The 19th century and first half of the 20th century is one of those periods in history of rapid economical, technical and social changes. There is an ongoing mechanization, followed by a movement to rationalize production and to make it cost effective. This has created a heavy burden of occupational deaths amongst workers. In this period occupational safety is developing into a professional field. Engineers are enclosing hazards and fencing heights, shaping up safety technique, and writing very practical publications on occupational safety. These publications, predominantly published in the United States, are leading to quite some safety related metaphors, with the iceberg and the domino’s as the most famous ones. Sociologists, psychologists, and physicians are more concerned with questions related to accident causation, and these specialists are conducting research leading to two different safety theories. Causes of occupational accident are found either in the workers’ capacity to handle hazardous situations, or in external causes, like very long working hours, dangerous machines and the increased pressures of work and speed of production. The Pittsburgh survey, the first extended analysis of occupational accidents in a steel district, strongly advocated the environmental hypothesis, while the so-called ‘individual hypothesis’ is favored by the American Safety First Movement, starting as a private initiative in 1906 by US Steel, and later spreading out over Western European countries. The British Industrial Fatigue Board has given the individual hypothesis its scientific justification. Despite scientific criticism just after World War II on the concept of accident proneness and ‘unsafe acts’, its popularity is not fading. Even nowadays the famous metaphors are still part of the vocational training of safety experts, also in The Netherlands. Apparently professional and scientific developments in occupational safety are belonging to two separate worlds. Before World War II, The Netherlands is not a leading country in occupational safety but a follower, first of France and the German speaking countries. After World War I its focus is directed towards the Anglo-Saxon countries.

1. Introduction

Occupational accidents have been analysed and discussed for the past 100 years. Everybody will recognise the accident proneness theory, the falling domino’s, later followed by Swiss cheese, Tripod, and Bowtie’s. This theory and these metaphors allow us to understand accidents and disasters that have occurred. But the domain of safety science is rather poor in theories, which will not only explain past events, but also can predict present and future events from happening.

At the beginning of the 20th century two hypotheses were dominant: the individual and the environmental hypothesis, reflecting the controversy over heredity and environment, the nature versus nurture debate. The accident proneness theory is an example of the individual hypothesis, explaining accidents as a result of individual predisposition for accidents. The environmental hypothesis on the other hand is looking for external causes of accidents, like the speed of work, dangerous machines, or the long working hours. These metaphors and theories are the topic of this literature review, which is structured according to the following research questions:

- Which theories and metaphors have been developed?
- What is the basis of these theories, and when available, which data formed the foundation of these theories?
- In which context safety metaphors and safety theories have been developed?
- Which are the consequences of the theories for the professional field of occupational safety in The Netherlands?
These questions make a distinction between the development of occupational safety as an academic field of research, and as a professional field, assuming that developments in academic knowledge do not necessarily enter the professional field.

Personal safety, occupational safety and process safety are terms used in the safety literature. Process safety is referred to as asset integrity, or technical integrity of installations or systems, while personal safety is dealing with the slips, trips and falls, and is primarily affecting one individual worker for each occurrence. As explained by Hopkins (2008), there is an assumption that personal and occupational safety are the same. This is problematic, because all hazards at work will affect occupational safety. Because original articles of this review does not allow a clear distinction between personal and process safety, the term occupational safety will be used consequently.

The German and French developments in occupational safety only will be discussed marginally in this article. These two countries do have a long tradition in the safety domain. Till now, authors did not have the opportunity to include the developments in these two countries and the review will be restricted to the countries mentioned in the title of this article.

The review is based upon an extensive literature search. Most of the original references are present in the Central Library of the Delft University of Technology in The Netherlands. If not, original references are collected from libraries abroad. For the Dutch developments, two journals are consulted to from their year of formation; 'De Ingenieur' (The Engineer) from 1886 till 1945, and 'De Veiligheid' (The Safety Journal) from 1927 till 1945. As much as possible the developments in occupational safety in the countries under discussion are presented chronologically.

1.1. Occupational safety till the beginning of the 20th century

Occupational safety has attracted systematic attention in the 19th century, in a period the United Kingdom is leading the industrialisation and its great technical discoveries. The industrial revolution, which has started over a century before, has given a leading position to the textile industry, and slowly European countries are changing from a feudal agricultural society to, what is called ‘the modern society’, an industry state with an upcoming middle class. The installation of the British Factory Inspectorate, in charge of the supervision of the law, dates from 1833. And from 1844 onwards the inspection also has the duty by law to monitor safety in factories, like various forms of guarding machines and installations (Hale, 1978; Le Poole, 1865). In the same year Friedrich Engels is publishing ‘The conditions of the working class in England’, based upon his survey conducted in Manchester (Engels, 1844; Sheeman, 1973). And in the 1860s and 1880s the results of extensive sociological surveys amongst the London working class are becoming public, describing the effects of the economic barbarism during the 19th century (see for instance Anonymous, 1889a; Booth, 1889; Mayhew, 1861, and for the pre-World War I period see Reeves, 1913). Also in other European countries results of similar surveys are published (Rosen, 1976). These studies present a picture of life and work in the big city as an ingenious balanced mechanism, where every social class is staying alive on the remains and waste of the class above. Big parts of the city look like giant ant heaps with the ever lasting smell of decay and excreta. This large scale pauperization, both in cities and factories confirm the picture already presented by Thackrah and Engels.

