Accident Investigations: Paradoxes, Trends and Opportunities

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Abstract

During the last decade, accident investigations have gained much attention due to the fact that major accidents have occurred worldwide. In particular, the transportation industry has suffered severe accidents with many lives lost, and public debate has continued long after the accidents occurred. This paper describes some observations and discusses some lessons learned from major accidents in aviation and shipping. Four dominant factors appear to be present: changes in the aviation industry, changes towards the notion of 'integral safety,' changes in administrative and political response to major accident occurrence, and changes in the role of accident investigation practices. These changes reveal paradoxes in emergency and rescue strategies and call for new approaches to integration of emergency services. These changes also influence the role of transport safety boards and call for a possible repositioning of the accident investigation concept. A combined effort is required to manage emergencies and to understand disaster.

Introduction

In October 1996, the Congress of the United States of America passed the Aviation Disaster Family Assistance Act. This act followed the president's executive memorandum asking the National Transportation Safety Board (NTSB) to be the lead federal agency for coordinating federal assets at an accident scene. The legislation gave the Board the authority to bring together various federal, state, and local government agencies to better serve the victims of transportation accidents and their families. The need for such legislation emerged from a number of major accidents in aviation in which relatives and families were left unprotected by the authorities. In meetings with NTSB, numerous experiences were exchanged regarding lack of information, untimely notification, misidentified remains, personal effects being mishandled, unidentified remains not being handled with dignity, and the use of confidential information obtained during the grieving process in the litigation that inevitably followed. At a time when they most needed guidance, assistance, and compassion, relatives and families felt abandoned and sometimes abused.

The approach of assigning such a family-assistance task to a special force proved its value in several serious accidents, including aviation crashes, bus accidents, and cruise ship fires. As a result, for the first time, there is an effective coordinator on the accident scene who can integrate the major resources of the federal government and other organizations to support the efforts of local and state government agencies and the airlines to better meet the needs of victims and their families. At the same time there now is an entity available to help these stakeholders to be more proactive, so that they are better prepared in advance of an accident. Especially in these cases where recovery of victims and wreckage from an en-route crash is extremely difficult, a cooperation between all parties involved should be coordinated. The existence of such a family support organization proved its validity in the Korean Air 801 crash, where compassion combined with adequate planning and coordination facilitated the success of the program. Due to the involvement of many foreign parties in an aviation crash, the US Congress expanded its legislation to foreign air carriers, impelling foreign carriers to give due consideration to family assistance and support in their emergency response plans. The Swissair 111 crash proved the validity of this requirement, where Swissair and its code-sharing partner Delta Airlines had a plan which allowed them to respond quickly and effectively to the needs of the victims' families.

This development of family assistance has also been expanded to the maritime sector as the result of major accidents with passenger ferries in the Scandinavian waters and cruise vessel fires in the Caribbean. The Estonia capsized on 28 September 1994 in the Baltic Sea, taking the lives of 852 of the 989 passengers on board. The tragedy caused a public debate about whether to recover the bodies from the wreckage or to cover the remains by a concrete casing. Finally, it was decided to leave the remains of the victims in the wreck on the seabed. During the investigation process by the Joint Accident Investigation Commission of the Estonia, Finland, and Sweden, several shortcomings emerged in the rescue and emergency activities that were undertaken. A significant factor in the Estonia accident was the very quick increase in the list to an angle exceeding 30 degrees, leading to the loss of maneuverability and to difficulties in leaving the vessel. As a result, many were trapped and were incapacitated to leave the vessel. Recommendations of the Investigation Commission urged action to develop new life-saving concepts and equipment, especially for passenger vessels where large numbers of untrained people are involved, including the rescue of people from the sea in heavily inclement weather. It was suggested that certain key persons, such as deck officers and rescue center radio operators, should regularly update their practical knowledge of distress and safety communications using a radio simulator. Analyzing rescue activities, several deficiencies emerged, on-site as well as on-shore. Alarms and rescue maydays did not ring in passenger and crew quarters, leaving their occupants unalarmed. The first mayday calls were in Finnish, not in Swedish, after which formal confirmations were required for notification of the accident to the authorities. Rescue at sea was severely hampered by the bad weather and high seas, reducing the capabilities for vessels and helicopters to approach victims in the water. Language problems between professional rescue services occurred by the simultaneous use of

Finnish, Swedish, and English. Finally, the accident occurred in international waters, while passengers of many nationalities were on board.

