimation of risks due to lack of knowledge	Increased consequence of potential risk
Froland	Counter measures are inadequate	Risks not assessed or taken into account	Increased likelihood of potential risk
Froland	Counter measures are terminated too early	Risks not assessed or taken into account	Increased likelihood of potential risk

4 Counterfactual reasoning

An important reason for investigating large incidents is the need to learn from them, so that similar situations can be avoided or handled in a better way in the future. Investigation reports will therefore often make explicit or implicit claims about what could have happened if some circumstances had been different, such as the responders choosing a different course of action from the one actually taken. In other words, they employ counterfactual reasoning. It is therefore worthwhile to take a look at the challenges associated with such reasoning. In the following we first present briefly some of these challenges, before discussing the use of counterfactual reasoning in the investigation reports.

4.1 Challenges of counterfactual reasoning

Counterfactual reasoning has received much attention in the fields of history and political history, and remains a controversial issue. However, as explained by Bunzl (2004), if historians want to make causal claims, then implicit counterfactual claims come along for the ride. Stating that event B followed because of the preceding event A implies that if event A had not happened, then B would not have happened either. Of course, the same applies to those who write investigation reports. Hence, the goal is not to avoid all kinds of counterfactual reasoning, but to ensure that conclusions can be properly justified. As noted by Jervis (1996), this can be extremely difficult when dealing with a complex system of interconnected units. In such a system we cannot imagine a change in one unit, without also considering the impact this would have on all the connected units. For example, when reasoning about whether double hulls on oil tankers would have led to fewer oil spills during a given period, we would also need to take a number of other considerations into account. Would the captains then have taken more chances, knowing that their ships were less vulnerable? Would the shipping companies, due to higher cost of double-hull tankers, have spent less on other safety measures? Both these factors – as well as a number of others – could impact the amount of oil spills.

Tetlock and Belkin (1996) proposed six criteria for judging counterfactual arguments. The first criterion is clarity, meaning that the hypothesised antecedent and consequent should be specified and circumscribed. The second is logical consistency or cotenability, meaning that connecting principles should be specified that link the antecedent with the consequent. Furthermore, these connecting principles should be cotenable with each other and with the antecedent. The third criterion is historical consistency, also called the minimal-rewrite rule. This means that antecedents should be specified that require altering as few 'well-established' historical facts as possible. The fourth and fifth criteria concern theoretical and statistical consistency. Finally, the sixth criterion is projectability, meaning that we should seek testable implications of the connecting principles and check these against additional real-world observations.

4.2 Counterfactual reasoning in the investigation reports

All investigation reports included in this review makes counterfactual claims to some degree, and we now illustrate with some examples. Many of the claims concern things that, even if they had been done differently, would not have had an impact on the final outcome. For example, the Ålesund landslide investigation report states that no more victims could have been rescued even if the search and rescue had continued for a longer period (Ålesundsutvalet, 2008, p.124). This is justified by referring to information received by the investigators after the emergency, but no more details about this information are given. Similarly, the Åsta investigation report states that even if the brief interruption of water supply that occurred when switching from the water tank on one truck to another had been avoided, then this would not have any impact on the failure to put out the fire in time (NOU, 2000a, p.261). The report explains that the water supply from the tanks in any case was insufficient, and lists a number of additional circumstances that explain why the fire fighters were not able to put out the fire in time.

The Froland report, on the other hand, states that if the responders had had a better understanding of the potential dangers of the forest fire in an earlier phase, then they could have organised the extinguishing of the fire in a way that would have prevented the fire from flaring up again on the second day (Arbeidsgruppe skogbrannberedskap, 2008, p.19). It does not go into more detail about how this conclusion was reached.

Among the investigation reports included in this review, the Lillestrøm report (NOU, 2001) is by far the one that goes furthest in counterfactual reasoning. There are separate subsections devoted to analysis of alternative courses of events (Section 9.2.1.2), how close we came to a catastrophe (Section 9.3) and what the impact of different weather or a larger gas leak would have had on the outcome (Section 9.4). The report makes a number of clear counterfactual claims. For example, on page 97 it states that if the fire fighters had not been able to cool down the tanks at the time they did, then we would have had a catastrophe by four o'clock in the morning. On the same page it also states that if the weather conditions had been different, then a BLEVE would likely have occurred before the cooling of the tanks was initiated. These counterfactual claims are based on two other reports produced by different companies to analyse how close we came to a catastrophe. These two reports arrive at similar conclusions even though their methods differ, thus significantly strengthening the basis for the claims.