Around 1875 England’s frontrunners position in industrialisation is taken over by de United States and Germany. Increasingly, technical progress is based upon scientific insights, both in the products produced, the organisation of the production and the planning and management. Scientific discoveries in chemistry and physics are the basis of new and emerging industries in these countries, like the organo-chemical and the electro-technical industry. Technique becomes technology.

Industrialisation in The Netherlands is starting at a later period than countries around. Steam engines are only introduced on some scale, halfway the 19th century (Lintsen, 1995b). Also surveys in The Netherlands on working conditions at workshops and factories are initiated somewhat later. Following the Socialist International Organisation, founded in London 1864, national inquiries are used to list working and living conditions. Between 1870 and 1880 three such inquiries are conducted by the Workers Association Arnhem, the General Dutch Workers Association and by Domela Niewenhuis. All three inquiries are pointing to long working hours, on average 16–17 h a day, and the low salaries earned. General living costs for working people in that period are higher than the salaries earned, providing a financial incentive for child and women labour. The enquiries reveal a sad picture on safety conditions. Supervision on boilers, steam engines and other dangerous installations is absent, and the conditions in factories aggravate the pauperized condition of workers (Booth, 1889; Roland Holst, 1902; Welcker, 1978).

Next to these inquiries Samuel Coronel, a physician and hygienist, has published a long list of articles on conditions in factories and workshops. One of his review articles on industrial hygiene is paying attention to occupational accidents (Coronel, 1876). According to the author, mechanisation has two side effects, apart from the mitigation of labour: first the introduction of new hazards, like steam, dangerous machines causing accidents, and workshops crowded with machinery, leaving hardly room for workers to move. And secondly, Coronel notices that grown up workers are replaced by ‘weaker forces’, such as the rapid hands of children and women.

The first social legislation in The Netherlands is introduced much later than in the United Kingdom. The first Factory Acts originates from 1874 and forbids child labour under the age of 12 years. This legislation is symbolic in nature, because of the lack of any form of supervision. Thirteen years later The 8th Parliamentary Enquête (inquiry) is conducted on the effectiveness of this law.

The results came as a real bombshell, because results of the interviews, including many workers, are published very rapidly and
confirmed in detail the observations made by Coronel and previous national inquiries (Buitelaar and Vreeman, 1985; Giele, 1981). The Enquête has revealed working and living conditions of the Dutch working class, which the public opinion only could imagine in countries abroad, like England, and Germany. In 1892, 5 years after the Enquête, the annual reports of the Dutch Factory Inspectorate again confirm the deplorable conditions of factories, the overcrowding of machinery, and the bad conditions of most installations. But for the first time carelessness, inattention, inaptitude and recklessness of victims are mentioned as causes of accidents (Anonymous, 1892). This attribution of causes is also a sign of emancipation of the working class. While before, workers are simply part of the indefinite ‘poor’, they are now seen as a group which will need attention, both from a health (cholera) and a safety perspective. The upcoming liberals, with a strong focus on education, have organised a national discussion on the so-called ‘Sociale Questie’ (social issue), also called the ‘arbeidersvraagstuk’ (problem of the working class). The inevitable class difference, forced by God’s will, could no longer be admitted, due to the results of the national and parliamentary enquiries (Brugmans, 1958; Romain and Romain, 1973). The liberal answer to the Sociale Questie is improved training and hygiene for workers. Healthy workers after all are more productive. According to the liberal philosophy, these initiatives should not be initiated by government, but by private initiative.

One of the leaders is Westerouwen van Meeteren, who, with some disgust, is looking at the German and its state induced inspections and control of factories. He makes an appeal to all Dutch industrialists to start a safety society, before the government will take any action. This initiative, mirroring the French ‘Association pour prevenir les accidents de Fabrique’ (Association for the prevention of accidents in factories) from Mülhausen, Elzas (Reid, 1987), has become the ‘Nederlandse Vereeniging tot Voorkoming van Ongelukken in Fabrieken en Werkplaatsen’ (Dutch Society to Prevent Accidents in Factories and Workshops). The society has operated between 1890 and 1901. Its aim is to prevent avoidable accidents, to start up factory inspections, safety education, and propaganda and to prize inventions of new safety equipment (Anonymous, 1889b, 1890, 1893, 1896, 1897b; Krap, 1890; Schwitter, 1991). From 1893 onward the association issued the professional periodical ‘Veiligheid’ (Safety) for a period of 11 years. This journal contained many contributions from Westerouwen van Meeteren. He is also the author of the first Dutch reference book on occupational safety and health, using predominantly German and French reference materials (Bakker and Berkers, 1995; Kerklaan et al., 2002; Westerouwen van Meeteren, 1893). This publication will be discussed further down this article.

Despite the opposition of liberals, the Factory Inspectorate is installed in 1890, and social legislation is slowly starting, like the Factory Act (1889), prohibiting child- and women labour, the Safety Act (1895), with regulations on machine guarding, and the act on industrial injuries (1901), regulating financial compensation (Anonymous, 1897a; Binneweld, 1991; Kerklaan, 2006; Lochem, 1943; Schwitter, 1991).

