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Developments in the Safety Science Domain and in Safety Management From the 1970s Till the 1979 Near Disaster at Three Mile Island

DEVELOPMENTS IN THE SAFETY SCIENCE DOMAIN AND IN SAFETY MANAGEMENT FROM THE 1970S TILL THE 1979 NEAR DISASTER AT THREE MILE ISLAND, a review of literature

Paul Swuste[1], Coen van Gulijk[2], Walter Zwaard[3], Saul Lemkowitz[4], Yvette Oostendorp[5], Jop Groeneweg[6]

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Manuscript for Safety Science

[1]Safety Science group, Delft University of Technology, The Netherlands p.h.j.j.swuste@tudelft.nl

[2]Reader in Railway Safety, University of Huddersfield, United Kingdom

[3]Trainer and advisor, Delft, The Netherlands

[4]Product and process engineering, University of Technology, The Netherlands

[5]Council for Environment and Infrastructure, The Hague, The Netherlands

[6]Institute Psychology, Cognitive Psychology University of Leyden, TNO Leyden, The Netherlands

Content

1. SUMMARY

Objective: What has been the influence of general management schools and safety research into causes of accidents and disasters on managing safety from 1970 till 1979?

Method: The study was limited to original articles and documents, written in English or Dutch from the period under concern. For the Netherlands, the professional journal *De Veiligheid* (Safety) has been consulted.

Results and conclusions: Dominant management approaches started with 1) the classical management starting from the 19th century, with scientific management from the start of the 20st century as a main component. During the interwar period 2) behavioural management started, based on behaviourism, followed by 3) quantitative management from the Second World War onwards. After the war 4) modern management became important. A company was seen as an open system, interacting with an external environment with external stakeholders. These schools management were not exclusive, but have existed in the period together.

Early 20th century, the U.S. 'Safety First' movement was the starting point of this knowledge development on managing safety, with cost reduction and production efficiency as key drivers. Psychological models and metaphors explained accidents from ‘unsafe acts’. And safety was managed with training and selection of reckless workers, all in line with scientific management. Supported by behavioural management, this approach remained dominant for many years, even long after World War II.

Influenced by quantitative management, potential and actual disasters after the war led to two approaches; loss prevention (up-scaling process industry) and reliability engineering (inherently dangerous processes in the aerospace and nuclear industries). The distinction between process safety and occupational safety became clear after the war, and the two developed into relatively independent domains.

In occupational safety in the 1970s human errors thought to be symptoms of mismanagement. The term ‘safety management’ was introduced in scientific safety literature as well as concepts as loose, and tightly coupled processes, organizational culture, incubation of a disaster and mechanisms blinding organizations for portents of disaster scenarios. Loss prevention remained technically oriented. Till 1979 there was no clear relation with safety management. Reliability engineering, based on systems theory did have that relation with the MORT technique as a management audit. The Netherlands mainly followed Anglo-Saxon developments. Late 1970s, following international safety symposia in The Hague and Delft, independent research started in The Netherlands

2. INTRODUCTION

This article is part of a series on the knowledge development of the safety domain. Previous publications in Safety Science discussed periods from the late 19th century till the 1970s (Swuste et al., 2010, 2014). According to authors, these reviews will provide insight into the development of the scientific safety domain. It shows the temporal character knowledge on accident causation, and why ideas emerge, disappear or lay dormant for some time. In this article the knowledge development for managing safety at the company level is mapped. The terms of safety management and safety management system were introduced only in the 1970s.

Authors start from the assumption that developments in managing safety, as reflected in the literature, are fed by both the knowledge about the causes of (severe) accidents, and by more general ideas about managing companies and their production. However, authors are not suggesting these relations will be clear during the period under discussion.

Until the early 1970s previously published articles are summarized briefly, then the discussion will be more extensive. For these publications questions below are leading:

1. Which general management schools and which theories and models for accident causation have been developed?
2. What is the influence of these developments on knowledge on safety management?
3. What was the context in which context this development took place?
4. What are the consequences for the professional field of safety in The Netherlands?

3. MATERIALS AND METHODS

An extensive literature research of documents and scientific articles, written in English or Dutch, has been the basis for answering the leading questions. The research was mainly limited to developments in the safety domain of United States, United Kingdom and The Netherlands. Original references and sources have been accessed via the library of the Technical University of Delft, and via internet. The national professional journal for safety specialists *De Veiligheid* (Safety Journal) was studied for consequences for the Dutch professional field of safety

The period under study has been divided into five subsections, general management schools, safety theories and models in occupational safety, idem in process safety, knowledge development related to managing safety and finally, the development in the Netherlands. General management schools are based on the common format of management literature and distinguishes between the classic, the behavioural, quantitative and modern management (Pindur et al., 1995).

The relationship between general management trends, safety theories and models, and safety management is not obvious. General management developments are based on market developments and production efficiency, while the other two topics will originate from developments in occupational and process safety. The discussion and conclusion section will provide an synthesis between these topics

In this article developments in safety legislation are only discussed sporadically. Although legislation will be leading for many companies, regarding the introduction of safety management (systems), and legislation can have a stimulating role in knowledge development, it is still based upon previously acquired knowledge.

Tables 2 and 3 at the end of this article will present an overview of knowledge developments of safety theories, models, metaphors, safety management and general management approaches from the 19th century onwards. This table will also use information from two previous articles (Swuste et al., 2010, 2014)

4. GENERAL MANAGEMENT APPROACHES

4.1 Classical management and behavioural management

The classical management school began in the late 19th century and put (top) managers of companies at the centre of decision-making, which at that time was a revolutionary thought. The classical management trend has two fundamental movement – scientific management and general administrative management. Scientific management centres on ways to improve industrial and labour productivity by redesigning tasks and working methods. Administrative management theory examines organizations as total entities and focuses on ways to make them more effective and efficient (Pindur et al, 1995). The Americans Fredrick Taylor and Frank and Lillian Gilbreth were known pioneers of scientific management. The Franco-Turkish Henri Fayol and the German Max Weber were the pioneers of the administrative management. With the exception of Weber these authors had engineering backgrounds. This technical background determined the characteristics of these management schools. An organization was seen as a mechanical entity and every person in the organization was supposed to judge and act rationally. This view was reflected in the publication 'The Principles of Scientific Management' of Taylor (1911). In the early 20th century business flourished in America, there was plenty of money, but labour was the limiting factor. In the late 19th century Taylor experimented with different working methods at the Midvale Steel Company in Philadelphia, Pennsylvania, where he worked. In particular, participation of employees in the production decisions showed an increased production, as long as it resulted in a standardized workflow. Complex processes were divided into simple sub-processes. The ideal was an employee who did not have to think about work. According to his beliefs, employers and employees had similar goals. After all, a higher production increased profits for employers and higher wages for the employee. The approach was a first attempt to influence the behaviour of employees through reward systems. However, in most organizations the management was hardly aware of the content of work and could therefore not give guidance to the system. According to Taylor's opinion this was the biggest obstacle for efficient production. His approach was based on:

- observations, measurements, registration;
- selection and training of workers;
- the development of standards and regulations;
- close cooperation between management and employees.

Later on this led to the known and infamous' time and motion studies', initiated by Frank and Lillian Gilbreth (1917). The classic management was characterized by the use of 'scientific methods' in management. Science in this context meant that empiricism was introduced, with measuring, monitoring, recording and it was the start of planning, organizing, influencing and controlling the production. The limitation of this approach was the assumption that employees and employers are economic beings. Workers were mainly seen as a tool to achieve management goals.

The rise of industrial psychology before World War II introduced a new movement in management schools: the so-called behavioural management, with human behaviour, motivation and leadership as key features. This management movement was inspired by the then modern behaviourism, an empirical approach within psychology, which explained human behaviour from incentives offered, from conditioning and from the context in which behaviour occurred. The 'human relations movement' is part of this movement. Well-known pioneers were the Americans Elton Mayo and Fritz Roethlisberger, who in late 1920s-early 1930s investigated behaviour of workers by the Western Electric Company Hawthorne, a company just outside Chicago, Illinois. Productivity was determined by psychological factors, group dynamics at work, the attention of supervisors and management, and much less by economic benefits or physical work conditions. Another pioneer was the American psychologist Abraham Maslow. He published his hierarchy of needs in 1943, a theory of psychological health predicated on fulfilling innate human needs in priority, culminating in self-actualization, as a basis for motivations of human behaviour. The main limitations of the behavioural management was the complexity of human behaviour. Behaviour and changes in behaviour are simply too difficult to predict. Human motivations seemed to play no significant role. The psychoanalytical movement of Freud (1911), although arguably one of the first attempts to understand the backgrounds of human error, did not create any response in the safety domain. All that is left of his approach is the 'slip', an act that occurs without any planning. In the 'behaviourist climate' of that time no value was attached to drivers of behaviour.

