HARMONY IN DIVERSITY

Methodological issues in independent accident investigation

John A. Stoop

Delft University of Technology[1]

Keywords: Methodology, accident investigation, safety board

Abstract

Performing an accident investigation requires specific skills and a distinct investigative methodology. Such an investigation should be separated from allocating blame and should be based on a systems approach. Such skills and methodologies are not identical with academic methods and procedures and prove to vary across the 5 principal processes. An encompassing and structured case-based fact finding strategy is required to establish an eventual causal chain of events. Such fact finding has to be put in a systems perspective and should eventually lead to acceptable and implementable systems changes. Academic research, in contrast, focuses on experimental verification of assumptions, derived from a theoretical framework with implicit scientific paradigms involved. Although scientific proof may well be required throughout the five investigation processes, this methodological distinction should be recognized. Until recently, this investigative methodology has not been made explicit to researchers outside the safety board community. A methodological evolution of TSB's is discussed and options are explored for co-operation with academic disciplines, as well as possible priorities for global harmonisation with respect to its methodology.

Introduction

<u>Three schools of thought</u>

Safety in modern transportation systems has been an issue for about 150 years. It evolved as a discipline from several different domains and disciplines and has a strong practical bias. Consequently, various 'schools of thought' have been merging, of which the most important can be categorized as 'Tort Law School', 'Reliability Engineering School' and 'System Safety Engineering School' (McIntyre 2000).

Each of these schools represent a different pattern of thinking and can be considered as consecutive, representing the societal and scientific safety concepts of their times. These schools are supported by extensive literature covering a wide variety of domains and scientific disciplines.

The 'Tort Law School' as defined by McIntyre, has a long history and roots in the U.S. railway industry since the end of the 19th century. It goes back to the introduction of safety engineering design in the railway industry to cope with the carnage among railway workers. Lorenzo Coffin is stated to be the first railroad safety advocate and champion of safety legislation in the USA. He was the first in line of a series of safety advocates, followed by people such as Ralph Nader in the

[1] Delft University of Technology, Faculty of Technology, Policy and Management, P.O. Box 5015, 2600 GA Delft, the netherlands. Tel ++31 15 278 3424, email johns@tbm.tudelft.nl

automobile industry or Mary Schiavo in the aviation sector. He had a pioneering voice for the merging of two streams of safety technology and government policy control. Out of this development, an engineering design approach emerged, focusing on certification and standardization of technical designs and products. This development found its counterpart in 'forensic engineering'. This discipline focuses on technical failure and factfinding for the benefit of tort and litigation in liability issues concerning accident investigation, mechanical and structural failure of buildings, constructions and products (Carper 1989). Driven by a number of catastrophic events from the sixties to the eighties of the previous century, legislative efforts expanded safety litigation to almost every area from occupational and environmental to product safety, all modes of transportation and other major hazard activities. Moreover, the concept of failure is central to understand engineering, for engineering design has as its first and foremost objective the obviation of failure (Petroski 1992). Lessons learned from disasters can do more to advance engineering knowledge than succesful machines or technical designs. Such learning does not only refer to enhancing the safety of design products, but refers to enhancement of the design process as well (Stoop 1990).

Reliability Engineering became a new engineering school based on the problems of maintenance, repairs and field failures during the second World War. In communication and transportation, the rapid growth in complexity and automation fueled the development of sophisticated techniques in probabilistic risk assessment (PRA). The drive to understand the likelyhood of hardware malfunctions and errors led to the adoption of PRA in many high-risk industries, including the process industry and energy supply sector (McIntyre 2000)

After laying a basis for the design of man-machine interfacing in the Second World War in the military sector, the ergonomics area rapidly expanded to these industrial domains. It was only a natural development that the focus of mechanical reliability engineering expanded to the area of the human factor, predicting human reliability. Cognitive aspects of human error came to maturity by the work of James Reason, defining and operationalizing the concept of human failure. Most recently, the reliability concept has expanded from the technical aspects into organisational aspects of systems. The concept of High Reliability Organisations by Laporte and Normal Accidents by Perrow examined the complex relation between organizational culture and safety.