Before the 20th century there is hardly any written evidence on occupational safety for the United States. This changes in the period around World War I. Occupational safety is becoming a professional field of activities, initiated by two major events in the United States: the birth of the Safety First Movement and the results of the Pittsburgh survey. The Safety First Movement is a private initiative started by the American steel industry, and the Pittsburgh survey is the first sociological survey in the US, investigating working and living conditions of workers in the Allegheny district. Occupational accidents no longer are caused by an ‘act of God’, but are ‘man made’. The professionalization of occupational safety is also apparent by the birth of organisations, specifically dealing with the topic, and a stream of publications in both academic and professional press. Looking at the number of publications, the United States is leading, compared to the United Kingdom of The Netherlands. A major part of this literature review is devoted to the developments in the United States, covering the period till World War II, with some minor excursions to periods just after the war.

2. The United States

2.1. The American Safety First Movement, 1906

In the United States, mining, steel and product industry and trade are becoming large sized industries, dominated by big conglomerates of companies. As far as occupational safety is concerned, this area is seldom the domain of managers in that period of time. Managers are not looking after issues related to shop floor level. Here the foreman sets the rules, hiring and dismissing workers. And not surprisingly, unskilled labour shows a large turn over, and the accident rate in industry is very high. In the beginning of the 20th century, national accident figures in industry are available, and in 1907 a first international comparisons are made. According to these statistics, American steel industry has an occupational mortality 3–4 times higher than Germany, where the mortality rate is 0.2 per 1000 man-h. Two years later, Fredrick Hoffman, a statistician of an insurance company, presents an estimation for the Bureau of Labour Statistics of the annual mortality in industry: 30,000–35,000 deaths, 350,000 severely wounded, and 2,000,000 medical treatments, numbers which are larger than those of the civil war of 1861–1865 (Aldrich, 1997; Anonymous, 1915, 1926a; Hoffman, 1909). The reliability of the figures mentioned is not clear. But the overall picture of a high mortality in the American industry, compared to Europe, is a repeated argument in various publications. There is only a rudimentary concept on causes of these accidents; accidents are part of the job, they are inevitable, or are caused by workers behaviour. The shop floor has become an extremely hazardous location, and by emphasizing the guild question, prevention of occupational accidents is almost impossible.

US Steel is one of the companies where the growing burden of accidents is jeopardising its production, and productivity. This company is the country’s largest steel company, with branches spread all over the country, and the initiator of the Safety First Movement in 1906 (Palmer, 1926). An illustrative poster from 1913 is showing a country path as a metaphor for occupational safety. The poem at the bottom of the poster explicitly focuses on workers’ behaviour and attitude (Fig. 1). It is the first time such a national safety campaign is launched. Many companies accepted the initiative with open arms; DuPont, a gunpowder manufacturer, being one of them. Due to its production, this company has a natural interest in safety.

2.2. The Pittsburgh survey, steel is war, 1906–1907

US Steel has always emphasized the humanitarian motives of the campaign, but it does not alter the fact the company suffered from negative publicity. One of the common slogans at that time is ‘Steel is war’, and clear titles in the Chicago weekly press as ‘Making steel and killing man’ and ‘The law of the killed and wounded’ are asking attention for the working conditions at the company (Hard, 1907). Not only is the steel industry under attack in that period. Also other branches of industry, like the meat industry, the textile and car industry are subjects of novels and photo books. Known examples are ‘The Jungle’ of Upton Sinclair about the conditions of the Chicago slaughterhouses (Sinclair, 1906), the 1908 photo’s of Lewis Hine for the National Child Labour
Committee (Anonymous, 1977; Doherty, 1981; Freedman, 1994) (Fig. 2), a general survey on living conditions in New York, Riis’ ‘How the other half lives’ (Riis, 1890), and Céline’s report of the Ford factories in New York published a few decades later in ‘Voyage au bout de la nuit’ (Céline, 1933).

Another source on living and working conditions of workers are the results of the American survey in the Allegheny district in Pennsylvania, better known as the ‘Pittsburgh survey’, conducted between 1906 and 1907 (Kellogg, 1909). This survey provides a detailed image of the rough side of capitalism in this industrial town, which is dominated by US Steel.

‘Work accidents and the Law’ of the sociologist Crystal Eastman is one of many publications of the Pittsburgh survey (Eastman, 1910). She has pioneered by making an analysis of hundreds of occupational accidents, as well as the financial consequences of these accidents for the families concerned. At the start of the 20th century, compensation of occupational accidents is not regulated by law, this in contrast to West European countries. Most states in the US enforced compensation laws around the 1920s (Aldrich, 1997; Ashford, 1976). The survey shows the financial contribution to families of victims, received from the company. In case of fatalities this contribution is hardly enough to pay for the funeral costs. Fig. 3 provides an overview of the amounts paid per body part in 1907 ($100 in 1907 equals $2050 nowadays). This picture is part of Eastman’s publication and represents Meunier’s statue, the puddler from 1890.

Fig. 1. The road to happiness, Safety First Movement, 1913, from Aldrich (1997).

Fig. 2. Child labour in America by Lewis Hine (Freedman, 1994).
1. Occupational accidents occur as frequently amongst educated white Americans, as amongst uneducated immigrants.