4.2 Qualitative management and modern management

During and just after World War II seven manuals on safety, damage prevention and managing security were published in the United States (Heinrich, 1941, 1950; Armstrong et al, 1945 1953 Heinrich and Crannis, 1959, Blake, 1963 Bird and Germain, 1966). In the United Kingdom in the period appeared only one publication (Association of British Chemical Manufacturers, 1964). All these publications have appeared against the background of two management schools: quantitative management and modern management

Quantitative management started before World War II, based upon mathematical and statistical approaches for military problems. After the war, these techniques were applied in the private sector. This approach, originally known as ‘operational research’ supported management decisions during the planning phase and the monitoring of projects (Moore, 1968). Quantified and mathematical models, were both its strength and weakness, because for decision not all relevant input is quantifiable.

After World War II modern management emerged. This trend focused on management processes, management was seen as a decision-making and information-processing activity in which managers had to plan, organize, manage and supervise. Also, the concept of an organisation as an open system was important. Companies were no longer seen as a closed system, as in previous schools, but interacted within an commercial environment and with external stakeholders. The Americans Deming (1982) and Juran (Juran, 1951; Juran and Barish, 1955) were its pioneers. Immediately after the Second World War they played an important role in rebuilding the Japanese industry. Their focus was quality control, which moved from finished products to the production. Employees and customers played a major role in this quality control.

Later on it was stressed that the production and market environment and stakeholders are sector or even company specific. Universal management techniques did not seem to be obvious, leading to the design of management systems for individual organizations (Schein, 1972). Another trend came from Mintzberg (1979), which was not emphasizing the uniqueness of companies, but postulated a consistent pattern in companies responses to external influences. This pattern was determined by the structure of the organization and subsequent decision-making processes.

5. OCCUPATIONAL SAFETY

5.1 Safety theories and models, and 'accident prone conditions'

The focus of safety science research in the 1970s was in the United Kingdom. There have been some breakthroughs. The concept of multi-causality of accidents was introduced. 'People, not things are causing accidents'. This still looked like the 'accident proneness theory' (for an overview see Swuste et al., 2010), but unsafe acts and unsafe conditions were now more clearly explained as symptoms of a faulty management and not as a cause of accidents (Petersen, 1971). The term "accident prone conditions' made its appearance in the United States, as opposed to 'accident prone workers' (Pfeifer et al, 1974). Therefor unsafe acts were placed in a context.

Research on occupational accidents in the United Kingdom was mainly conducted by psychologists and ergonomists, working at Aston University, Birmingham. Unlike previous accident models and theories, which were based upon hazards, or reflex reactions during process disturbances, their focus was on information available to workers just before an accident took place (Hale and Hale, 1970; Dunn, 1972). During an accident, information could be disturbed, there could be an information overload, there could be physical limitations preventing adequate responses, or a worker had choosing a wrong strategy of action. Ergonomists developed ergonomics of information, the type, design and the quality of information offered to employees at their workplace and the classification of errors that could result from this (Singleton, 1971, 1972).

In general ergonomics had an increasingly influence in the safety domain. According to the theory of task dynamics of the Dutchman Winsemius (see for more information Swuste et al., 2014), ergonomic (re)design of machines and workplaces was a direction for solutions. The theory of task dynamics task momentum was also reflected in a large prospective study on accidents in the metal, assembly and distribution sectors. This study was remarkable, since safety research hitherto only had used a retrospective study design, or was based on case studies. The study also showed the general disinterest of safety management in companies under study. A director could find safety important, but mostly it remained a paper statement without further consequences for business operations (Powell et al, 1971). Similar conclusions were also drawn in an extensive literature review of 80 years of publications on accidents. In addition to an extensive analysis of the accident proneness literature, the survey pointed to conflicts at company level between safety and production, to process disturbances as risk factors for accidents and a relative low effectiveness of safety training for employees (Hale and Hale, 1972).

In the United States there was attention for a topic, which later on in the Netherlands was called ‘humanization of labour’. Short-cycle work on conveyor belts was described as monotonous and demotivating. In the literature, a comparison was made with Modern Times, Charlie Chaplin's 1936 movie (Swain, 1973) (Figure 1).

figure 1, Modern times

Higher wages, strict employee selection, training and motivational programs, punishments, all these measures had no demonstrable effect, or only in the short run. The suggested solution was job enrichment, matching the task to humans, and a greater degree of control of workers on the organization of their work (Pfeifer et al, 1974; Cohen et al, 1975). The need for an active involvement of top management of companies was also pointed out. And not only for saving time and money, but for a demonstrable attention to the welfare of employees. The concept of 'workers welfare' from the United Kingdom was introduced in the United States (Ellis, 1975; Cohen, 1977; Cleveland et al, 1979; Nye, 2013). Finally, there is criticism of the lack of scientific evaluation of safety initiatives or of generally accepted determinants of safety. Cohen complained about the extensive literature on safety training, without any evaluation study (Cohen et al, 1979). For the same reasons Ellis (1975) was reticent about the effects of safety legislation, inspections, statistics, and government standards on safety in companies.

6. PROCESS SAFETY

6.1 System approach and increasing complexity

After World War II the large-scale process industry started. This development resulted in a process safety movement in the early 60s, an important movement within the safety domain, and became known as ‘Loss Prevention’. Due to upscaling of production processes in the chemical industry, the control of these processes became more complex, resulting in fires, explosions and emissions of toxic substances, which also had profound effects outside plant premises. A growing fear emerged among the population for large-scale accidents and various forms of pollution (Carson, 1962).

Publications on loss prevention appeared in both the United States and the United Kingdom (Association of British Chemical Manufacturers, 1964; Fawcett, 1965a, 1965b). As with safety technique an engineering approach was dominant. The topic was no longer the unsafe act, but the control of ‘loss of containment’, to keep chemicals inside their pipes. In both countries methods and techniques were developed to improve equipment and process reliability. These techniques partly originated from the process industry (Hazard and Operability Study - HAZOP) and partly from the military sector (Failure Mode and Effects Analysis - FMEA and Fault Tree Analysis - FTA error or tree). An extensive discussion of these methods can be found in a previous publication (Swuste et al., 2014).

6.2 Major industrial accidents and process safety

In the 1970s sociological studies were published, dealing with the complexity of production processes (Reeves and Turner, 1972) and their organisations with their internal codes, rituals and socialization processes (Turner, 1971). The relationship has been established in three medium sized to large companies between the organization of work, the technology of the production process and the control of management on production. In the early 70s of the last century, automation of production in the manufacturing sector was were relatively limited and production was mainly organised in batch wise processes. These processes had a high degree of complexity, caused by the multitude of intermediate products and consequently many process steps, which made a production planning hardly possible. Foremen and middle managers had to resolve problems in production and planning on an ad hoc basis. This was not different for safety related issues.

The description of socialization processes in companies was the result of an extensive sociological study. With informal interviews and observations researchers could crawl under the skin of a company, while characterizing organizational characteristics, the so-called ‘grounded theory’ approach. These studies were relevant to occupational safety, but even more for process safety. A sociological approach does not focus on individual behaviour of employees but investigates and describes how production companies are functioning and how decision-making works. Such an approach was also followed in the United States, only different conclusions were drawn. In the British study a batch wise production was seen as an obstacle, due to an increased complexity. By definition a batch wise production was loosely coupled. In the US study the benefits of a loosely coupled production system were investigated, their flexibility, their ability to respond to local needs and reduced vulnerability compared to tightly coupled production systems (Weick, 1976).

In the 1970s a number of major accidents and disasters occurred in the process and nuclear industries, receiving a lot of media attention, and creating a fear amongst the general population. At the July 1st 1974 at Nypro, Flixborough, North Lincolnshire disaster in the United Kingdom at the caprolactam plant, 28 workers were killed and 89 wounded, including 53 civilians. DSM owned 55% of Nypro. A year later, on November 7th, 1975 the naphtha cracker II exploded at DSM Beek plant in Limburg. Fourteen workers were killed and 109 were wounded. Again a year later, on July 9th, 1976 a reactor exploded at the Icmesa Chemical Company in Meda, near Seveso, Italy. A gas cloud escaped with the highly toxic TCDD (2,3,7,8-tetrachlorodibenzodioxin). This disaster has caused a great slaughter amongst animals in the region. No direct fatalities or injured were reported as a result of this disaster, but spontaneous abortions occurred amongst a number of exposed pregnant women. On March 28th, 1979 a malfunction in the secondary cooling system of the nuclear power plant Three Mile Island, near Harrisburg, Pennsylvania, United States created an increased risk of a so-called 'meltdown'. During this near-disaster radioactive gases were discharged into the atmosphere. Also during this incident, which in the media was depicted as a ‘disaster’, no injuries or deaths occurred, and later, no adverse public health effects near Harrisburg could be demonstrated. These four events are just a few examples of the number of disasters occurring during this period, leading to serious doubt safety. The reference book of Lees (1980) will provide an extensive overview.