Search and rescue communications were dominant and prevailed over other communications and information supplied to relatives, local and regional police, and emergency services. By the presence of the mass media, information supplied to this group had to be structured. Because of the time of the day--the accident occurred in the early hours--local police was unprepared, which left families in distress and confused. Grieving facilities for relatives had to be set up all over the country in Sweden, Finland, and Estonia. Eventually, from this tragedy three areas of safety concern emerged: recommendations were made to set up national coordination centers for disasters, family and victim organization in the maritime sector were founded and international regulations were issued by the International Maritime Organization (IMO).

On October 4th, 1992, a Boeing 747 full freighter crashed into an apartment block in the Bijlmermeer near Amsterdam, killing 39 people on the ground and 4 on board the airplane. After six-and-one-half years, a Parliamentary Enquiry was set up to finally conclude the debate on the causes and consequences of the accident. Allegations, rumors, and health complaints had been ongoing for more than six years, disturbing society and eroding public faith in the political system. The ultimate goal of the enquiry therefore was to find the truth and to learn lessons for the future.

Although no major deficiencies during the rescue and emergency activities were found, recommendations were made to improve the cooperation at the site. The most important recommendations, however, focussed on the role of various administrative services and responsibilities of political and administrative authorities. On-site cooperation between investigative authorities and rescue and emergency authorities could be improved. Some parts of the wreckage disappeared from the site because the area was not sealed off. Cooperation between the investigator in charge and local authorities was poor, while the chief investigator was not involved in the decision to accelerate the rate of debris removal. Questions about the hazardous nature of the cargo and the subsequent possible ill-health effects, the presence of depleted uranium, unidentified men in white suits, and the disappearance of the cockpit voice recorder were answered unsatisfactory, if at all. Also, authorities did not ponder on possible health effects of the crash on professionals and civilians beyond the formal definition of hazardous materials. Since local authorities seemed to cope well with the disaster, no formal decision was made to scale-up responsibilities to a higher administrative level. Despite continuous signals and complaints, only long after the crash did various authorities take action to investigate these signals.

A fragmented image of authorities arises from the hearing reports in three respects: divided performance, fragmented organization, and poor coordination. A divided performance is characterized by a reactive and ad-hoc response towards society. Authorities respond only when addressed and restrict their response to partial answers. The division between policy areas characterizes a fragmented organization. Where in practice 'aviation' and

'health' do not meet, they do not meet also during catastrophic events. The lack of a 'one stop shopping concept' severely hampers communication and retrieval of information. Poor coordination between various administrative authorities is demonstrated by the international and national implications of the different legislative and regulatory systems. Aviation is organized internationally, leaving little possibilities for a national administration to deal with aviation crashes. The aftermath of a disaster should not be restricted to the framework of a short-term regular administrative policy, but should be coordinated long after the disaster occurs to deal with long-term effects and consequences. Finally, disaster planning should be based on policy scenarios in which various disasters are elaborated into consequences and hence performance requirements for rescue and emergency services.

Observations and Trends

From the case histories, a number of observations can be made:

- there is an increased public attention to major accidents. Although major accidents are rare events, they attract the public eye and remain discussed long after the event itself. By increasing traffic volumes and passenger numbers involved, especially in aviation and shipping, the absolute number of incidents is likely to grow in the near future, as accident frequencies will remain constant.

- the extent of major accidents in transportation has increased. Not only the number of people involved, but the complexity has increased as well. International composition of crews and passenger population, different legislative systems, and various languages put high demands on communication and coordination.
- administrative organizations and authorities are in their initial phases of responding adequately to major accident handling. A fragmented, divided and uncoordinated image forces itself onto the observer. In general, a low preparation level is combined with ad-hoc response strategies without coordination beyond the level of policy making on isolated aspects.
- the accident site becomes more and more important for reasons of accident investigation, rescue and emergency activities, medical support, litigation and liability aspects, publicity, and grieving of relatives. The accident site becomes a multifunctional and multilingual environment where conflicting interests exist.