2. The common opinion of workers as well as foremen that 95% of the accidents are caused by their victims implies that every accident is seen as a unique event. As a consequence the necessity for prevention is absent.

3. The analysis of accidents shows the repeated occurrence or same types of accidents. Many of these accidents are preventable.

4. The foremen and the superintendents are primarily responsible for safety. This is the result of a sharp distinction between those who are in the position of authority and the worker. Most foremen are sending inexperienced workers to dangerous places, because they are cowards and would not go themselves, as a result of high production demands, or because of indifference.

5. In the fast majority of the cases, the financial burden of accidents is shifted towards the families of the victims.

6. The consequences of these accidents are a big social waste. From a point of view of social justice legislation is needed to prevent these accidents and to manage the financial consequences.

The most important causes of occupational fatalities in the steel industry and presented in Table 1. For the first time in the United States insight is presented in dominant accident scenario’s, as a necessary towards prevention strategies. And the table shows the prominent position of scenario’s related to cranes, trains, heights and high temperatures, as is expected in an environment of a steel works.

The responsibility of occupational accidents, reflected in conclusion 2 and 4, is classified by Eastman, using five different categories (Table 2). Out of the 526 occupational fatalities, information could be obtained from 410 cases. The first two are the victim and their fellow worker. Inattention plays a dominant role. Later in the report this ‘inattention’ is put in perspective, as most of the victims are young children, or workers not aware of the dangers encountered. For those cases the third category of foreman was used. Accidents of the fourth group, the employer, are the result of machine disturbances, machine design, insufficient inspection, and a high speed of production and working pressure. Also accidents due to the organisation of the work and an insufficient guarding against moving parts of machinery are part of this group.

The last group of accident are those where no direct cause could be assigned to. The results show that victim’s responsibility in fatal occupational accidents is much smaller than commonly understood and advocated by the Safety First Movement. The list of categories in Table 1 and the responsibilities in Table 2 are starting point for prevention. Twenty years later these arguments are repeated in a review article of the head of the medical services of the International Labour Office (ILO) in Geneva (Carozzi and Stocker, 1932).

Many scientific journals were full of praise on Eastman’s publication, and specially admired the scientific approach adopted (Anonymous, 1911a; Abbot, 1911; Deibler, 1911; Martin, 1911; Nearing, 1911). And in a later publication, Eastman is advocating a thorough accident investigation method, an extensive safety supervision by the government and a liability system which will reward prevention activities and punishes employers who do not take safety seriously (Eastman, 1911).

2.3. Safety initiatives and publications

The focus on occupational safety appears in a period of time of a rapidly growing rationalisation and mechanisation of production processes, with a central role of Fredrick Taylor’s publication ‘The Principles of Scientific Management’ (Taylor, 1911). ‘Scientific’ in
In this context, is referring to a decision making process based upon rational arguments. Taylor’s message is relatively simple, and revolutionary in that time; managers are the centre of decision making, and with methods which are described as scientific, the production must be controlled with catchwords as ‘selection, training, task analysis and design, time studies and control’. The stopwatch is used as ‘scientific’ method for the time and motion studies. Tasks of workers are cut down to the smallest possible subtasks, are documented, transformed into procedures, and linked to a salary system. The increasing of the speed of work, reduction of costs, and a far-reaching separation of manual labour and brainwork are the main characteristics of this change. This radical change in the American and European industry, leading to the introduction of conveyor belts and mass production, has had a clear effect on the publications on occupational safety.

The Safety First Movement, the Pittsburgh survey and the media attention has given rise to much safety related initiatives, and the connection between safety and production efficiency is gaining ground. Slowly the assumption of the inevitability of occupational accidents is changing. In 1910 a review appears for the Carnegie Steel Company, with 54 references of American and some European publications on occupational accidents, both in industry, mining, railways, as on fire prevention, safety technique, and first aid techniques (Anonymous, 1910). The publications on occupational safety pay a lot of attention to safety technique, the engineering approach towards accidents with its attention to technical measures, predominantly enclosures of moving parts of machines. The first American pamphlet on occupational safety includes this topic together with illustrations of safety devices for steam boilers, electrical apparatus, and elevators (Law and Newell, 1909).

In 1911 the American Museum of Safety is opening its doors, and the museum is organising safety initiatives, such as a professional journal ‘Safety’, national safety congresses, and safety medals for companies with best safety practice examples (Anonymous, 1928a,b; Palmer, 1926). Also within companies various local initiatives started to emerge, like suggestion boxes with prizes for safety suggestions, safety contests, safety boards and bulletins with examples of accidents, and safety scores at entrance gates (Fig. 5).

With the start of the National Safety Council in 1912, established by private companies, professional associations of engineers, and insurance companies, the Safety First Movement is gaining momentum. Unions are not involved in this initiative. They are scarcely active in the domain of occupational safety, with the United Mine Workers’ Union as the only exception (Berman, 1978). The Council is starting as a focal point for safety related initiatives, and is comparable with the British Royal Society for the Prevention of Accidents (RoSPA), starting in 1916, and the Dutch Safety Museum, opening its doors in 1893 (Anonymous, 1891, 1914a; Zwaard, 2007; RoSPA, 2008).