The modern Systems Engineering school developed with the dawn of space transportation. This approach focused on accident prevention and was heavily supported by the development of safety standards, specifications and operating instructions. The Systems Safety concept calls for a systems life cycle safety analysis and hazard control actions from the conceptual phase of a system on into the design, development, manufacturing, construction, operation until modification and finally demolition.

However, this quantifcation of risk standards raised questions about the acceptability of such risk levels and the application of scientific methods in assessing design consequences. The terrifying accidents in aviation with the El-Al 747 freighter crash in Amsterdam, the Valuejet crash and TWA-800 underscored the need to draw a distinction between regulatory compliance for 'certification' and 'safety' when communicating risk to the public (McIntyre 2000). Based on the analysis of a series of disasters, the sociologist Turner defined disaster not by its physical impact, but by its social impact: a significant disruption of existing cultural beliefs and norms about hazards and their impacts. He introduced the systems concept to sociological analysis of accidents and expanded the technical systems approach into socio-technical systems. An even further expansion of the systems scope of a disaster redefined disaster as 'crisis': unique events, embedded in the social context in which they occur, irrespective of their origin and causation, deprived from their specific (technological) characteristics. The focus shifts from sectoral and technical-analytical towards social-managerial, in which 'crisis' is a 'battlefield of subjective constructions, definitions and feelings, where objective risk analysis and expert based norms do not work any longer'

(Rosenthal 1999). As a consequence, causes of accidents may remain obscured or even become irrelevant. The complexity and dynamics is assumed to be so overwhelming, that a shift in focus to administrative responsibilities of national and local authorities is legitimate. This concept implicitely restores the notion of blame.

As a consequence of expanding scopes, attention should also be paid to higher order systems levels and post-event consequences dealing with rescue, emergency and crisis management or administrative responsibilities, institutional constraints and policy decision making and policy management issues. Demarcation lines between investigating major accidents and Parliamentary Inquiries become thin. After a major accident or disaster a Parliamentary or Public Inquiry may be installed to find out what happened, focusing on administrative and policy management responsibilities at a national administrative level. Such inquiries however are not functionally independent due to limitations in investigative potential, legal powers and political involvement at a national level in defining their mission statement. Consequently they cannot serve as a substitute for independent investigation agencies.

A fourth school of thought

In addition to these three 'schools of thought' a fourth school has emerged during the last decade. Based on the operational experience of Transportation Safety Boards throughout the world, a school of 'safety deficiency and system change' is developing. Essentially, this school elaborates on the systems engineering approach and transforms notions from accident investigation experiences into a theoretical framework. In this school the concept of independence is crucial, separating the investigative mission and efforts from allocation of blame and vested interests of major stakeholders. This school also separates the investigations from scientific preferences or biases of a technical, behavioral, organisational or cultural nature. A fundamental issue is how to achieve a neutral and objective analytic result as a basis for safety enhancements. Consequently, this school does not focus on 'deviation' from a normative performance, but refers to 'system deficiencies'. It emphasizes the need to implement sustainable safety changes in the system rather than issuing recommendations without monitoring their lasting effects. (De Kroes and Stoop 1992, Hengst, Smit and Stoop 1998, Kahan 1998, Johnson 1999). A 'layered' model of the complexity and dynamics of socio-technical systems is being developed (Evers et al 1994). The focus is on safety critical characteristics in its structure, culture, contents and context with respect to safety critical performance throughout the life cycle of the systems (Stoop 1990). These characteristics can be identified and analysed along the lines of:

- an analysis of the primary processes and relevant actors during design and operation including their safety critical strategic decision making isues. However, such a preventive encompassing analysis is not always feasible in practice due to the complexity and dynamic nature of transportation systems.

Therefore, a second reactive approach is indispensable:

- an in-depth and independent investigation into systemic incidents, accidents and disasters. Such independent investigations may provide a temporary transparency as a starting point for removing inherent deficiencies in such systems.