The public resistance against industrial disasters, took off from the 1960s. This led to extensive media coverage. The chemical and nuclear industry had an image problem and action groups published in Nature, one of the most important scientific platforms (Anonymous, 1977). It was not accepted any more for companies to control their industrial activities so badly. In the case of

Three Mile Island, this was reinforced by the movie ‘China Syndrome’, which was released twelve days before the near-disaster occurred. This movie, starring Jack Lemmon and Jane Fonda, told the story of safety problems at a nuclear power plant. The title was a metaphor for a meltdown at a the plant. When occurring, it was expected the core would reach China.

Disasters and accidents triggered attention to process safety, and two trends became important; reliability engineering and loss prevention. Reliability engineering originated from the military, nuclear and aerospace domains (Barlow and Proschan, 1975) and loss prevention from the processing industry (Lees, 1980). These two movements introduced the concept of risk in the safety domain. More information is provided in the article of Oostendorp et al., 2013.

The disasters at Flixborough and DSM Beek, but also the 1978 BLEVE (boiling liquid vapor explosion) of a LPG tanker at the campsite Los Alfaques in Spain Tarragona, were decisive for loss prevention. These events generated a stream of publications both in professional and in scientific journals. The devastating effects of vapour cloud explosions were poorly understood, as became clear in official reports of these disasters and in literature (Parker, 1975 Ficq, 1976; Sadee et al, 1976). Much research was started to understand the dangers and spreading of these gas clouds (see eg Nettleton, 1976 and 1976/1977). At industrial sites, offices, and control rooms were situated in the vicinity of process, or amidst the plants, creating disastrous effects of these disasters for workers in these locations. The official report of Flixborough of the Department of Employment (1975) was surprisingly mild on the quality of the management of the company. Management was safety conscious, according to the report, there were no indications production was more important than safety. However, the understaffing of the technical support was mentioned. Other reports and articles drew very different conclusions. Attention was drawn to very low standard of safety management, the dominance of production over safety and the inefficiency of licensing of local governments, allowing large volumes of flammable substances stored on site. (Also see Lees, 1980; Carsen and Mumford, 1979; Harvey, 1979). Trevor Kletz (1976) from Imperial Chemical Industries (ICI) was the most critical. He denounced the fascination of management for accident rates as a measure of safety in the process industries. The frequency of ‘loss of containment’ and the analysis of near accidents were more important. These data indicated, in line with the loss prevention approach, information on the reliability of plant components and, according to the author, represented a more realistic picture of the safety of the process.

‘First time safe’ was the motto of reliability engineering. This motto was facing the 'fly-fix-fly' routine, which was customary. The fire in Apollo I in 1967, which killed three astronauts, did realize the consequences of the old motto was unacceptable for complex systems. Safety system, based on a life cycle approach, hazard analysis and fault tree analysis techniques were the basis, along with the calculation or estimation of chances and probabilities of system errors. The assumption was 'what could happen, would happen when the time is ripe'. With a number of seminars, organized by the United States and held in the UK, Germany, Netherlands, Switzerland and Denmark, reliability engineering was promoted. A schematic presentation is given in figure 2, a model developed for the Danish Atomic Energy Commission to investigate chances of failure in the nuclear reactor industry systematically (Nielsen, 1971; Nielsen et al., 1975).

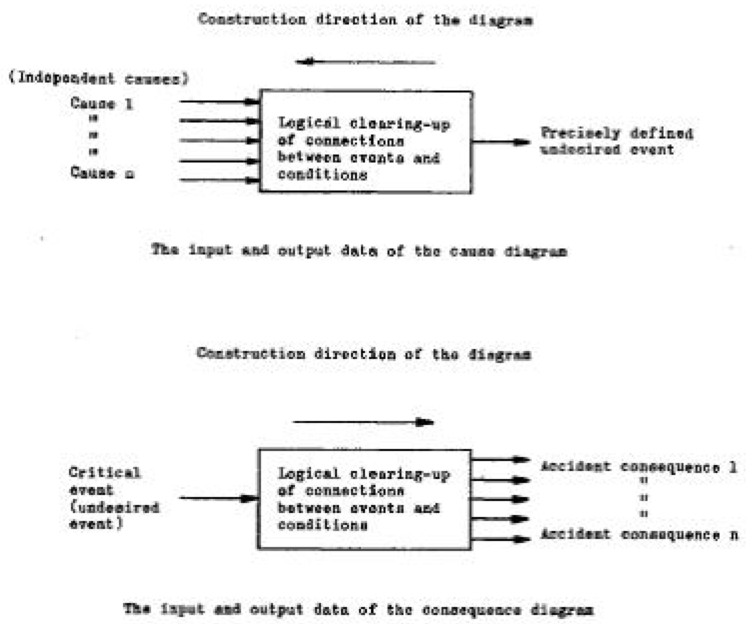

Figure 2, the cause of consequence diagram (Nielsen, 1971)

The model consists of two fault trees surrounding an unwanted event, a first presentation of the later bowtie. The adverse event was defined in the same way as in a fault tree; a functional failure of a system or component. The system approach, previously advocated by ergonomists in the safety domain, was introduced and became apparent in the graphical presentation of figure 2. Also technical solutions for safety problems were preferred, because they were relatively easy to define.

In 1976, results were published of another descriptive sociological study to companies and organizations. This time the companies and organizations involved were from outside the process industry sector: a portion of a colliery tip on a mountainside at Aberfan, Wales slid down into the village in 1996; a collision of an express train with an exceptional transport in Hixon, Staffordshire (1968); and a fire at a resort in Douglad, Isle of Man (1974). These accidents have caused dozens of deaths (Turner, 1976). And the question was asked ‘what had gone wrong in these organizations’. It was assumed that a single human error could not cause such accidents, causes had to be found in complex and branching chains of events and decisions made within organizations. Despite the differences in type accidents, organizations only seemed to recognise and value deviant signals with great difficulties. Big accidents proved hardly predictable. This study, like many safety research, had the benefit of 'hindsight'. In retrospect, disturbances workers were facing, seemed fairly clear and well defined. At the time of the accident, this could be quite different. Problems, for example during production, could emerge quite diffuse, were not understood or were ignored; causing early signs of major accidents to be very vague for workers. Stage II of the model of figure 3, named ‘incubation period’ is addressing this point.

The Sequence of Events Associated with a Failure of Foresight

Stage I	**Notionally normal starting point:** (a) Initial culturally accepted beliefs about the world and its hazards (b) Associated precautionary norms set out in laws, codes of practice, mores, and folkways.
Stage II	**Incubation period:** the accumulation of an unnoticed set of events which are at odds with the accepted beliefs about hazards and the norms for their avoidance.
Stage III	**Precipitating event:** forces itself to the attention and transforms general perceptions of Stage II.
Stage IV	**Onset:** the immediate consequences of the collapse of cultural precautions become apparent.
Stage V	**Rescue and salvage — first stage adjustment:** the immediate postcollapse situation is recognized in ad hoc adjustments which permit the work of rescue and salvage to be started.
Stage VI	**Full cultural readjustment:** an inquiry or assessment is carried out, and beliefs and precautionary norms are adjusted to fit the newly gained understanding of the world.

Figure 3, stages of major accidents (Turner, 1976)

In a later publication, the term "man-made disasters' was used for the first time (Turner, 1978), and the study was extended to 84 reports of major accidents in civil aviation, water heaters, trains, ships and mines.

7 SAFETY MANAGEMENT

7.1 Managing of safety, the safety ladder and the control of damage

After World War II the first publications on managing occupational safety appeared. The term ‘safety management’ would, moreover, only be introduced 20 years later. The 1950 edition of his reference book Heinrich discussed basic principles for the prevention of accidents, graphically represented as a ladder, a metaphor for a management system. A comprehensive article on Heinrich’s publications was published by Gulijk and co-authors in 2015. In this approach, the manager had an exemplary role in realizing a safe and efficient production. This message was expressed in the same way in the first edition by Armstrong and co-authors, five years earlier, (Armstrong et al., 1945).

'Damage Control', the work of Bird and Germain followed Heinrich's tradition of domino metaphor, where the unsafe acts was seen as the primary cause of accidents. Only the scope of the consequences widened, from injury accidents to accidents and near-accidents with damage (figure 4).