Occupational safety is translated by the National Safety Council into a ‘3-E-slogan’, referring to Engineering, Education and Enforcement. Mechanical safety devices have to be designed, workers have to be trained to work safely, and safety is documented by the employer in rules and procedures, while compliance is monitored through supervision. General safety rules for all workers are announced through posters (Fig. 6) and safety boards and bulletins. These rules and posters stress behavioural aspects of safety.

### Table 1
Order of industrial fatalities in the steel industry in 1907 (*n* = 195), Pittsburgh survey.

<table>
<thead>
<tr>
<th>Categories of accidents as % of total accidents</th>
<th>1 Catch by crane activities</th>
<th>2 Catch by machines, trains</th>
<th>3 Falling from heights</th>
<th>4 Hit by explosion, hot metal</th>
<th>5 Contact with and loading of metal and steel products</th>
<th>6 Contact with electricity</th>
<th>7 Exposure to furnace gas (CO)</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Catch by crane activities</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>2 Catch by machines, trains</td>
<td></td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Falling from heights</td>
<td></td>
<td></td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Hit by explosion, hot metal</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Contact with and loading of metal and steel products</td>
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<td></td>
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<td></td>
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<tr>
<td>6 Contact with electricity</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>7 Exposure to furnace gas (CO)</td>
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<td></td>
</tr>
</tbody>
</table>

### Table 2
Responsibility for industrial fatalities (*n* = 410), Pittsburgh survey.

<table>
<thead>
<tr>
<th>Indication of entire or partly responsibility as % of total accidents</th>
<th>26</th>
<th>12</th>
<th>10</th>
<th>29</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victim</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fellow worker</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreman</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employer</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None of the above</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4. Death calendar, Pittsburgh survey.
Next to general rules, task and machine specific safety procedures do appear as safety codes. This focus on safety codes and procedures is in line with the documentation of tasks and working procedures, initiated by Taylorism. Compliance with the safety rules is the job of the foreman, and not of the safety officer of the company. The special position of the foreman in safety is emphasized in all publications; he is the key to the workers. If a foreman is not convinced of safety it is like banging one’s head against a brick wall (see also Greenwood, 1934). Together with control and supervision, occupational safety is put in the centre of management activities. This will become the main message of the Safety First Movement; laws and regulations will only have limited effect on occupational safety as long as an active support from management is missing. DuPont even goes so far, that any injury is an expression of a failing operational management (DeBlois, 1919).

In the upcoming safety publications in the United States there are three dominant topics: the financial compensation of accidents, safety technique, and (safety) management. Publications on financial compensation have a legal focus. Stimulated by Eastman’s results and her call to manage the financial consequences of accidents, authors are visiting Europe to get informed on national compensation systems. The UK is seen as a minor example, and Germany will receive a lot of attention during these visits, because every occupational accident in this country, irrespective its cause, will be compensated. The Americans notice with surprise the impressive growth figures of the German industry, despite the high collective costs of the compensation insurance (Blanchard, 1917; Hoffman, 1909; Page et al., 1910; Schwedtman and Emery, 1911; Villard, 1913). The same topic has been addressed from a worker, and a union perspective, illustrated with cases of (financially) hopeless conditions of families of workers, who suffer from
accidents, or are killed on the job (Dunn, 1929; Eastman, 1908; Hard, 1910; Mitchell, 1911).

The second group is dealing with safety technique topics, and are professional publications from specific branches of industry. The state of the art of safety technique is described and illustrated with photos. The engineering approach is dominant in these publications (Anonymous, 1913, 1914b,c; Ashe, 1917; Beyer, 1916; Cowee, 1916; DeBlois, 1926; Heinrich, 1931). The publication of reference books were published in the period before World War II (Anonymous, 1914b,c; Ashe, 1917; Beyer, 1916; van Schaack, 1917; Williams, 1927).

The last group are reference books, with both a general overview of safety technique and not restricted to a particular branch of industry, as well as extended discourse on organising safety in companies. Nowadays we would use the term ‘safety management’, but in these publications the term is not used as such. Three reference books were published in the period before World War II (Cowee, 1916; DeBlois, 1926; Heinrich, 1931). The publication of these reference books is another sign of professionalization of the safety domain. Safety, and more specifically occupational safety, no longer is a chapter in a book on social medicine, but has achieved an independent status as a discipline.

2.4. Safety as a precondition for an efficient production

The biggest impact of occupational safety has been its capitalisation, by focussing on the costs of the lack of safety. The huge costs of the frequently occurring accidents are a repeating theme in all publications, and a hot issue for insurance companies. Beyer (1916) and Blanchard (1917) are explicitly pointing at the hidden costs of these accidents, including the loss of production, the replacement of workers, the costs of the care of the victim, and the possible legal costs in case of a complaint against the employer. The production is disturbed by accidents, and a high level of safety in a company is seen as a determinant of an efficient production, and a high quality of products produced (Beyer, 1917; American Engineering Council, 1928). In DeBlois’ reference book this is formulated rather explicit:

‘Process disturbances, for instance products jumping out of presses, occurring unexpectedly, and should be regarded as accidents, for many times these conditions do cause injuries of workers. Whether this happens or not, accidents and efficiency are each other’s opposites. You cannot have them both in your company. A company with unexpected process disturbances is by definition not efficient’ (Citation of Williams in DeBlois, 1926).