There is a growing consensus that such investigations may require separate institutions with formal and functional independence such as Transportation Safety Boards with their own, specific methodology (van Vollenhoven 2001, Stoop 2002). The concept of independent accident investigation has a generic potential, expanding its application to other sectors outside transportation, such as defence, other high-risk industry, natural disasters, threats to health and environment, and major events such as explosions, major fires or the collapse of buildings and structures (IDAIP 2001). The concept deals with an integral safety notion: a multidisciplinary investigation into all causes, before, during and after the event.

Independent investigation agencies consequently may evolve into public safety assessors and have a function as gatherers of information across stakeholders and actors. After the TWA 800 and Swissair 111 aviation crashes the American and Canadian Safety Boards took a role as clearinghouses for informing the public and victim's relatives after the disasters. In the near future, they may be seen as safety ombudsmen, the principle advocate for transportation safety and appropriate care of accident victims. Independent investigations are considered a right of every citizen and a duty of society and may as such be of great significance to a democracy to function properly. Such rights should be anchored in law (Van Vollenhoven 2001). The new Safety Investigation Board in the Netherlands will have the form of an Independent Administrative Authority (ZBO), guaranteeing its independence, and precluding any influence by commercial interests (IDAIP 2001).

It should be acknowledged however, that the objective of learning may serve two goals: on one hand the goal is to conduct an analytical and objective diagnosis on deficient performance of a system, while on the other hand such investigations should serve to help the victims and their relatives to come to terms with their suffering and to put an end to any public concern that may have arisen in the aftermath (Van Vollenhoven 2001). The definition of 'disaster' as 'battlefield of subjective constructions, definitions and feelings, where objective risk analysis and expert based norms do not work any longer' may get in conflict with mission, credibility and reputation of TSB's in their working environments.

In conclusion, accident investigation may have two major objectives.
Either to

- allocate blame and liability to stakeholders and involved actors as a part of the judicial framework, to support the collection of evidence in court and to take disciplinary, criminal or civil law actions

or to

- learn from accidents and incidents in order to improve the safety performance of a system and to prevent reoccurrence of the events.

These objectives ask for two different methods of investigation, as well as different legal frameworks for the conduct of these investigations.

Diversity

<u>Different notions and rationalities</u>

It should be realized however that actors involved in accident investigation also may have fundamentally different notions of risk and may apply completely different rationalities (Stoop 1996).

During the conceptual design phase, projects and products are defined by a systemic rationality derived from physics, mechanics, engineering design and construction. This phase is linear and confined to specialists. The results of these design decisions are firstly and only exposed to an outsider view and judgement after the detailing phase during testing or operation. Risk perception of operators and users is based on a political and societal rationality. Such rationality is defined by interactions with other actors, negotiating and defining social reality in which operators have to cope with the complex and dynamic operational environment. Decisions made by commissioners and designers have led to a product which can be perceived by its physical appearances without revealing the inherent decisions of the earlier phases. Its operational performance can only be reconstructed by its physical appearance and behavior as exposed to operators and users. The technology which is applied is therefore 'to be discovered' to actors during the operational phase, taking the earlier design decisions as incontestable facts. Characteristics of the design may manifest themselves during the operational phase by incidents, accidents or disaster. Transparency of safety aspects in both rationalities is a crucial issue since safety may be outbalanced and obscured by other interests of a higher order. Such interests may manifest themselves only after an independent investigation into major accidents (Van Vollenhoven 2001).

Rationality of a designer and engineer focuses on realisation and is reasoning from goal and concept towards function and form. It follows a synthesizing and decision oriented line of reasoning. Rationality of an operator and user focuses on perception and knowledge. It follows a line of reasoning from observation, perception, towards structure, function and goal. It is analytic and conclusion oriented. Both lines are therefore contradictory in their development. To understand risks and safety issues two different lines of reasoning are available:

- an 'inside-out' vision of commissioners, designers, engineers and other actors which have an oversight of structure and contents of complex systems during their design, development and manufacturing. They are capable of defining complex interactions, couplings and causal relations within the system, risk management, mitigation and control included. They are less capable of dealing with the actual behavior of the system in its dynamic social environment in terms of risk perception and risk acceptance issues.
- An 'outside-in' vision of operators, users, risk bearers, regulators, administrators and other stakeholders which have to cope with the system characteristics in its operational environment. They are capable of dealing with global risk notions and and causal relations at an aggregated level, but lack a profound insight into the functioning of complex systems. They may concentrate on perception and acceptance rather than controlling risks.