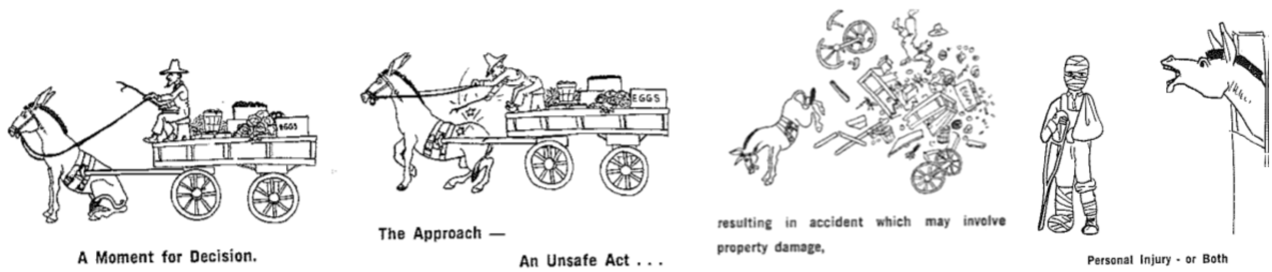

Figure 4, damage control (Bird and Germain, 1966)

Both authors worked at the Lukens Steel Co. in Coatesville, Pennsylvania, where they investigated 90,000 injury accidents between 1959 and 1965. Until then damage to objects not yet covered by US safety literature. Based on the 1: 29: 300 distribution of the accident mechanism (see table 2 at the end of this article), pointed out the large number of accidents without injuries and near misses, causing a lot of damage. This led to the 'damage iceberg' with different ratios, as shown in figure 5. According to the authors, costs connected to with these accidents were many times larger than costs of accidents. Furthermore, this investigation revealed to management a multitude of unsafe acts, which also played a role in non-damage accidents. The damage control program required an accurate strategy of accident and damage reporting, work preparation, audits and cost calculations. The books of Bird and Bird and Germain gave extensive examples of forms for these reports (Bird and Germain, 1966; Bird, 1974).

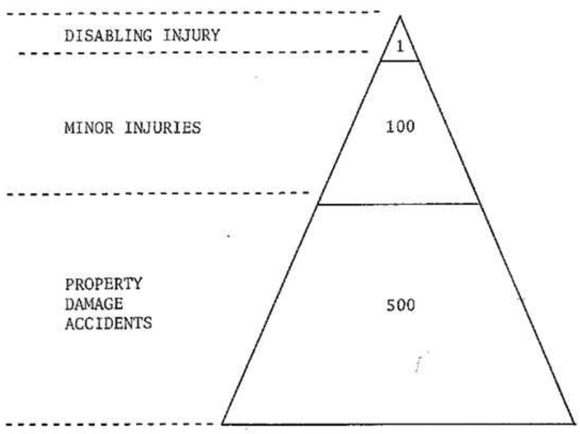

Figure 5, the damage iceberg (Bird and Germain, 1966)

7.2 Occupational and process safety management (systems), and –audits

The government of the United Kingdom took the initiative for consequences of safety and management of companies. The well-known Robens report started with a reflection on the role of the government (Robens, 1972), leading to the installation of the Health and Safety Commission (HSC) in 1974. One year later the Health and Safety Executive (HSE) was charged with safety related research and monitoring safety in companies. In the United States several safety reference books on safety management were published in the 1970s (Petersen, 1971, 1975, 1978; Bird, 1974; Bird and Loftus, 1976). Petersen was the first to use the term 'safety management' in the title of his books. Finally a significant contribution appeared on the accident sequences and management (Johnson, 1973a) leading to an accident management model for the nuclear industry, the Management Oversight and Risk Tree (MORT) technique (Johnson, 1973b).

The Robens Committee (1972) started with a fairly broad remit to evaluate the quality of legal provisions for occupational and process safety. The results were shocking. Occupational mortality and morbidity were alarmingly high in the United Kingdom and next to accident also new occupational diseases, like bladder cancer and asbestos-related cancers were highlighted. The impact of safety legislation was seriously questioned, like in the United States a few years later (Ellis, 1975),. 'What is wrong with the system?'. This was the title of the first chapter of the report and the answer was clear. There are nine groups of laws with as many controlling bodies, spread over five different ministries. Adjustments of laws lasted an average of 15 years. The laws were not in use, there were too many laws, they were too detailed and too poorly structured. There were far too many technical, descriptive regulations, while human and organizational factors remained greatly underexposed. The remedy was relatively simple. The committee suggested to delegate the technical control of hazards to those who create them, being industry. Businesses must take the initiative, leaving safety mainly to an issue of private parties. The Committee also proposed to establish a single organization with responsibility for research and monitoring. That organization was the HSC and HSE. The HSC produced two reports on "major hazards" (HSC, 1976 and 1979), in the immediate aftermath of the Flixborough disaster. These reports gave an inventory of British companies using toxic and very toxic gases, flammable liquids and unstable, highly reactive materials, which fell under legislation if the quantities were to exceed certain limits. The reports gave overviews of explosions in almost all continents and stressed the leading role of the top management of companies for safety, as also mentioned in the Robens report. Companies had to show their management systems had an impact on safety, and hazard and risk analyses were mandatory. This focus on management was also present at the HSE, who conducted research into conditions for occupational safety improvements.

A humanitarian approach to the working conditions was also promoted in the UK, beyond noting that surprisingly few managers had attended some training in safety (HSE, 1976). Strikingly enough, none of the reports used the term safety management, unlike the American textbooks of that time.

Models of accidents and their prevention in manuals of both Bird and Petersen looked very similar. Both authors are indebted to Heinrich's domino model. Bird used a modified version of the domino's and made a distinction between the root and direct causes (see figure 6 and 7). Root causes were personal and work-related causes. Personal factors were skills, motivation, mental or physical problems. Work factors were standards for tasks, design, maintenance, inadequate purchases, or simply wear. The direct causes resembled factors Heinrich published in 1941 (figure 7).

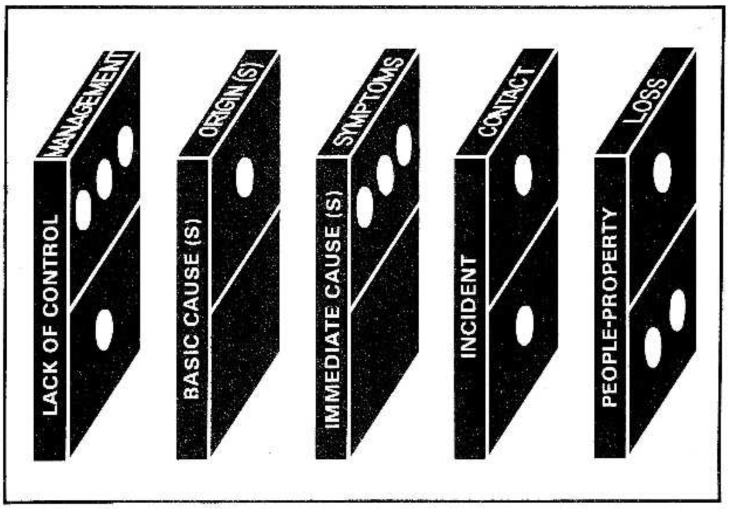

Figure 6 domino's (Bird, 1974)

Instead of ‘social environment’ and ‘fault of person’, the first two domino stones of Heinrich, Bird’s first domino stone was pointing at a lack of management control of the company concerned. This resulted in a badly functioning safety program, consisting of regular inspections, task analysis, safety procedures and training, and personal contacts with employees.

UNSAFE CONDITIONS

1. Inadequate guards or protection
2. Defective tools, equipment, substances
3. Congestion
4. Inadequate warning system
5. Fire and explosion hazards
6. Substandard housekeeping
7. Hazardous atmospheric conditions: gases, dusts, fumes, vapors
8. Excessive noise
9. Radiation exposures
10. Inadequate illumination or ventilation

UNSAFE PRACTICES

1. Operating without authority
2. Failure to warn or secure
3. Operating at improper speed
4. Making safety devices inoperable
5. Using defective equipment
6. Using equipment improperly
7. Failure to use personal protective equipment
8. Improper loading or placement
9. Improper lifting
10. Taking improper position
11. Servicing equipment in motion
12. Horseplay
13. Drinking or drugs

Figure 7, causes immediate or accidents (Bird, 1974)

The manual of Bird and Bird and Loftus took the reader by the hand and was written in a very practical and executive manner, including extensive chapters on psychological insights in behaviour and motivation of employees. This latter subject was also covered by Petersen’s reference books. These authors turned against the early 20th century 'Safety First' movement (US Steel, 1913). Safety should be integrated in the business and be part of working procedures. This was expressed in the 3rd point of figure 8. Again both Bird and Petersen provided many examples of forms for accident investigation reports of safety inspections and other initiatives. A combinations of these topic were a first draft for a safety audit. Petersen introduced SCRAPE, a systematic model to measure the safety efforts of foremen, like safety inspection rounds, safety training and meetings, and accident investigation (Petersen, 1971). These activities were point scores and the management could weekly award a score for each leader based on a record of activities forms. A second system was the Technic of Operations Review (TOR), which enabled to detect mistakes in the organization after an accident, a near-accident or damage. An example is given in figure 9. The reference book of Petersens in 1975 gave an extensive report on psychological and management models on motivation, behaviour and different styles of managing a safety program.