The American Engineering Council has published similar results in their 1928 report ‘Safety and Production’. The survey amongst 14,000 companies has shown a strong correlation between occupational safety and the efficiency of industrial production (Aldrich, 1997; American Engineering Council, 1928; Tolman, 1928).

Professionalism is further taking shape as the American Society of Safety Engineers, established in 1911 from the insurance branch, is merging with the National Safety Council in 1925. A differentiation of safety relevant information is taking place. Following examples of German insurance companies, the US Bureau of Statistics and American insurance companies are developing risk measures. Lost time accidents, for instance, are defined as accidents with a minimum of at least one lost day. And injury frequency rates are obtained by dividing the total number of accidents by the total number of hours of exposure. These measures of safety are being accepted generally, and relative simple forms of benchmarking between companies are becoming possible. A second development is the classification of causes and consequence. This classification can be considered as the start of a scenario based analysis in a rising domain (Anonymous, 1920, 1921, 1926b). Also safety codes are undergoing quite some changes, mostly because of the experience of World War I has emphasized the importance of standardisation. In 1919 the National Safety Council together with the Bureau of Standardisation are starting this operation, and 40 different codes for various machines and equipment have been developed. Public hearings are used to decide on these codes (Groeneveld, 1948; Williams, 1927).

2.5. American reference books, George Alvin Cowee (1887–1975)

The first reference book on occupational safety of Cowee, ‘Practical safety, methods and devices, manufacturing and engineering’, is published a few years after the foundation of the Council (Cowee, 1916). Cowee is manager of the safety department of the Utica Mutual Compensation Insurance Corporation. Apart from the topic of occupational accidents, Cowee has published on insurance issues as well as on stock markets (Cowee, 1911, 1931, 1938, 1942, 1960). Most probably, occupational safety only has his attention for a limited period of time.

The reference book is an extensive review on the status of safety technique in dangerous branches, among which the construction sector, metal and steel industry, and mining, together with a limited number of hazards, like fire, explosives, and electricity. Detailed information on causes of accidents is not discussed, and in Cowee’s opinion workers behaviour is a dominant factor in accident causation, by stating that 30% of all occupational accidents are preventable by guarding dangerous parts of machines, while for 60% of the accidents education is the route to prevention. The origin of these percentages and this division is unclear, but his message is close to the one of the National Safety Council, focuses on reckless behaviour of workers, who need to be educated to work safely in a mechanical environment. Safe work should be a habit, a message which resembles the today’s slogan of ‘you do it safely or not at all’ (Anonymous, 1914b; Ashe, 1917; Beyer, 1916; van Schaack, 1917).

Cowee addresses safety management by extensively explaining both the role and organisation of safety committees. These commissions should meet without the presence of a superior, and rotate chairmanship on a monthly basis. The aim of the commission is to spot unsafe conditions in factories and work places and to report these to the plant’s safety committee.
Reckless behaviour of workers is a topic in quite a few publications. The first American pamphlet on occupational and public safety is stressing care and faithfulness as main defences against accidents (West, 1908). Some publications adopt the view that recklessness is just a part of men's nature. To ask workers to work safely is hardly effective, nor are repeated warnings with a similar message. Instead, experiences from accidents should quickly be translated into 'lessons learned', to teach the worker he will be the loser in case of an accident (Anonymous, 1913). But there is also some counterpoise. Reckless behaviour of workers is not a cause of accidents, but a consequence of the increased speed of production, monotonous work, and long working hours of 70–80 h a week or more. Reckless behaviour of workers is nothing more than a state of chronic exhaustion (Bogardus, 1911a,b; Lee, 1919; Muntz, 1932; Myers, 1915; Whitney, 1925). Employers are never accused of reckless behaviour, while they are responsible for the choice of machinery, the selection of raw materials and the frequency of maintenance (Eastman, 1908).


Lewis DeBlois reference book is the second one and titled 'Industrial safety organization for executives and engineers' (DeBlois, 1926). DeBlois worked as chairman of the safety commission of the DuPont de Nemours department 'high explosives', and later as chairman of the central safety commission of the company. In 1929 he was elected the 9th president of the National Safety Council. Compared to Cowee, DeBlois is rather outspoken on the management role in occupational safety, on the reliability of accident figures and on causes of accidents. Different from other publications, DeBlois is arguing a central role of the company's manager and his prime responsibility for occupational safety. Frequently percentages like 75–90% are quoted for the contribution of the victim's behaviour to accidents. That might be, according to DeBlois, but when repeated accidents are occurring, apparently management has not taken the topic seriously, and no action is taken. The employer should propagate the safety message by his attitude and behaviour, and become the leader of safety, just like he is the leader in other topics. He must show personal commitment and regularly repeat his safety message.