An 'inside-out' vision is likely to define risk in terms of a program of requirements and standards, as a consensus document for the actual design and manufacturing. An 'ouside-in' vision is likely to define risk in terms of a defined reality among actors, negotiating risk as a 'social construct' to achieve consensus on perception and acceptance between stakeholders. If such a consensus is lacking during events with a high social impact such as disasters, a 'battleground' situation may occur.

A number of questions can be raised in which finding facts and communicating risk become critical succes factors in system deficiency identification and system change:

- can these subjective risk perceptions and differences in acceptance levels be taken into account in establishing transparency and objectivity concerning the occurrence?
- can we avoid such a battlefield and lack of expert based opinions and decision making during the formulation of recommendations for change?

<u>Differences in context and expertise</u>

Differences in context exist among the working environments of Transportation Safety Boards:

- there are differences per country, modality and sector. In aviation, there is an international standard (ICAO Annex 13), in other modes and sectors there are no or hardly any arrangements available.
- there are differences in world regions. In the North-American region the influence of 11th Sept is present, in Europe oncoming draft EU Directives are important and in the Asian and South American region the issue of new-entrants and low-resource agencies plays an important role.

With respect to the various knowledge domains a substantive diversity is present and scientific disciplines vary widely in their phase of development:

- regarding a technical-analytical approach a fair harmonization of methods and techniques has been achieved and a practical working relationship with judicial forensic investigations has been established. There is little development in the technical-analytical area. Principles from the aviation sector are more and more often applied in other modalities such as data recorders, reconstruction, metallurgic research, etc

- in the area of human factors and organizations, theoretical development is almost completed. The 'James Reason' school has become dominant. A translation and implementation from theory into practice is taking place. Many investigators however do still lack practical skills and a uniform interpretation of the human factor during their investigations.
- factors concerning management, administration and policy are not yet fully developed. Scientific theoretical developments are ongoing and a variety of preferences for multiple theories exist (such as learning organizations, safety culture, change management or participative decision-making in network configurations). Practical applicable methods and techniques are not generally available or are only founded on a single theory or experiences within a single domain. Theoretical models and normative notions seem to be dominant in the investigation of facts, establishing findings and drawing up of recommendations.

Acknowledging the differences in rationalities, visions, context and expertise, methodological questions arise, such as; how do we achieve transparency; how can we reconstruct major events, what kind of expertise and experience is required and; are TSB's suitable instruments for such an effort?

Do TSB's suit the purpose?

Maritime accident investigation courts were established by the second half of the 19th century in most of the sea-going trade nations. A judicial approach enabled disciplinary action against the misconduct of a captain and officers endangering vessels, cargo and passengers. Such an approach required an investigation into the naval disaster which had occurred, the responsibilities of the officers on board and their involvement in the event. Most of the present maritime accident investigation boards evolved from these earlier maritime courts, adding a learning aspect to their mission.

The role of the government was explicite and exclusive: the findings of the boards were addressed to the ministry which held jurisdiction over the issue. In most cases this was the ministry of transportation. The investigative efforts were conducted by the inspectorates of the ministries which also issued the reports on which boards could base their decisions. The investigative authority therefore was not functionally indepedent from administrative powers, although it could take a formal independent position, such as in the British administration. Similar administrative investigation agencies were established in the railways in many countries, although the disciplinary aspect was less prominent or even abandoned for the sake of learning.