These observations are made in a changing context. First, technological changes have influenced the extent and nature of major accidents. Accidents occur within seconds or minutes, combined with a high initial number of fatalities or injuries and therefore have a characteristic 'signature.' This signature puts high demands on rescue and emergency responses, especially when these accidents occur in the public eye. The 'normal accident' phenomenon, as already described by Perrow in 1984 by its parameters of 'complexity' and 'tight coupling,' seems to come to maturity with respect to its

consequences. At the same time, self-reliance of passengers and other risk bearers decreases rapidly due to the 'signature' of the accident sequence. There are simply too many people to be evacuated in too little time. Simultaneously, risk acceptance in society has decreased. Modern society combines a high-risk awareness with a low-risk acceptance with respect to major accident occurrence. The concept of a caring society does not seem to accept major losses, expressed in a high-risk aversion. A fundamental change in rescue and survival concepts seems to be inevitable.

Secondly, an analysis of crisis management in The Netherlands shows an image of fragmentation. An approach of isolated safety aspects by each of the authorities is combined with unfamiliarity of responsibilities by other ministries, a lack of coordination between various types of crises, and a threat of competence struggle. Coordination between policy making at a governmental level and field organizations is hampered by privatization and decentralization.

As a result of the end of the cold war and the passing of the millenium, a re-engineering of crisis management has taken place. The new concept abandons the 'worst-case scenario' and defines 'crisis' as a major incident. Although some incidents may be rather small, they may contain valuable lessons to be learned as well. Simultaneously, the focus has been shifted from the vital role of a ministry towards the field organizations, where coordination and context are dominant factors. Principal requirements in the new concept are networking, disaster planning, and quality assurance, including training and exercises. The concept of a 'pilot flame' organization, which should be activated in case of warfare, is abandoned in favor of integrating crisis management in regular policy making and emergency planning activities. Topics focus on environmental pollution, transportation, flooding hazards, hazardous material incidents, underground infrastructure, and information network breakdown.

Finally, the notion of safety has been changed. The concept of 'Integral Safety' has expanded beyond a sectoral approach in which working conditions, internal safety, external safety, transportation safety, social safety, and rescue and emergency response each had its own definition and institutional context. Today, these aspects are correlated and seen in a more common perspective with respect to their mutual interactions and preventive and pro-active potential. New areas of safety concern have appeared and put new players in the field, such as rescue workers and victim organizations. Long-term medical effects should be taken into account due to low dose exposure and stress syndromes. Instead of measuring safety levels by defining Individual and Group Risk standards, a process approach is favored. This approach delegates responsibilities towards various stakeholders, who must monitor and control their performance. Their responsibilities in safety have increased, and consequently, their attention is drawn to accident causation and liability claims. This may disrupt accident investigation procedures considerably. Finally, a new problem owner has appeared on the stage with a thus-far unique task: in the USA, the NTSB is charged with family assistance and aftercare for accident victims.

Paradoxes

From these case histories, observations, and trends, a number of paradoxes emerge:

- the perception paradox: although technological systems have become more reliable and safer, public perception shows a decreased confidence in their safety performance. Authorities are confronted with very low probability events, which decreases their risk awareness. Responsibilities for safety measures in the 'high-probability/low-consequences' range are delegated to private partners and lower echelons of administration as a shared responsibility. The extent, nature, and frequency of major accidents, however, seems to increase, putting higher demands on a coordinated disaster preparedness of these authorities.

- the preparedness paradox: although major accidents will remain rare events with a relatively unique character by their context and operational conditions and put high demands on improvisation and ad-hoc responses, they require increased and detailed preparedness to avoid social disputes and litigation procedures. At the same time, national authorities delegate responsibilities to lower administrations and private partners. National administration has dismissed its 'cold warfare' role of centralized manager of disasters and crises.