From the overview above it may seem that most of the counterfactual reasoning concerning the emergency response in the investigation reports fall far short of fulfilling the criteria proposed by Tetlock and Belkin, at least when it comes to explicit justification. However, the counterfactual claims made in the investigation reports are of a quite different nature than the kind of claims historians might typically make. The claims presented above all deal with a short time frame, from a few hours to a couple of days. Moreover, many of them are related to physical processes, such as the amount of water needed to put out a fire or cool down a tank. Such questions can often be addressed through use of established theory, simulation, experiments, or simply experience. Although an emergency response might in some senses be viewed as the kind of complex system of interconnected units discussed by Jervis, the processes involved in the counterfactual claims discussed above are, after all, comparatively simple. This, in addition to the need to keep investigation reports reasonably short, means that addressing all the criteria proposed by Tetlock and Belkin explicitly may not be desirable. Even so, we believe that investigations may benefit if investigators keep these criteria in mind when making counterfactual claims.

5 Discussion of results

As documented in Section 3, three of the five reviewed investigations documented that lack of knowledge in the early phase of operations, before the external expertise arrives, was the most important factor affecting risks. Lack of acknowledgement of the potential for escalating of a situation leading to new risks in three cases lead to inadequate counter measures, which again lead to either increased likelihood or increased consequence of a potential risk. It is important to note that we have reviewed the *potential* for new events that may harm rescue personnel and civilians after an incident has occurred – not what actually happened. In two of the investigated incidents the risks did not materialise and luckily no one was harmed and no material values were lost due to shortcomings in the decision making. In one of the investigated incidents, however, lacking acknowledgement of the risk level lead to decisions that the investigation committee found to cause 11 km^2 of forest to be lost, thereby heavily increasing the consequence of the present risk both in terms of lost property and increased costs of the rescue operations.

An investigation into a discotheque fire in Gothenborg in 1998 that claimed 63 lives showed similar results with regard to factors affecting risks during the rescue operation. This investigation was not included in our review, as it did not fulfil the selection criteria, but we found it interesting to go through the report of the committee investigating the fire (Statens Havarikomission, 2001), to compare with the results of our review.

Four youths started a fire in the emergency exit of the hallway of the discotheque after a quarrel about the entrance fee with the organisers of the party. The fire developed rapidly and when it was detected later by the participants at the party, the intensity was so high that the rest of the building very soon filled with smoke and flames. At that time 375 youths were in the building. Of these 63 died and 213 was taken to the hospital. 40 persons needed medical care for at least a week and several of these had serious injuries.

The committee investigating the fire identified several factors of the response that affected the risk level. We have listed some of them in Table 12. The types of faults related to decision making and the reasons for them fits the categories found in the Norwegian investigations, described in Section 3.2.

The investigation of the Gothenborg incident supports what we view as the most important findings of our review:

- Risk analysis during emergency response is highly challenging. It requires knowledge about general risk analysis, i.e., how to identify potential risks and assess their likelihood and potential consequence, as well as knowledge about the specific domains of relevance for each incident.

- Responders often lack this knowledge. As a result, they often adopt a reactive rather than a proactive approach, thereby allowing incidents to escalate.

Our findings indicate that better and faster access to necessary information and knowledge is necessary to reduce risk factors in rescue operations. In order to address this problem investigation committees have recommended to establish task forces of experts and trained leaders with access to quick transport, in order to aid the local rescue team in large operations. Improvement of the training and education of fire services has also been proposed.