Developments in aviation were slightly different from the maritime and railway sector. Accident investigation into major air crashes was established mandatory as an international obligation of a state by ICAO under Annex 13 in 1951. Initially, the investigation of accidents had the objective to mitigate the international juridical and administrative consequences of an air crash. Any state of operation, manufacturer and company should reduce the annoyance to the state of occurrence by establishing the causes of the accident, publish a report on the findings and issue recommendations to prevent the accident from happening again. The focus was on the technical reliability of the aircraft, the performance of the pilot and compliance with regulations.

In the sixties of the previous century, independent and permanent investigation boards appeared with the mission to investigate major aviation accidents. The concept was adopted in other modes of transportation as well, leading to the establishment of multi-modal transportation safety boards throughout the world (De Kroes and Stoop 1992, Hengst, Smit and Stoop 1998). This concept is now expanding to other sectors of industry. Draft Directives are prepared in the European Union to establish mandatory safety agencies and modality specific independent accident investigation agencies.

The mission of present independent safety board covers four principal purposes:

- determine preventable or mitigable causes of major accidents, disasters and catastrophes in transportation as well as other sectors
- identify precursors to potential major events
- increase safety by making acceptable and implementable recommendations
- assure public confidence in safety on a national or sectoral basis.

The strength of a board for its mission comes from its independence, credibility and ability to address recommendations to any relevant party. Their responses to the board are not only based on a legal mandate of the board to demand timely responses to recommendations but also on the evidence that emerges from its investigations.

Harmony

To guarantee a successful mission, five primary working processes of boards have been identified in an international survey of best practices of multi-modal boards in the USA, Canada, Sweden and Finland and a number of single mode boards in the Netherlands. These five processes of a safety board move the board from the decision to undertake an investigation of one or more accidents or incidents through the analysis of the events into formulations of recommendations to prevent or mitigate future accidents and finally to assessing the effects of those recommendations. Accompanying these actions are ongoing communications with the involved parties (Kahan 1998).

These five processes are:

1. an *initiation process* to decide whether to take action. A board obtains information about specific transportation accidents and incidents, as well as summary statistical information on transportation conditions and events and the results of research relevant to transportation safety. In the case of specific events, the board has a mechanism that helps it decide which events merit an intensive investigation.
2. A *fact-finding process* to assemble all relevant data bearing on an event and to determine findings about the main factors contributing to the event or general situation. There are three forms that the fact-finding may take: a reactive *event investigation* of an accident or incident constituting the majority of most boards' efforts, a *retrospective safety study* to attempt to determine the factors associated with and preceding events or a *pro-active safety study* in which the board plans a research study that includes primary data collection of events as they occur.
3. A *safety deficiency identification process* that takes the facts at hand derived from single events or from safety studies, and determines systematic threats to transport safety. The safety deficiency identification process can use modern scientific tools such as pattern recognition, multivariate regression, modelling or can be based on operational experience or a combination of these two.
4. A *recommendation process* that formulates effective steps to prevent or mitigate the harms of accidents and incidents. These steps should also be economically and politically acceptable. The recommendation process may include considerations of how proposed actions might be implemented.
5. A *feedback process* that maintains contact between the work of the board and the external public world. A central feature of this feedback process is a systematic monitoring of the recommendations of the board, both in terms of the actions taken in response to the recommendations and the effects of these actions on transportation safety.