- the chaos paradox: although the site of an accident should be put under control as soon as possible, chaos will increase shortly afterwards by the presence of a wide range of stakeholders with conflicting interests. Accident investigators, police forces sealing off to prevent intruders and plunderers, casualties, relatives, medical services, fire fighters, officials, solicitors, the press, and sensation seekers will visit the scene shortly after the accident occurs. Although the site should be as freely accessible as possible to evacuate victims and people in danger, the site should also be confined to prevent the entrance of unwanted people.

- the integration paradox: although all aspects of accident management come together on the accident site, each and every authority has only restricted responsibility for a limited aspect of the event. Especially when the prevention of similar accidents is discussed, preventive strategies should be based on the identification of systematic deficiencies rather than isolated causal factors and deviations from normative procedures. Societal groups have a broad perception of safety due to their exposure to all aspects of the accident, while governmental agencies and authorities only deal with aspects incorporated in their own policy domain.

To sustain support in society for technological developments, the consequences should be contained within acceptable limits. In several sectors, a concept of 'zero accidents' is introduced, which could be translated into the public domain as 'no catastrophes' with respect to crisis management and major accident prevention.

At this point, several key questions arise: Is it possible to address the paradoxes and integrate safety aspects into new concepts of crisis management and accident prevention? Should we make a distinction between on-site approaches and organizational approaches?

Some possibilities emerge:

- for on-site approaches, a 'one stop shopping' concept seems to have potential. As already experienced in aviation, the one-stop shopping concept addresses the organization and coordination on-site by defining a new problem owner. A new authority is installed to deal with all parties and aspects involved. The most outstanding example in this development is the new role of NTSB dealing with family and victim assistance. Such an agency should apply a broad safety perspective, incorporating all perspectives in dealing with the accident. Such an authority should not necessarily be a local authority, such as a mayor. Professional expertise, operational experience, coordinative, and communicative components probably require a dedicated agency, irrespective of local contexts or conditions.

- notification, communication, and information management could be centralized and standardized, as is already the case with the Global Maritime Distress and Safety Systems. Experiences with major shipping incidents indicate the possibility of an off-site coordination of an event without jeopardizing coherence or performance, and this could even increase the transparency of the process. Coordination with medical disciplines for diagnostic and logistic reasons seems self-evident. Opportunities also emerge with respect to on-line data collection and processing by the availability of Information and Communication Technology (ICT) applications. Data recording and retrieval becomes increasingly important for incident analysis and liability reasons. Not only the causes of an accident could be established, but the crisis and emergency management could be scrutinized as well.

- integration of emergency and crisis management disciplines into one institution. Such an institution could be the focal point to cope with a growing interest in safety. Such an institution could be the coordinating authority for crisis and incident management in a network setting. It could play a pivotal role in coordination between authorities with parochial interests. Although major accidents may play an important role in learning processes, proficiency could be kept up by dealing with minor accidents as well. Road traffic accidents could keep crews alert and well-trained. In case of major incidents, necessary capacity can be mustered by mobilizing spare capacity in an extended region.

Changing Context in Accident Analysis

Aviation

Major changes in the aviation industry are in progress. They can be characterized by:

- merging carriers. A transition is taking place in which former national airlines merge into multinational private enterprises. Eventually, a limited number of global players will remain in commercial aviation.

- privatization and delegation of responsibilities to private partners. Formal governmental responsibilities and administrative procedures are delegated to private partners, monitored by notified bodies. Air traffic control and airport infrastructures are becoming privatized.

- new tasks and focuses on victim care and family assistance. Working conditions of rescue and emergency workers as well as long-term exposure consequences are debated.

- internationalization of production processes and manufacturing of aircraft. A complex system of co-makers and subcontractors has been established throughout the industry, leaving two major players in the branch; one European and one American manufacturer.

- introduction of new design methods and project management concepts, introducing user experiences, ICT support of design decision-making, and collaborative engineering concepts.

- a worldwide implementation of ICT applications, introducing new concepts such as free flight, adaptive control, or on-line in-flight data recording.

Consequently, accident investigations are confronted with these developments, requesting a response to these changes in external conditions.