NEW PRINCIPLES OF SAFETY MANAGEMENT

1. An unsafe act, an unsafe condition, an accident: all these are symptoms of something wrong in the management system.
2. Certain sets of circumstances can be predicted to produce severe injuries. These circumstances can be identified and controlled:

Unusual, nonroutine	High energy sources
Nonproductive activities	Certain construction situations

3. Safety should be managed like any other company function. Management should direct the safety effect by setting achievable goals, by planning, organizing, and controlling to achieve them.
4. The key to effective line safety performance is management procedures that fix accountability.
5. The function of safety is to locate and define the operational errors that allow accidents to occur. This function can be carried out in two ways: (1) by asking why—searching for root causes of accidents, and (2) by asking whether or not certain known effective controls are being utilized.

Figure 8 Safety (Petersen, 1971)

This was called the safety climate program with a distinction in:

- The overzealous style; Personal protective equipment should be worn, machines are shielded so they are difficult to reach and operable, there are severe penalties for violation of procedures and there is an endless stream of safety films, talks and meetings. There is an overexposed to safety;
- rewarding style; the company starts safety competitions and rewards individual employees for their safety performance. The rewards are small. Employees see the company takes safety seriously;
- The lively style; the company starts safety competitions between factories or departments. Big signs at the entrance of the company show number of days worked without an accident. These companies teach employees that safety is an integral part of the work;
- The negligent style; safety in these companies is only important just after a serious accident. Employees see that the company is not interested

TOR TECHNIC OF OPERATIONS REVIEW

1 COACHING

10 Unusual situation, failure to coach (new man, tool, equipment, process, material, etc.) 44, 24, 62

11 No instruction. No instruction available for particular situation 44, 22, 24, 80

12 Training not formulated or need not foreseen .. 24, 34, 86

13 Correction. Failure to correct or failure to see need to correct 42, 20, 30

14 Instruction inadequate. Instruction was attempted but result shows it didn't take 15, 16, 42

15 Supervisor failed to tell why 44, 24, 83

16 Supervisor failed to listen 11, 81

17

18

19

2 RESPONSIBILITY

20 Duties and tasks not clear 44, 34, 14, 53

21 Conflicting goals 80,

22 Responsibility, not clear or failure to accept 26, 14, 54, 82

23 Dual responsibility 47, 34, 13

24 Pressure of immediate tasks obscures full scope of responsibilities 36, 12, 51

25 Buck passing, responsibility not tied down 44, 26, 55, 60

26 Job descriptions inadequate 80, 86

27

28

29

3 AUTHORITY (Power to decide)

30 Bypassing, conflicting orders, too many bosses 44, 13

31 Decision too far above the problem 36, 83, 85

32 Authority inadequate to cope with the situation 81, 83

33 Decision exceeded authority 20, 26, 14

34 Decision evaded, problem dumped on the boss 36, 14, 85

35 Orders failed to produce desired result. Not clear, not understood, or not followed 40, 46, 13, 15

36 Subordinates fail to exercise their power to decide ... 26, 12, 83, 85

37

38

39

4 SUPERVISION

40 Morale. Tension, insecurity, lack of faith in the supervisor and the future of the job 15, 56, 64, 80

41 Conduct. Supervisor sets poor example 13, 84

42 Unsafe Acts. Failure to observe and correct 24, 11, 52

43 Rules. Failure to make necessary rules, or to publicize them. Inadequate follow-up and enforcement. Unfair enforcement or weak discipline 25, 38, 12, 52

44 Initiative. Failure to see problems and exert an influence on them 22, 34, 30

45 Honest error. Failure to act, or action turned out to be wrong 10, 12, 15, 81

46 Team spirit. Men are not pulling with the supervisor . 40, 21, 56

47 Co-operation. Poor co-operation. Failure to plan for co-ordination 23, 25, 15, 66

48

49

5 DISORDER

51 Work Flow. Inefficient or hazardous layout, scheduling, arrangement, stacking, piling, routing, storing, etc. 41, 24, 31, 80

52 Conditions. Inefficient or unsafe due to faulty inspection, supervisory action, or maintenance 21, 32, 14, 86

53 Property loss. Accidental breakage or damage due to faulty procedure, inspection, supervision, or maintenance . 43, 20, 80

54 Clutter. Anything unnecessary in the work area. (Excess materials, defective tools and equipment, excess due to faulty work flow, etc.) 44, 36, 80

55 Lack. Absence of anything needed. (Proper tools, protective equipment, guards, fire equipment, bins, scrap barrels, janitorial service, etc.) 44, 36, 80

56 Voluntary compliance. Work group sees no advantage to themselves 40, 15, 41

57

58

59

6 OPERATIONAL

60 Job procedure. Awkward, unsafe, inefficient, poorly planned 44, 32

61 Work load. Pace too fast, too slow, or erratic 44, 51, 63

62 New procedure. New or unusual tasks or hazards not yet understood 43, 44

63 Short handed. High turnover or absenteeism 80, 40, 61

64 Unattractive jobs. Job conditions or rewards are not competitive 81, 46

65 Job placement. Hasty or improper job selection and placement 80, 86

66 Co-ordination. Departments inadvertently create problems for each other (production, maintenance, purchasing, personnel, sales, etc.) 45, 35, 13

67

68

69

7 PERSONAL TRAITS (When accident occurs)

70 Physical condition — strength, agility, poor reaction, clumsy, etc. 44, 26, 65

71 Health — sick, tired, taking medicine 44, 24, 65

72 Impairment — ampulee, vision, hearing, heart, diabetic, epileptic, hernia, etc. 44, 24, 65

73 Alcohol — (If definite facts are known) 80

74 Personality — excitable, lazy, goof-off, unhappy, easily distracted, impulsive, anxious, irritable, complacent, etc. 44, 13

75 Adjustment — aggressive, show off, stubborn, insolent, scorns advice and instruction, defies authority, antisocial, argues, timid, etc. 44, 13

76 Work habits — sloppy. Confusion and disorder in work area. Careless of tools, equipment and procedure 44, 13

77 Work assignment — unsuited for this particular individual 42, 65

78

79

8 MANAGEMENT

80 Policy. Failure to assert a management will prior to the situation at hand 24, 81, 83

81 Goals. Not clear, or not projected as an "action image" 83, 86

82 Accountability. Failure to measure or appraise results . 36

83 Span of attention. Too many irons in the fire. Inadequate delegation. Inadequate development of subordinates 12, 86

84 Performance appraisals. Inadequate or dwell excessively on short range performance 20, 65

85 Mistakes. Failure to support and encourage subordinates to exercise their power to decide 36

86 Staffing. Assign full or part-time responsibility for related functions 66

87

88

89

Figure 9, management audit (Petersen, 1971)

In this approach the role of management was not essentially different from that in the 1950s. Cost control and production efficiency were central. Only emphasis was added to the welfare of workers. A combination of a safety analysis of each task, task-specific training and ongoing safety observations, the so-called JSA JIT SO system (job safety analysis, job instruction training, safety observations) gave companies a high degree of control over labour. From that moment on, safety of a company or plant was seen as a measure of the quality of the supervision and safety observations. Just like stated by Heinrich, the foreman was the key. If a foreman could not organize safety, also his control of costs and product quality and production would be questionable. The responsibility for safety was laid on the shoulders of the middle and lower management. At the same time system approach had a direct relationship with training and design. As industrial system failed, it meant that those operating the system were trained insufficiently for the design of the system (Johnson, 1970; Cleveland et al, 1979). This is reflected in the definition of accident, where the concepts of ‘energy transfer' and 'barrier' were referring to the models of Gibson (1961) and Haddon and co-authors (1964):

> *An accident is the result of a complex series of events, related to energy transfer, failing barriers, and control systems, causing faults, errors, unsafe acts, and unsafe conditions and changes in process and organisational conditions* (Johnson, 1970).

Johnson (1973a) presented an integrated management model for occupational and process related accidents. Accidents were multi-causal and developed over a relatively long sequence of changes and errors; the accident scenario. All components of the industrial process could be part of this sequence; management, design, environment, machinery, equipment, supervision and employees. Before accidents occurred, scenarios were already partly active through interactions and changes in process and organizational conditions. Examples of these non-routine conditions shown in figure 9, paragraph 5 and added to the complexity of the accident, that only in retrospect developed as a disaster scenario (figure 10).

This concept of accident causation led to the MORT technique. The technique was developed by the United States Atomic Energy Commission with the aim to establish a perfect safety management system, by combining accident models with quality systems. MORT is also useful as an in-depth analysis technique of system failure. MORT is built up from a number of fault trees, starting from the functional failure of a system. The use of these error trees had previously been represented by Nielsen with the logical connection between causes and consequences (figure 11).