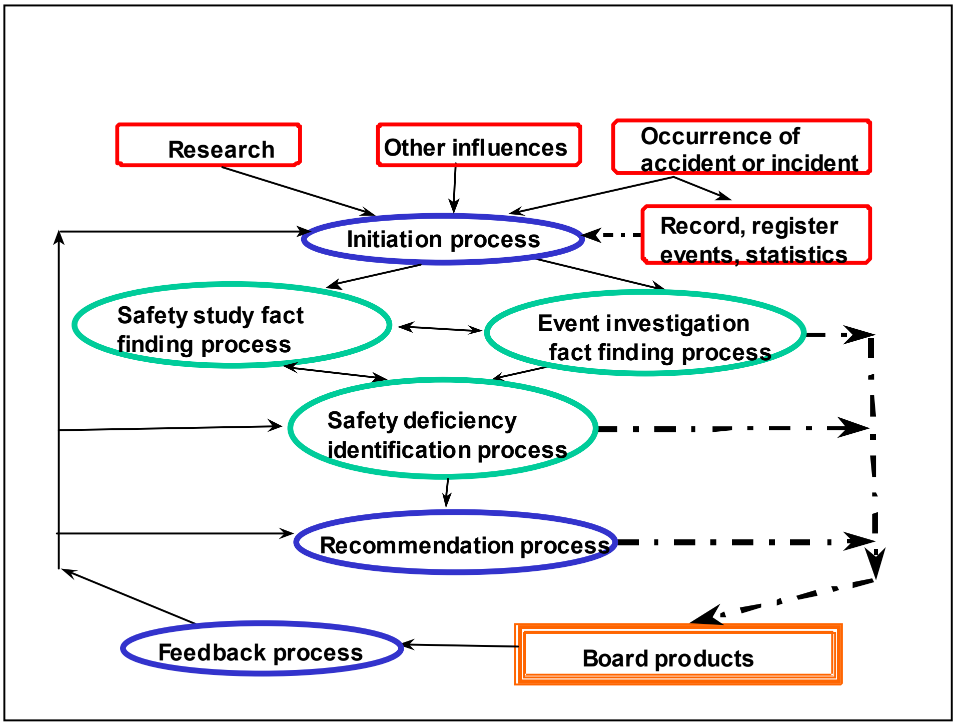
In practice, a wide variety of knowledge needs to exist. Together, they cover many aspects and can be allocated to the primary phases of the accident investigation process.

They can be categorized and allocated in particular to fact-finding, analysis and recommendations.

a. fact-finding focuses on collection of facts and other 'volatile' information. This phase provides information to answer questions about the WHAT and HOW of the accident. This phase concentrates on the sequence of events during the occurrence and provides information on the accident itself.
b. the analysis phase is focused on WHY the accident could occur and supplies additional post-scene investigative information. Collection of background information takes place and in-depth specific analyses are performed. This phase focuses on arriving at a satisfactory explanation of the occurrence and identification of systemic deficiencies.
c. recommendations focus on lessons to be learned and WHAT can be done by WHOM to prevent repetition of similar occurrences. This phase leads to a final report and drawing up of recommendations. All three phases are closely connected and require cooperation between all actors involved in the investigation process.

The processes can be characterised in a conceptual model as a benchmark for understanding the evolution of safety boards. The generic model identifies and links the five processes (see fig):

Figure 1: Five processes define work of a board



During the fact-finding phase a basic operational background knowledge is required to assess the need for specialist expertise for the interest of the investigations and to assess which information might be relevant to proceed with the investigations. In view of this operational focus, it is crucial to be aware of methodological pitfalls and shortcomings in accident investigation methods.

During analysis, data collected in the fact-finding phase are analyzed and additional information is collected by specific investigations and research in various disciplines. The investigator controls and manages the investigation process and assesses the methodological aspects.

During reporting and recommendations a translation is required into general learning aspects and a transition from explanatory factors into control variables, aiming at change in the system and acceptance of recommendations by all stakeholders.

Discussion and conclusions

A fundamental reason to introduce independent accident investigation was that parties involved began to realize that criminal law inquiries focus on allocating blame. To learn lessons for the future and to take steps to prevent similar accidents, it was essential to identify the causes of these accidents. Another type of investigation was thus needed. From a judicial point of view however, investigation methodology is restricted to inductive logic as the more useful tool for criminal intelligence analysis. It has strong ties with conventional 'forensic engineering' methodologies applied to determine liability for structural failure in engineering design. In the English language a clear distinction is made between inductive and deductive logic, by applying the notion of 'investigation' versus 'research'. Deductive methodologies have been considered less useful for investigations, since their inference does not go beyond the premises of their scientific discipline, not arriving at any new causes, conclusions or recommendations. In addition, the scope of criminal inquiries was restricted to discovering the direct cause of an accident and to identify an unacceptable deviation from a normative standard, not the underlying causes. This was aggravated by the fact that suspects were permitted to withhold information not to incriminate themselves. Conventional accident investigation methodologies therefore tended to focus on cause and not on prevention.