Accident investigations

Due to these changes, there is a growing need for investigation resource management. On the one hand, due to the increased complexity of aviation and shipping accidents and the importance of family assistance and after-care, efforts in a singular accident investigation increases. The absolute number of major accidents causing public concern seems to increase as well. By its reputation, NTSB is confronted with an increasing request for assistance in non-US involved accident investigations. This calls for selectivity.

On the other hand, the shift in focus towards systems deficiency identification makes different demands on accident selection, investigation skills, and resource allocation. In addition to substantive abilities such as operational experiences and qualified skills in the mode, accident investigators have to deal with methodological issues in order to adequately conduct a qualified investigation and to manage and control the fact-finding process on-site.

Role of investigators

Due to these changes, the roles of investigator and chairman of accident investigation teams are gradually changing. During the evolution of accident investigation committees into safety boards, the role of investigator and chairman of the board have become separated. In smaller organizations, early

evolutionary steps, and non-permanent committees the roles merge, while in further steps of evolution the roles have been separated completely. In a first step, the 'playing captain' leads the investigation as the chairman of the committee. In a second step, a 'non-playing captain' chairs the committee during hearings prepared by a pre-investigator, ad-hoc assigned by governmental or other organizations. In a next step, a permanent investigator appointed by a governmental agency, reports his findings to the judgement of a committee. The chairman and his committee may serve as an 'appellate court' or 'commentator' on the findings. In a next step, the roles are separated institutionally with respect to the independence of the investigator from governmental agencies. An investigator in charge reports to a chairman of the safety board, serving as an 'in house team' with distinct responsibilities. Finally, the role of the investigator changes by adding a managerial component to its substantive nature. The board, its chairman, and its investigator in charge participate in a wider knowledge network and act as 'knowledge purchasers,' focussing on their principal role of being qualified and independent experts.

In this final phase, a separation exists between responsibilities for fact-finding and deficiency identification versus recommendations and feedback. These responsibilities can be allocated to different individuals. The systems' complexity forces investigators to teamwork in managing knowledge, expertise, quantity of information, speed of the investigation process, and mutual discussion between team members in dealing with their working hypotheses.

Accident Investigation Methodology

The transition from establishing the probable causes of an accident towards the identification of systems deficiencies bears consequences for the concept of accident causation. Establishing probable cause pre-assumes a deviation from a 'correct course of action' and focuses on compensation for such shortcomings. The concept of probable cause is normative with respect to human behavior and, by its nature, concentrates on the systems level, where operator performance is at stake. Juridical records of accidents tend to focus on liability and blame. It is not surprising that statistical analysis shows an 80% human behavior involvement. A strong bias towards the 'human factor' is the inevitable result.

Identification of systems deficiencies makes no use of a normative concept in identifying deviations. This approach focuses on identification of several possible sequences of events, expressed in a limited number of accident scenarios. For this reason, various working hypotheses are tested during the investigation process. Establishing such accident scenarios provides safety experts with a unique instrument to enhance safety: Scenarios are open to intervention by a variety of opportunities to interrupt the sequence of events or by eliminating necessary links in the chain by taking safety measures or by design modifications.

Just as an examination of one patient gives no indication of a syndrome, one accident does not effectively show a pattern or trend. Combining several

accidents may provide a pattern in hindsight, leading to systems deficiency identification, and may explain thus-far unsolved accident occurrences. However, such an effort requires a structured search strategy from the investigator, and management of his data support and his hypotheses. It also requires a multi-disciplinary investigation team. When an accident will occur is determined stochastically. Finding causes is a deterministic process. Therefore, accident investigation is performed on the demarcation lines between causality and correlation.

Accident analysis is not only a unique approach that has proved its value in practice, but also a necessary condition to provide feedback to systems performance and to adjust system deficiencies. It facilitates a 'zero accident' approach in aviation and shipping, similar to nuclear power and process industry.