Table 12 Decisions affecting risks related to the Gothenburg discotheque fire

Decision	*Reason for decision*	*Effect on risk level*
No fire extinguishing while life rescuing was going on	Reactive decision making, focusing at the problems at hand. Other risks not assessed	Possible increased likelihood of civilian deaths due to escalating fire in the building
Too few fire squadrons allocated to the scene in the initial phase	SOS central did not grasp the seriousness of the situation. Inadequate communication and cooperation between the SOS central and the operation central of the fire and rescue service. Reactive thinking on-scene.	Increased likelihood of civilian deaths due to inadequate rescue effort
Too few ambulances allocated to the scene . in the initial phase	SOS central did not grasp the seriousness of the situation.	Possible increased likelihood of civilian deaths due to shortage of ambulances

An important question is whether the proposed recommendations are sufficient to provide rescue personnel with the necessary expertise in the very early critical phase of an operation. As noted by the investigation of the Åsta incident:

> Normally there will always be a deficit of professional rescue personnel in the early stage of a large incident, no matter where they happen." (NOU, 2000a, p.264)

In the light of this we believe that the following significantly contribute to improved risk analysis during emergencies:

- All first responders should receive training in general risk assessment.
- Suitable methods and tools should be adopted to ensure that the first responders can receive necessary support from the first phase of an emergency. The methods and tools should facilitate support from external domain experts as well as the command centre.

How to design such methods and tools is an interesting subject for further research.

6 Threats to validity

In this section we discuss the quality and validity of the selected primary studies and threats to validity of the review in general.

A possible threat towards the validity of a review of incident investigations, is that it only presents the subjective view of the investigation committees with regard to what the risks were, and not the objective, or actual risks. It has been argued that reconstruction of on-scene behaviour is difficult, due to the widely held view that firefighters make decisions based on the so called Recognition-Primed Decision (RPD) model (Klein et al., 1988; Ross et al., 2004). This model describes how humans make decision in situations with extreme time pressure and where the consequences of the decisions could affect lives and property. Based on a study of decisions made by fire ground commanders, RPD describes how decision makers recognise a plausible course of action as the first one to consider, instead of comparing several courses through thorough analysis. Since this type of reasoning is difficult to reconstruct at a later stage, it is argued that researchers must assess the response in real time, and not only base their research on logs and interviews afterwards. Participatory action research is advocated as a viable method for studying incident command on-scene (Njå and Rake, 2008).

Despite the arrangements to ensure the quality of public investigations, there have been controversies surrounding the outcome of investigations. Investigations from recent years and in particular the investigation into the Åsta-incident in 2000, have been criticised for being too heavily dominated by engineers that promote theoretical solutions far removed from the everyday needs of the practitioners. The investigated enterprises have requested more dialogue and involvement and fewer decrees from the authorities. The investigation committees have even been accused of using the investigations as a lever to promote the use of risk analyses offered by their own industry (Njå and Rake, 2002).

In spite of these criticisms, we believe that publicly appointed investigations are a useful source to systematically review factors that affect risks related to decision making in emergency operations. We also believe that a systematic survey, as presented here can supplement results obtained through more direct methods, such as for example participatory action research.

Large incidents normally happen without warning, so investigators or researchers are rarely in place to observe the rescue operation in real-time. Interviews and checking of logs after the incident are therefore the best available sources of data for uncovering the course of events. The resources available to investigation committees for uncovering all relevant aspects of an incident are on a scale seldom available to us as researchers. The scale of the technical investigations in public investigations provide a unique source of information which is only possible to obtain through analysis of events afterwards, not through direct observation. A review of such reports is therefore, in our view, highly worthwhile for studying the way risk considerations affect decision-making during an emergency.

One potential weakness of this study is the small number of emergencies that are covered, so one might ask to what degree results can be generalised. The reason for the low number is that, fortunately, few large incidents occurred in Norway in the selected period of time. To increase the number of emergencies we would have to either cover a longer period of time or include smaller incidents or incidents occurring outside of Norway. All these options would defeat the original aim of our study. Although we realise that more cases would have strengthened the results, we are convinced that valuable lessons can be learned from the incidents that are covered. Finally, one may ask whether any unified conclusions can be drawn from such a diverse set of incidents. But the point is that they are all large incidents that are handled by similar types of actors and organisations. Given the goal of the study we therefore do not view the diverse character of the incidents as a threat to the validity of the results.