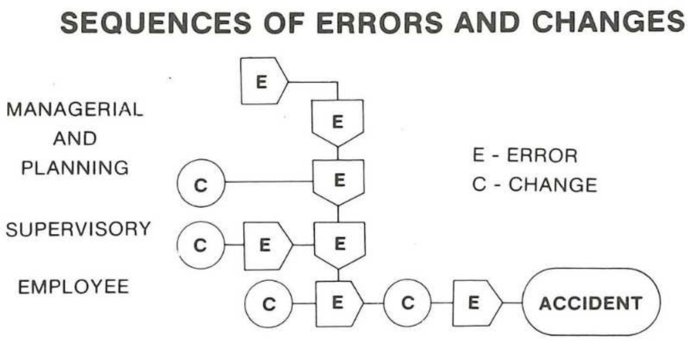

Figure 10, errors and changes leading to accident scenarios (Johnson, 1973a)

The top event in MORT is an accident or damage. Below the top event four different fault trees are used for analysing the event: 1) assumed risks, 2) the energy model of Haddon (1963), 3) a feedback and control system, and 4) the life cycle of the system (Figure 14).

Figure 11, bowtie precursor (Nielsen, 1971; Johnson, 1973b)

Was Petersen first in using the term 'safety management', the report of the United States Atomic Energy Commission was the first time the descriptor 'safety management system'. MORT was like a fault tree, not based on systematic research but on a logical expression of the functions required for an organization to manage its risks effectively. The report concluded that overall safety programs in companies were far from optimal, as was the literature on safety tools for major accidents. The programs were poorly defined and the information collected was flawed, saddling middle managers and workers with blame in case of damage or accidents. In this respect, the situation did not seem to be very differ from the beginning of the century. Management had, according to the report, the legal and moral obligation for the safety of the production. First an answer should be given on questions regarding dominant accident and disaster scenarios, which were probable, and which consequences of these scenarios were likely to occur. Then the question arose whether the risks were controlled, which residual risks were present and which arguments were used to rejected measures for reducing risks. Finally, there was the question of the quality of the safety program of the company, was it effective as designed?

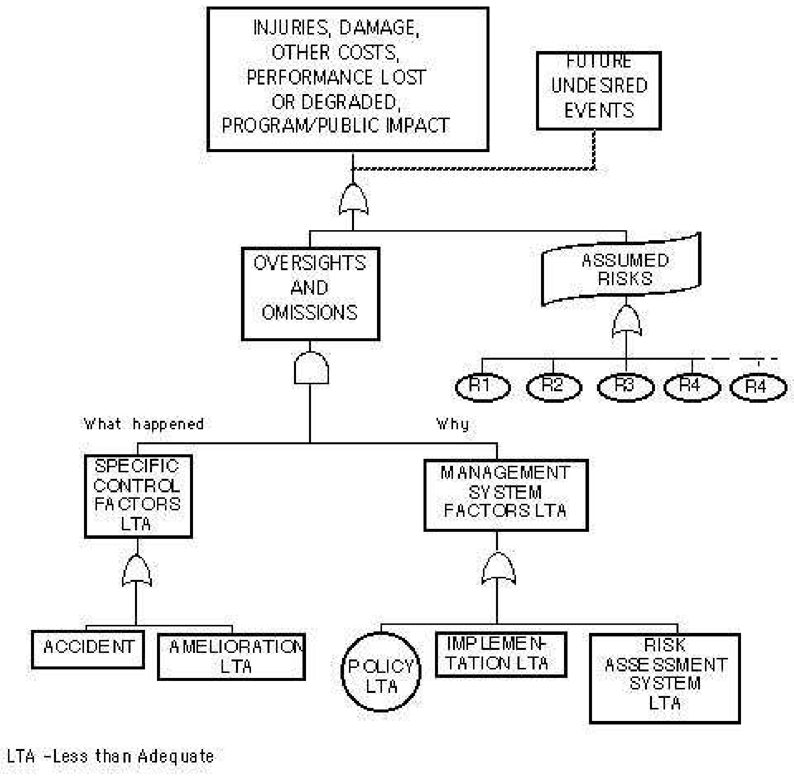

Figure 12, MORT (Johnson, 1973b)

The report also gave a characterization of five quality levels of safety programs and covenant with the risk of a major accident or disaster (see table 1). The origin of the probabilities presented was not given, only the remark that companies had sufficient data to justify an order of magnitude difference between the successive levels. Reactors from the nuclear energy sector fell in the fifth level.

safety program level	disaster probability
sub-minimal, less than minimal compliance with regulations,	1×10^{-3}
minimal, minimal compliance with enforced regulations,	5×10^{-4}
manuals, applications of manuals and standards,	1×10^{-4}
advanced, advanced programming, examplified by leading industries,	1×10^{-5}
systems, system safety,	1×10^{-6}

Table 1, quality of safety programs and disaster probability (Johnson, 1973b)

8 DEVELOPMENTS IN THE NETHERLANDS

In 1970s, the focus in the Dutch professional journal *De Veiligheid* on accident proneness theory, and Heinrich's unsafe acts, which was dominant from the 1930s onwards, was somewhat weakened. Other developments from the safety science domain, mainly coming from the United States and the United Kingdom were discussed. Also, two international symposia on safety were organized in The Netherlands. The first was the Loss Prevention Symposium in The Hague and Delft by the Royal Institute of Engineers (KIVI) and the Royal Dutch Chemical Society (KNCV), which closed one day before the Flixborough disaster (Buschmann, 1974). The second symposium was organized by the then Technical High school of Delft, the Foundation for Road Safety Research (SWOV), the Safety Institute (VI) and the Directorate General of Labour (DGA). This Delft symposium discussed academic education and research on safety (THD, 1978). In the same year, the organization psychologist Hofstede (1978) published an article where he denounced systems thinking. Also in 1979, a new journal *Riskobulletin* (Risk Bulletin) appeared, edited by the Adviesgroep Veiligheid en Gezondheid in de Industrie (Advisory Group Safety and Health in Industry). This Group included members of the Union of Scientific Workers, which was created in reaction to the Vietnam War, and of the Association of Scientific Researchers, which was created after the World War II atomic attack on Nagasaki and Hiroshima. Science Shops, present at almost all Dutch universities and supporting knowledge related questions from workers, environmental and community groups, were also connected to this Adviesgroep.

The major disasters with ample media attention were discussed in the professional journal *De Veiligheid* (Groothuizen, 1976; Versteeg, 1979). And there was extensive coverage of the theories and models of Winsemius (1951), the task dynamics (Anonymous, 1974; Andriessen, 1974 Wijk, 1977), prevention strategies and hazard-barrier-target model Haddon (Cooper, 1973; Bergsma, 1974), loss control management of Bird and reference books of Petersen (Pope, 1976 Bird, 1978; Fletcher, 1978; Wright, 1978; Leij, 1978, 1979). Also The Netherlands received his first book on safety management (Zwam, 1978). With the review of Petersen's safety manual, the term safety management was introduced in the Netherlands and with a certain regularity the control of process deviations and organizational change was seen as sources of prevention (Dop, 1977 Radandt, 1979). Remarkably enough MORT as well as developments within the nuclear industry were not addressed in the journal. This was different for the topic of 'humanization of labour', addressing negative effects of an extensive division of labour and the separation of management and execution, head and hand, which were created under the scientific management, (Strien, 1978). Conflicts over responsibility were also evident in the so-called working group 13 of the Dutch Society for Safety Science (NVVK). Here the dilemma was outlined of company interests versus the interests of employees. A role as safety inspectors was difficult to combine with the promotion of the welfare of workers, was the argument (Meertens and Zwam, 1976; Kraan and Schenke, 1976; Oostrom, 1979). This debate about the ethics of the safety profession, was not unique to the NVVK. Within universities, the role of scientists and engineers in society was discussed, with chemistry and science shops as a result (Zwaard, 2007).

Other topics in *De Veiligheid* were systems theory, system and process safety. These were complicated issues creating quite some resistance amongst NVVK members. ‘There is relatively little overlap between safety experts and system thinkers’, according to Koornneef (1979). Incidentally, this system approach had resulted in the accident model of Wijk (1977), which like the one from Johnson and Nielsen, could be seen as a precursor of the bowtie (figure 13).