The term 'Safety First Movement' is not use in DeBlois' book. If this expression is taken literally, it will induce the behaviour of a coward. Risks and risk taking is an essential part of the upbringing, this expression is taken literally, it will induce the behaviour of a coward. Risks and risk taking is an essential part of the upbringing, which either direct, or on the long term, will cause harm and damage. Hazard is the starting point of an accident, and hazard is equivalent for potential of kinetic energy, or can be of a mechanical, electrical of chemical nature. The chain of events is further subdivided into the release of energy, and in causes of harm, the direct cause of received harm. Examples of long term effects are decisions of management and foremen, which address safety insufficiently. Furthermore DeBlois is introducing the terms of probability and exposure. Probability is nothing more than common sense reduced to calculation. It determines with exactness what a well balanced mind perceives by a kind of instinct, without being aware of the details of the accident process. Exposure is exposure to a hazard. The probability for an accident might be low, but if the exposure is high, the chance of an accident increases. Also the rules for prevention are quite easy. Primarily prevention must be found in the reduction of hazards, by reducing speed, mass, pressure, temperature, replace chemicals or by other means to stop the release of energy. A second method of prevention is the reduction of exposure, like for instance the guarding of moving parts of machinery. Prevention by control measures to reduce harm is in general less effective than the other two strategies.

Finally DeBlois is making some remarks on psychological tests to select workers for specific jobs and tasks. In the army these tests are applied, and they might be used to select accident prone workers. Without referring to the British research on accident proneness, the topic of the next chapter, he mentions the experimental stage of tests, which will make the tests not suitable yet for application in an industrial setting.


Heinrich, a known name in safety, has made the costs of accidents manageable for insurance companies. The third reference book on occupational safety, Heinrich's 1931 'Industrial accident prevention, a scientific approach' is also using the term 'scientific', like Taylor. This term should not be taken too literally, because it refers to an approach based upon facts instead of beliefs. Heinrich is working as an assistant superintendent at the Engineering and Inspection Division of Travelers Insurance Company. The content of this reference book is basically a summary of previous publications and textbooks by other authors. The state of the art on safety technique is presented, and like DeBlois he supports a management approach, and makes a clear distinction between causes and consequences of accidents. Heinrich's main contribution is the numerical presentation on accident costs, on causes of accidents and on accident mechanisms. The hidden costs of accidents, mentioned earlier by Blanchard (1917), are a 1:4 ratio (Heinrich, 1927). These hidden costs are four times higher than costs on compensation, and consist of similar groups as those in the publications of Beyer and of Blanchard. A second ratio relates to the causes of accidents. And the percentages presented deviate from those of Cowee. According to Heinrich 98% of all accidents are preventable, 10% through improved technique, 8% are the result of unsafe acts of workers, and to a much lesser extend of the foreman. This way his famous 88:10:2 ratio is born, illustrated in his 1941 edition of his textbook by the metaphor of falling domino stones (Heinrich, 1941). The other 2% of accidents are not preventable,
and should be regarded as ‘acts of God’ (Heinrich, 1928). Finally he presented a ratio for an accident mechanism: 1 (major injury): 29 (minor injury): 300 (no injury). In later publications this ratio is transformed into another metaphor, the well known iceberg (Heinrich, 1929). No justification of his ratios is given in his work, or any information on the quality and origin of the data behind these ratios.

Like DeBlois, also Heinrich is paying attention to psychological aspects of occupational safety. He is referring to the results of surveys sponsored by the British Industrial Fatigue Board, more specifically to the accident proneness theory and the tests to select accident prone workers (for details see the paragraph ‘the accident proneness theory’ hereafter). The results are hopeful, but still in its initial stage, according to the author.

3. United Kingdom

Different from the United States, in the United Kingdom the topic of occupational safety is not initiated by market parties, like insurance companies and big industries, but by the government. The British publications are not only more limited in number, but also different in nature. Two reference books have been published in the period till World War II, a practical guide to safeguarding (Calder, 1899), and an state of the art of safety research conducted by the Industrial Fatigue Board (Vernon, 1936). The focus on research is a typical British approach to occupational safety in that period of time. This contrasts the American efforts, with their more applied and managerial interpretation of occupational safety. The Pittsburgh survey, of course, is the notable exception. The scientific focus is initiated by a governmental committee investigating industrial fatigue. Already in 1904 such a committee has reported to the government on the large numbers of rejections on physical grounds of recruits to the army during the second Boer War (1899–1901). The conclusion has pointed at the ‘physical deterioration’, caused by several factors, as the nature and conditions of industrial work, and general living conditions (McIvor, 1987). And in its advice a scientific enquiry into the physiological causation and effects of over-fatigue is recommended. It would take another war before these inquiries would start. In 1915 the government has formed the Health of Munitions Workers Committee, which combined representatives of the medical profession, academics, labour, employers, the Factory Inspectorate and the government. This committee has been active till 1918, and is transformed to the Industrial Fatigue Board, a governmental research organization on a permanent basis to continue the work started by the Health of Munitions Workers Committee. In 1929 the Board is renamed the Industrial Health Research Board.

3.1. British reference books, John Calder, 1899

Calder’s contribution to occupational safety ‘Prevention of factory accidents, being an account of manufacturing industry and accident and a practical guide to the law on safeguarding, safe-working, and safe-construction of factory machinery, plant and premises’ is the first British book on the topic. Calder is an engineer and inspector of factory for the North of Scotland, and in the introductory chapter he is noticing a complete absence of any literature dealing with the practical aspects of industrial accident prevention (Calder, 1899). The main part of the book is dealing with legislation and with prevention, safeguarding of machines and installations in various industries, and illustrated with drawings. An example of safeguarding of a vertical engine is pictured in Fig. 8, preventing workers from falling and getting caught in moving parts of the engine.