Paradoxes

From the above observations, a number of paradoxes arise:

- the redundancy paradox. Due to the transition from mechanical equipment towards electronic equipment, less data may be physically retrievable on-site or may be lost due to power failure. At the same time, more information is required to reconstruct the complexity of task performance and its environment, and this information may be present in an electronically recorded format. Abundant information of operator and vehicle performance may be available, while information on other system components, such as air traffic control and other shore-based systems representing a complex systems configuration, may be lacking.
- the overexposure paradox. The availability of operational parameters by Flight Data Recorders and Cockpit Voice Recorders facilitates a detailed reconstruction of complex operational environments and operating strategies. Recording additional data such as voyage parameters, voices, and video images may increase the amount of available information considerably. Opportunities originating from other systems' life-cycle phases or systems levels revealing the involvement of other, non-operational actors and factors may remain concealed if the investigation process focuses on on-site data collection and analysis. By their generic nature, these causal-relation towards and significance for singular accident sequences may not be revealed.
- the selectivity paradox. In general, data recording will supply abundant information to facilitate accident reconstruction and analysis. However, not all data supply necessary information for systems deficiency identification. Recovery of all physical items and data from a site may flood the information processing and complicate the establishment of actual contributing factors in the causation of the accident. Recovery of all items and information may be very costly, influencing the cost-effectiveness of accident investigation and allocation of scarce resources. A definition of critical information needs and process parameters seem to be required.

- the credibility paradox. In a complex and major accident investigation involving high-tech equipment and major players, dominant players may settle for consensus on accident causation for liability and litigation purposes. They do not necessarily focus on systems deficiency identification. To achieve a sustainable support for research findings and acceptance of recommendations, all actors should be able to accept the results of an investigation. The independence and control over the investigation process and outcomes should be guaranteed.
- the transparency paradox. Insight into systems performance is required based on quality assurance considerations, such as the Flight Operations Quality Assurance program in aviation. This quality control generates a need for data and information management systems. The transparency of the operator's working environment will increase. At the same time, involvement of management and administration may be obscured by application of the 'no need to know' principle. A lack of transparency at managerial and administrative levels could leave deficiencies in the system undetected.

Accident Investigation, a SWOT Analysis

To identify issues for future development of accident investigation methodologies, a partial SWOT analysis has been performed on the threats and opportunities (Strengths, Weaknesses, Opportunities and Threats).

Threats

Finding the truth about accident causation requires specific skills and a distinct investigative methodology. Such skills and methodology are not identical with scientific approaches and procedures. An encompassing and structured search strategy is required to identify all possible causal factors, which have to be tested and falsified to exclude them from an eventual causal chain of events. Such fact-finding, however, has to be put in a systems perspective. Scientific research, in contrast, focuses on experimental verification of assumptions, derived from a theoretical framework with implicit scientific paradigms involved. Although scientific proof of the existence of a causal factor may well be required, the methodological distinction should be recognized. Until recently, this investigative methodology has not been made explicit to researchers outside the safety board community. This poses a potential threat to the safety board community if the concept of inter-modal learning has to be introduced for new entrants in this community. A scientific approach may be applied without regarding the methodological differences.

Investigating modern aviation accidents becomes more complex by the technology involved, the complex operational environment, and the diffusion of safety arguments in decision-making during design and operation. Due to the low accident frequency and the required quality of the investigations, a proficiency issue occurs. Apart from the NTSB, where a high accident frequency is manifest, investigators may suffer from maintaining their proficiency in major investigations.

Costs of investigations are huge, especially where debris has to be retrieved from inaccessible areas. A first estimate of overall costs indicates amounts equivalent to replacement costs for aircraft and vessels. Consequently, questions are raised about the cost-effectiveness of such expensive learning from accident investigations. Also, the costs for taking the consequences are huge. Allocation of blame and responsibilities for the consequences seems to shift from operator levels to organizational levels. Delegated responsibilities put liability on private partners. In combination with a managerial, administrative, and political tendency to apply the 'no need to know' principle, risk is delegated or obscured. Instead of learning to increase reliability, a tendency to reinforce liability mechanisms seems to occur. A financial compromise between partners on liability issues may become a reflection of the 'shared responsibility.'