7 Related work

The research project (AcciLearn, 2011) is undertaking a review of investigations of two large incidents (NOU, 2000a, 2000b) in order to investigate what have been learnt from the investigations in terms of changes in organisational structure, management and technology that can be traced back to recommendations made by the investigation committees reports. The results from AcciLearn will provide interesting insights into the needs of rescue personnel during rescue operations. The scope of AcciLearn is, however, different from the one in this paper. AcciLearn has no particular focus on risk, but rather on what have been learnt both about preventing incidents and handling them, by all involved parties.

Several researchers have reviewed historical data obtained from incident investigations and interviews to study incident commanding. For example Klein et al. (1988) and Ross et al. (2004) developed the so called Recognition-Primed Decision (RPD) model based on a study of decisions made by fire ground commanders. RPD describes how decision makers recognise a plausible course of action as the first one to consider, instead of comparing several courses through thorough analysis. Fredholm (1997, 2000), Fredholm and Gøransson (2010) has later criticised the RPD model for having major shortcomings in handling crises with a high level of complexity and a number of different actors involved in combating the crisis. According to Fredholm the needs inherent in the crisis must be the key factor when decisions are made. The studies of Klein, Fredholm and other similar studies (Flin, 2011; Tissington, 2001) address the question of how decisions are made and how decision-making can be improved, whereas we have focused solely on the question of how decisions affect the risk level during response operations.

A study by Rake (2008) of the command leadership in 22 fires and incidents focuses on how risks are addressed in decision-making. Rake uses so called participatory action research, which involves putting the researcher in a cooperating setting with the crisis responders directly in the on-scene response in real time. His main findings were that leaders do not look ahead, they concentrate on the details rather than the big picture, and they expect to meet known situations. In order to address the shortcomings of current command and control he has developed a model for more effective leadership during incidents in order to handle uncertainty, called risk-based decision making. The findings of the review presented agree with the findings of Rake. For example in the landslide in Ålesund incident command priorities did not address the risk of a gas explosion until after the immediate problems were addressed.

8 Conclusion

We have presented a systematic literature review of investigations of large potential and actual incidents in Norway between 1999 and 2008. The purpose of the investigation has been to identify factors that have been documented to affect the risk level during emergency response.

In order to ensure relevance of the reviewed investigations, we required that the incident should be potentially large enough to instigate an investigation appointed by the Norwegian Government or another department of public administration. We only included investigations whose terms of reference includes an evaluation of how the rescue operation was carried out. Furthermore, we excluded investigations conducted before 1999, assuming that the rate of reforms and reorganisation of emergency planning implies that problems documented in operations more than ten years ago is less relevant than more recently documented problems. Based on these selection criteria we selected 5 investigations.

We found that the most important factor that was documented to increase the risk level in the investigated incidents was lacking acknowledgement of risks due to lack of knowledge or lacking assessment of risks, causing inadequate counter measures. The most critical mistakes are made during the early stages of the response operation, before the external expertise arrives on the scene. We are not aware of any assembled overview of investigations of emergency response and rescue operations in Norway for the purpose of comparing mistakes and shortcomings affecting the risk level.

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Appendix A: definitions and abbreviations

Table A1 Definitions and abbreviations

Term/acronym	*Definition*
Command post	The place from where an emergency response and rescue operation is lead at the tactical level (on-scene command point) (PBS, 2007)
DSB	The Directorate for Civil Protection and Emergency Planning
Emergency response	The actions taken during and after an accident to reduce casualties and damages and to minimise the impacts of an accident (Rake, 2008)
Incident commander	The incident commander is the predetermined manager and leader. The incident commander is ultimately responsible for all activities that take place at the incident ground (Bigley and Roberts, 2001)
Incident managing	Facilitating the emergency response of the three emergency departments (fire, police, ambulance), and coordinating resources and support functions (PBS, 2007)
Joint rescue coordination centre	The Joint rescue coordination centres have the overall operational responsibility during search and rescue operations[a]
Large incident	A sudden event satisfying at least one of the following criteria: five or more deaths or irreversible disabilities; damage to property or equipment for more than 30 million NOK; irreversible environmental damage (Sundet et al., 1990; Jersin, 2001, 2003)
The incident management	The incident management is responsible for incident managing. It usually consists of the incident commander and the technical commanders for the fire- and medical services (PBS, 2007)

[a] http://www.hovedredningssentralen.no/, Accessed December 17, 2011.