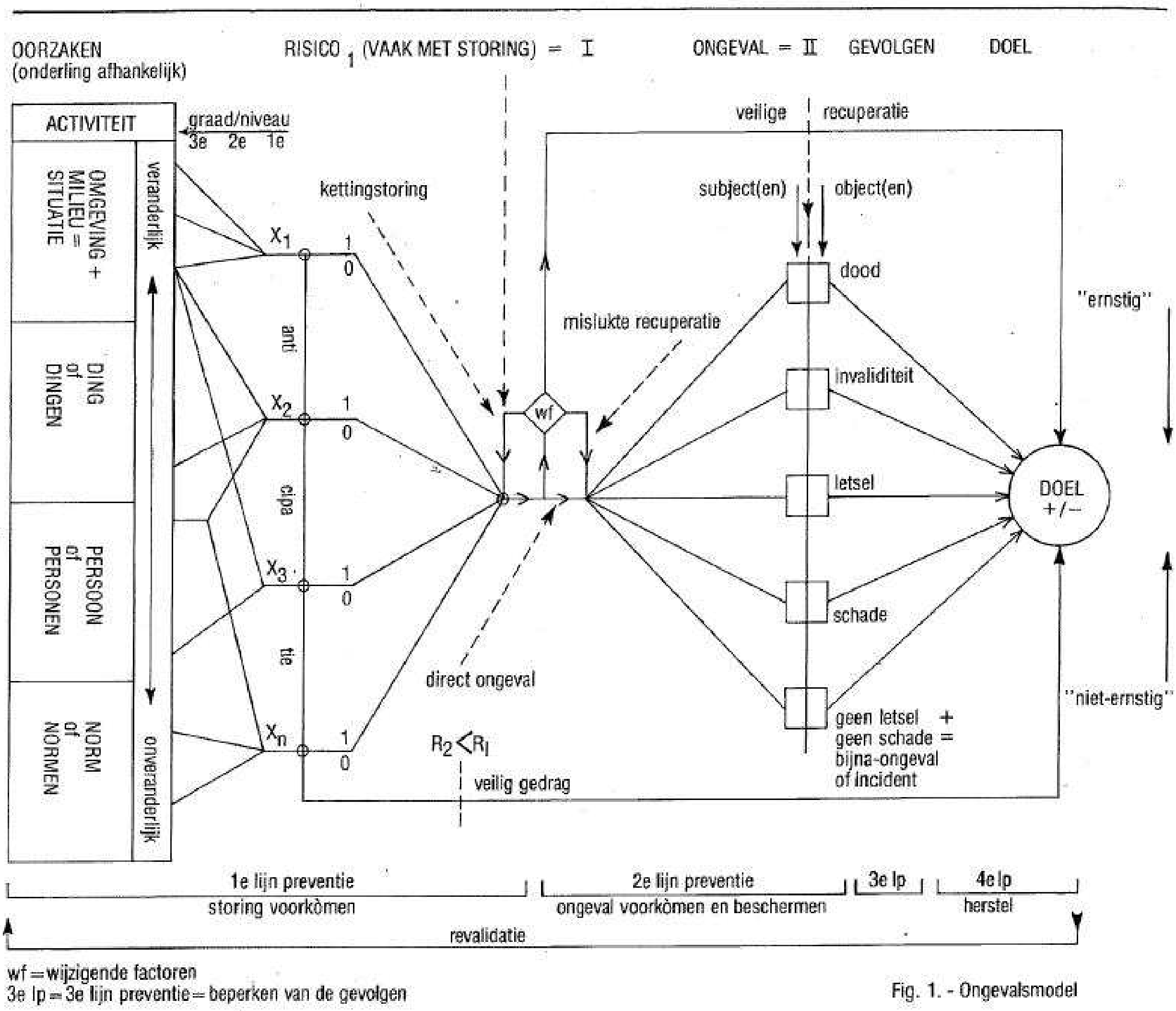

Figure 13 accident model (Wijk, 1977)

The model started with a block of 'activities'. From there, a network of lines through amending factors and disturbances runs towards the goal (doel, accident). The tangle of lines indicates the multi-causal nature of the accident process and the interdependencies of the various factors. This model is in its presentation more complex than the figures 2 and 11. Most likely, the models were developed independently of each other. It was not likely that the author was aware of the Danish or the United States Atomic Energy Commission models (Koornneef, 2013).

Publications about system safety, as from Pope, Wijk and Wansing (1976), could count on criticism. The argument mentioned was that safety science should focus on a human approach. Man, after all, was not a component of a system and did not fit into mathematical formulas, a commentary in line with from the United States and the United Kingdom criticism of failure probabilities of human behaviour (Rigby and Swain, 1971; Kirwan, 1994; Pasmooij, 1979). The system approach led to the quantification and assessment and evaluation of risk, followed by decisions on the acceptability, risk acceptance and the resulting measures and interventions, risk control. Extended comments were published in *De Veiligheid* en *Risikobulletin* on the risk quantification and acceptance. Probability calculations, it was thought, were often based on guesswork and uncertainties of probabilities were seriously underestimated (Wetenschap en Samenleving, 1978; Reijnders, 1979) (Figure 14).

Figure 14 special issue Science and Society, risk acceptance (W&S, 1978)

Furthermore, a comparison of risk figures, comparing non-equivalent activities, made little sense. Not all risks were taken voluntarily and risk acceptance was a political issue, which was presented as a scientific problem (Boskma, 1977 Leij and Mutgeert, 1977 Boesten 1978, 1979).

Moreover, these subjects were not discussed during the Delft, The Hague Loss Prevention Symposium. There items were presented as guidelines for safe design in the process industry and studies on hazards and risks of static electricity, gas and dust explosions, transportation of hazardous materials and the reliability of system components. Oddly enough, the topic of safety management was not addressed explicitly. The Symposium University Teaching and Research in Delft was much broader. At the symposium the safety domain was not restricted to occupational or process safety, but extended to include private safety, safety at home, at sport, and road safety. Also the topics of the presentations were broader. The Hague-Delft symposium was restricted to experts from universities, industry and government. At the Delft symposium there was also room for presentations from unions, chemistry and science shops and action groups which, next to technical aspects also highlighted social aspects of safety. The Delft symposium was the start of the Safety Science Group, which was established at the Technical University in 1979 (Goossens, 1981). Safety Science became an academic discipline in the Netherlands, following earlier initiatives of the University of Wuppertal (1974), the Catholic University of Leuven (1975) and the University of Aston, Birmingham (1976).

Apart from the symposium, Hofstede (1978) ventilated fierce criticism on systems thinking. The system approaches with its clear goals, its input-process-output scheme, its comparison with standards and his feedback and feedforward loops also had a strong presence in the management literature as a model to structure decision. Managing companies, however, is primarily a social process in a socio-technical environment. A systems approach is flawed because there are no clear defining goals, except some general remarks, coming from business visions. The claims, or the quality of management activities are not, or only hardly measurable, whereby feedback information is not usable, or is not used.

9. DISCUSSION AND CONCLUSIONS

In this review the development of knowledge of the accident process and management of safety is based upon articles and documents. Not necessarily this will implies that knowledge and ideas in the academic and the professional domain are common in the period in which they were published. Sometimes knowledge dies, sometimes it takes years or decades before ideas are accepted. An example is the theory of Winsemius on task dynamics, developed in the early 1950s and only referred to in publications in the 1970s This also applies to the "man-made disasters' Turner from 1978. The preface to the second edition (Turner and Pigeon, 1997) shows the publication was not noticed at the time of its appearance outside of a select group of academics. A summary of the knowledge developments within the safety domain and general management trends is shown in table 2 and 3.

The relationship between general management trends and knowledge development on managing safety in enterprises is not obvious. Here, too, the aforementioned delay can play a role. In addition safety and general management may be can considered his as two separate domains with their own dynamics. The first focused on accidents and guided by dominant explanations or models of accident processes. General management is primarily driven by market developments and production efficiency in industrial sectors and consequently management control in companies.

Dominant schools of management are limited in number. In the period four major schools have emerged, classical and scientific management, behavioural management, quantitative management and modern management. These schools are not exclusive for a certain period of time and could exist next to each other (Figure 15).

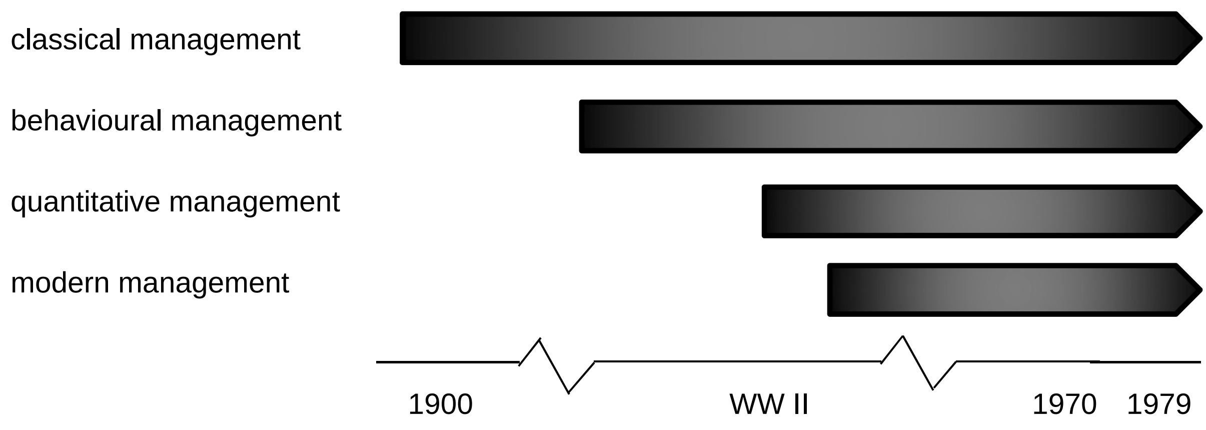

Figure 15 major management schools in relation to safety in Europe and the US

The focus to managing safety starts halfway the 19th century in the United Kingdom, later followed by the American Safety First movement. Companies with an obvious interest in safety, like US Steel, are pioneers. Safety First prioritized safety for a company and there is no relation with the classical and scientific management. Safety in the early days is safety technique, the domain of the technician.