A mystification may occur as a result of the shift in focus from fact-finding into the causes towards the aftermath of a major accident. Although the need for analyzing the complexity and multicausality remains, public attention is focusing on administrative and political consequences, especially in case of a Parliamentary Enquiry. A technical-analytical safety investigation becomes dominated by safety as a consensus notion between stakeholders as a 'social construct,' or as a public perception dominated by normative awareness of risk. Thus, rationality as a basis for decision-making and recommendations may erode.

Designing and manufacturing aircraft has become a highly complex activity. A tendency seems to emerge in accident investigation of non-interference with technological issues. Reasons for such a non-intervention are as follows:

- a delegated responsibility exists with the private partners which should be considered an exclusive mandate to develop technology. It should no longer be the responsibility of government to put requirements on product safety performance, but on services and goals, while the manufacturer demonstrates compliance with these safety goals.
- outsiders in such a private partnership situation should not have sufficient knowledge to intervene or participate in the design, development, and manufacturing processes.
- internal decision-making within private partners should already have optimized products and processes to such a cost-effective extent that outsiders should not be able to indicate safety gains in the decision-making processes.
- optimized designs should have such a low failure rate and such a high reliability, that a shift in focus to operational deficiencies is argued. Eventually, 80% of all error is claimed to be human and organizational error.

Also a tendency seems to emerge of non-interference with drawing up recommendations. Such responsibility should interfere with the independence of such safety boards, since recommendations are to be implemented in public and private policy making. Again, only the direct stakeholders in such a process should be able to make balanced judgements on feasibility, costs and effectiveness of the recommendations.

Opportunities

Accident investigation has developed incrementally during an evolutionary process. Originating as an ad-hoc accident investigation committee in aviation, focusing on deviant human behavior and technical failure, it has developed into multi-modal safety boards and an applied concept of learning from accidents and incidents by recommending systemic improvements in design and operations (Kahan 1999). However, a new phase in the evolution of safety boards seems to emerge due to changes in the aviation industry and institutional changes in an international context.

These changes offer opportunities for a next phase, as follows:

- establishing a critical size in the balance of powers among stakeholders by internationalization of safety boards. Co-operation between safety boards and establishing an international association of boards provides a response to internationalization of the industry by introducing a similar scaling-up of activities. The International Transport Safety Association (ITSA) provides such a role.

- maintaining independence from governmental, industrial, and other interests during the investigation process. Although knowledge providers may play an increasing important role, safety boards will have to maintain control over the investigative processes to fulfill their methodological objectives and independence.

- maintain unique resources on strategic knowledge aspects, such as analysis of data recorders and other crucial data sources. Multi-modal learning is possible by exchange of information, experience, and knowledge that may provide generic applicable knowledge across modalities and domains.

- participation in a knowledge network among industry, universities, and other knowledge-providing research institutes. Independent knowledge supply is no longer necessary similar with and restricted to in-house knowledge generation.

- additional focus on design methodological and engineering process issues and analysis of adequate application of safety principles in design and manufacturing. In addition to a product and accident sequence analysis, a safety analysis and assessment of design and manufacturing processes becomes interesting.

- the training of investigators, maintaining skills and proficiency, developing training programs will add to the quality of the investigator performance in

practice. Exchange of investigative methodological experiences among boards and modalities may be profitable.

- expansion of the scope of required disciplines that must be covered by the investigation process. To identify systems deficiencies, to draw up recommendations and to monitor accomplishments requires different scientific and operational skills and qualifications compared to technical-analytical investigation at an accident site.

Concluding remarks

Although observations, trends, and paradoxes only show some first indications of major changes, a number of challenging possibilities and opportunities seem to be present as well. Public support, self-organizing victim organizations, re-engineering of governmental agencies, ICT applications, and integral safety concepts may provide a critical mass for change. In addition to the interest of prevention and pro-action, repression, and aftercare require equal interest since the weakest part of a chain eventually defines the strength. Therefore, safety should be equally integrated in each part of the chain. Additionally, the analysis of major accidents may reveal system deficiencies, leading towards disaster. Due to a number of internal and external conditions, the role of safety boards is changing. Although threats appear to be present, major opportunities exist to adapt accident investigation methodology to demands of the coming century.

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