It may be concluded that independent TSB's represent a distinct school of thought in accident investigation. Historically, they have strong relations with engineering design and identifying failure in technical systems. Transportation Safety Boards however are evolving towards a socio-technical systems approach. Several methodological issues are yet to be resolved to guarantee their independence, credibility and reputation as a qualified agency. Historically, the role of fact-finding and accident reconstruction has firmly been established in relation to engineering design and operations in transportation. New sectors and scientific disciplines have emerged. TSB's need to develop their own methodology to comply with the need to link the processes of fact-finding and establishing system deficiencies to the process of drawing up recommendations and advocating systemic changes. It may be necessary to combine both processes in an appropriate form, despite the fact that fundamental differences exist between risk notions and rationalities across actors and stakeholders. It also clarifies the need for the TSB community to participate in an information infrastructure because TSB's will not be able to cover all required expertise on an in-house basis. It may be stated that in addition to a formal and functional independence, TSB's may also need to develop and maintain methodological independence.

References

Carper 1989
Forensic Engineering. Elsevier. New York. Amsterdam. London

Stoop 1990
Safety and the design process. Doctoral thesis. Delft University of Technology. April 1990

Petroski 1992
To engineer is human. The role of failure in succesful design. Vintage Books New York.

De Kroes and Stoop 1992

First World Congress on Safety of Transportation. Delft, 26-27 November 1992. Delft University Press

Evers, Bovy, De Kroes, Sommerhalder en Thissen 1994
Transport, infrastructuur en logistiek: een proeve van een integrerend onderzoeksprogramma. In Dutch. TRAIL Onderzoeksschool, Delft University of technology, february 1994.

Stoop 1996
Risicobeheersing bij technisch- complexe projecten. In: Grote projecten. Besluitvorming & management, De Bruijn, de Jong, Korsten en Van Zanten. In Dutch, Samson H.D. Tjeenk Willink

Hengst, Smit and Stoop 1998
Second World Congress on Safety of Transportation. Imbalance between Growth and Safety? Delft, 18-20 February 1998. Delft University Press.

Kahan 1998
Safety board methodology. In: proceedings of Second World Congress on Safety of Transportation. 18-20 February 1998, Delft University of Technology. Editors S. Hengst, K. Smit and J.A. Stoop

Rosenthal 1999
Challenges of crisis management in Europe. International conference on The Future of European Crisis Management. The Hague, nov 7-9, 1999

Johnson 1999
Organisation and activities of the TSB. Lessons from Independent Accident Investigation in Canada. Presentation to the Transportation Safety Conference Kansai University, 22 July 1999

McIntyre 2000
Patterns in Safety Thinking. A literature guide to air transportation safety. Ashgate Publishing Ltd

Van Vollenhoven 2001
Independent accident investigation: every citizen's right, scoiety's duty. The Third European Transport safety Lecture. European Transport Safety Council. Brussels, 23rd january 2001

IDAIP 2001
Main Points memorandum. Independent accident investigation. Independent Disaster and Accident Investigation project. Ministry of the Interior and Kingdom Relations. The Hague, the Netherlands.

Stoop 2002
Accident investigations: trends, paradoxes and opportunities. International Journal of Emergency Management. 2002, in press.

Author biography

John Stoop is an associate professor in safety science since 1993 at the Faculty of Technology, Policy and Management at Delft University of Technology. He is a senior research participant of the research school of Transport, Infrastructure and Logistics. He graduated as an areospace engineer and did his PhD on the role of safety in the design process. He is a specialist in transportation safety, firescue and emergency management, focusing on accident investigation. He was involved in the foundation of the Dutch Transport Safety Board. He is also the managing director of KINDUNOS, safety consultancy, established in 1990.