Knowledge on managing company safety started in the second decade of the 20th century in the United States and was the domain of large corporations and insurance companies. The knowledge was fuelled by psychological concepts. Management had to control unsafe acts through selection and training methods of scientific management. From the beginning of the 19th century, a comprehensive labour legislation existed in the United Kingdom, also dealing with occupational safety and health. Safety was the domain of government committees such as the Industrial Fatigue Board and the subsequently the Industrial Health Research Board (1918-1959), who gave orders to investigate causes of accidents. The management of safety was not an item in publications of these boards, neither in British literature of that period.

Before World War II the psychological models of the accident process connected to the behavioural management school. Safety technique could quite effectively solve 'unsafe conditions' of Heinrich's dominoes. Behaviour was more complex and would therefore have a greater role in the causes of accidents. The behavioural management approach has probably ensured that the domino metaphor has remained popular until well after the World War II. Dutch and American doctors and British and American ergonomists and psychologists developed theories and models of accident causation in the second half of the 20^{e} century, focussing attention to process disturbances, the barrier concept and errors and discrepancies in information to employees. These models and theory have no detectable influence on the development of knowledge concerning safety management, a term which has not yet been used in documents and articles. The management process for safety, first gained a clear presentation in the form of the Heinrich's safety ladder Heinrich. There seem no relation with general management schools, quantitative and modern management, which emerged during and after the war. Dominoes and the safety ladder had a relationship with the behavioural and scientific management school.

In the 1960s a separate development in the process safety emerged, loss prevention, with a focus on operability of complex technical systems. This did not generate knowledge on safety management, except the notion that safety must be an integral part of the design and performance of processes and that empirical knowledge should the reliability of parts of process installations.

period	theories	models, metaphors	safety management	general management
19th century		Safety technique Factory act (UK 1844), Westerouwen van Meeteren (Nl 1893), Calder (UK 1899)	Accidents are part of the job	Classical management
1900-1909	External facors; Heijermans (Nl 1905)	Road to happiness, Safety First Movement; US Steel, (US 1906)		
1910-1919	External factors Eastman (US 1910), Home Office (UK 1911) Accident proneness; Greenwood & Woods (UK 1919)	3E's: engineering, education, enforcement; National Safety Council (US 1914)	Selection of workers, training of workers in safety philosophy, safety committees; Cowee (US 1916)	Scientific management, observations, measurements, registration, selection, training of workers, standards, safety procedures, cooperation management-workers; Taylor (US 1911)
1920-1929	External factors; DeBlois (US 1926)	Hazard is energy, probabilistic approach to accidents; DeBlois (US 1926) Costs of accidents 1:4; Heinrich (US 1927) Causes of accidents 88:10:2; Heinrich (US 1928) Accident mechanism, iceberg, 1:29:300; Heinrich (US 1929a)	Appointment safety engineer, standardisation procedures; Williams (US 1927) Safety is condition for efficient production; American Engineering Council (US 1928) Good management is better than good tools; Heinrich (US 1929b)	
1930-1939	External factors; Vernon; (UK 1936)		Management supports safety initiatives, analyses accident causes, develops and implements solutions; DeBlois, Heinrich (US 1926, 1931)	Behavioural management, human relations, behaviour, motivation, leadership; (US 1930s)
1940-1949		Accident process, domino's; Heinrich (US 1941) Epidemiological triangle; Haddon – Gordon; (US 1949)	Methods of accident prevention are similar to quality control; Heinrich (US 1941) Management shows leadership in safety; Armstrong et al. (US 1945)	
1950-1959	Task dynamics, man-machine interaction; Winsemius (Nl, 1951)		Managing safety as a ladder; Heinrich; (US 1950)	Quality Management; Deming, Juran (US 1951, 1982)

1960-1969	Man-machine systems; Singleton (UK 1967a, 1969)	Human factors, ergonomics; Swain (US 1964), Singleton (UK 1960) Hazard-barrier-target; Gibson, Haddon (US 1961) Damage iceberg 1:100:500; Bird (US 1966) 10 preventive strategies; Haddon (US 1968)		Modern management, company as open system, managing as decision making and information processing activity
1970-1979	Prospective study, ergonomics system design, poor communication office-shop floor; Powell et al. (UK 1971)	Multi-causality of accidents, disturbed information flow; Hale and Hale; (UK 1970), Dunn (UK 1972) Organisational domino; Bird (US 1974)	Safety management, multi causality, audits, participative safety; Petersen (US 1971, 1975, 1978) Self-regulating system, from detailed descriptions to goal regulation; Robens report (UK 1972)	Humanisation of labour: Swain (US 1973) Management systems are organisation specific; Schein (US 1972) Typology of organisational structures; Mintzberg (Canada 1979)

Table 2, theories, models, metaphors and management approaches in occupational safety from the 19th century till 1979

period	major accidents	theories, models, metaphors	safety management	general management
1940-1949				Quantitative, operations research, decision making based upon mathematical, statistical models
1950-1959				
1960-1969			Loss prevention; Association of British Chemical Manufacturers (UK 1964) Process safety techniques; Hazop, FMEA, FTA, (US 1960, 1962, UK 1963)	Modern management, company as open system, managing as decision making and information processing activity
1970-1979	Flixborough (UK 1974) Beek (Nl 1975) Seveso (Italy 1976) Alfaques (Spain 1978) Three Mile Island (US 1979)	System safety; Johnson (US1970) Organisational culture; Turner (UK 1971) Lose, tightly coupled organisation; Reeves et al. (UK 1972) Gas cloud explosions; Nettleton (UK 1976 1976, 1977) Disasters, organisational incubation period; Turner (UK 1976 1978) Cause-effect diagram (bowtie); Nielsen (Denmark 1971) Changes, non-routine conditions causing accidents; Petersen (US 1971), Johnson (US 1973a, b)	Self-regulating system, from detailed descriptions to goal regulation; Robens report (UK 1972) MORT; Johnson (US 1973a,b) Loss control management; Bird (US, 1974), Bird and Loftus (US 1976)	Management systems are organisation specific; Schein (US 1972) Typology of organisational structures; Mintzberg (Canada 1979)

Table 3, major accidents, theories, models, metaphors and management approaches in process safety till 1979

Loss prevention emerged against the background of a strong upscaling of the process industry, the increased complexity of managing these processes and an increased critical public opinion.

The 1970s was a stormy period. Public opinion turned against major industries, including the process industry and was fuelled by a series of major accidents with ample media attention. The difference with occupational safety, which has already present in the previous period, only increased and the two domains followed their own dynamics.

Both the United States and the United Kingdom the human factor was revalued first in occupational safety, and later in process safety. This was not seen as a cause of accidents, but as a symptom of mismanagement. The effect of safety training in both countries has been seriously questioned. British researchers went even further. The numerous publications on safety could not prevent companies to limited their safety focus on paper statements without further consequences for workplaces. With the exception of reports on individual companies, serious research on the implementation and quality and safety management (systems) in various sectors was not (yet) implemented.

In the 1970s British sociologists investigated the emergence of major accidents in large organizations. Concepts such as loose and tightly coupled organizations make their appearance, as well as the concept of organizational culture, incubation time of a disaster and organisational processes which made companies blind for weak signals and omens of developing disaster scenarios. These contributions had a very strong focus on safety management, but only a limited to no relationship with technical aspects of the occurring disaster scenarios. This was different in the process industry, the aerospace and nuclear industries. Here are safety approaches have been developed relying on systems theory, on technical aspects of production processes, and had a relationship with the quantitative management; loss prevention movement and reliability engineering. Loss prevention had no clear relationship with safety management. After the devastating effects of Flixborough, Beek and Los Alfaque models and theories were developed to understand and control gas, vapour or dust explosions.

This survey shows the multidisciplinary nature of the safety domain. Technicians, engineers, doctors, psychologists, sociologists, ergonomists and safety experts have interfered with the discipline, each discipline with their own questions. In the early days there was little sign of any kind of integration of knowledge. That changed in the 1970's when the knowledge on safety management began to take shape, and models and concepts from different knowledge domains emerged.

With the exception of a few outliers around the start of the 20st century and the 1950's, the Netherlands after World War II always has been a follower of Anglo-Saxon developments. It took until the end of the 1970s until independent research is conducted in our country. Netherlands got a Safety Science Group at the Technical University Delft and Hofstede voiced sharp criticism of the system approach to management of companies and safety. However, in the period after 1979 this system approach only became more influential.

Many topic, which today dominate the discussions on safety, are also addressed in the period covered, such as the integration of safety and production, management commitment, the position of middle management, dominance of accident rates, quality of management and the lack of attention for the evaluation safety of interventions.

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