![Fig. 8. Fencing of a vertical engine for blowing and pumping, from Calder (1899).](image)

Like the early American publications there is only limited attention to causes of accidents. A combination of ignorance, carelessness and unsuitable clothing of workers are the first causes mentioned. Calder specifically is mentioning occupiers and foremen of factories, as well as many workers who are unaware of the nature of the forces and mechanical ‘arrangements’ which they have to control and can result in danger and accidents with often serious consequences. A second group of causes are insufficient lighting leading to falls, defect and badly designed machinery, and of course the absence of adequate safeguarding.

Calder also provides ample information on all registered factories and workshops in the United Kingdom, divided by trade, by workers employed (sex and age), accidents and accident rates. This leads to an explosion of numbers, a characteristic of many 19th century publications. All accidents, fatal and non-fatal, are tabulated according to the direct cause, or the consequences of the accident (Table 3).

3.2. Susceptible workers, 1919

Like in the United States, also in the United Kingdom national accident registrations has shown an alarming rise in accidents in industry during World War I. A number of explanations are given for this growth in accidents, like the increased level of mechanisation, and consequently the high speed of production, the introduction of new dangers, and the long working hours. Another argument has been the war conditions of the industry. While most men have been recruited by the army, there has been a massive influx of women, young and elder workers in the industry. These groups of workers are considered less competent by definition. And enquiries are started to study the influence Taylorism, not
only on the productivity of munitions workers but also in the incidence of accidents. A number of studies have been conducted, investigating perceived causes. But, according to the Industrial Fatigue Board, first of all the distribution of accidents amongst workers in hazardous professions is a prime point of focus.

The question to be answered is whether or not industrial accidents are equally distributed amongst workers, or limited to a specific group of workers. This question has been the starting point for the epidemiologist Major Greenwood and his assistant Hilda Woods of the British Ministry of Munitions (Greenwood and Wood, 1919). It is the first British published research on occupational accidents and has been conducted amongst women, working at munitions factories during the last 2 years of World War I. The population of the survey consists of 3889 women from 10 different factories. Only in two factories, all women have been included, at all other factories a random sample of women has participated in the survey. The period of the survey varies between 2 and 5 months and apart from the number of accidents, information on the location of the women working has been known for a limited number of factories; either heavy lathe operation, or profiling operation. Three different hypotheses have been tested by a statistical analysis on the number of accidents:

1. The distribution of accidents is guided by chance, and an exposed population on equal risks has an equal risk on industrial accidents.
2. All members of an exposed population have an equal risk on accidents. Only after the first accident, the chances on following accidents will change. The chance is either increased (accidents are contagious), or decreased (workers become more careful).
3. The chance on accidents and repeated accidents is not equally distributed in an exposed population. There are clumsy, awkward workers, and prudent workers.

The different hypotheses will give a different distribution of accidents over the population exposed. By the first one, a Poisson distribution is expected, and the third one will produce a negative binominal distribution. The second hypothesis generates a distribution different from the first and the third. Anyhow, the contagious view on accidents does look rather similar to the third hypothesis. Authors have defended the research by pointing out the determinants of accidents, both external as well as individual factors of workers. The survey only resulted in a rather vague definition of 'susceptible workers', only defined as a stable trait belonging to a person. And it is not even clear if all people who are accident prone are so for the same reason. Nevertheless, from the 1920s onwards the 1919 article of Greenwood and Woods becomes a standard publication, referred by many researchers in the field.

### 3.3. Occupational physicians and accident during the interbellum

From the 1920s onwards also occupational physicians are becoming interested in accidents by making a comparison between occupational accidents and two other major causes of death; cancer and phthisis, a then known name for tuberculosis. The incidence of accidents in professions investigated is 3.2 per 1000 workers (0.3–3.5), while cancer has an incidence of 2.0 (0.4–2.3), and phthisis 4.6 (1.0–5.6). Traditionally, reference books on occupational medicine, which started to appear around the turn of the century, did not pay any noticeable attention to occupational safety (see for instance Arlidge, 1892; Oliver, 1902). This is changing in the 1920s. Greenwood writes with the physician Collis an extensive work 'The health of the industrial worker', and the physicians Hope, Hanna and Stallybrass publish a similar work 'Industrial health and medicine' (Collis and Greenwood, 1921; Hope et al., 1923). Both works contain extensive chapters on occupational accidents, financial compensation of victims, and prevention. The state of the art on safety technique is presented and illustrated with photo materials, and there is ample attention to determinants of accidents, both external as well as individual

### Table 4

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<tr>
<th>Categories of accidents as % of the total accidents</th>
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<tr>
<td>Fatal</td>
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<td>7</td>
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<tr>
<td>8</td>
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<tr>
<td>9</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>
3.4. Accident proneness

In 1925, the psychologist Eric Farmer introduced the term ‘accident proneness’ in his paper to develop differential tests for susceptible workers. From that time onwards, accident proneness became the indication of the safety theory which explained accident by the individual hypothesis. At the same time, independently the same concept of ‘unfallneigung’ (accident proneness) and the ‘unfäller’ (accident prone worker) is developed in Germany by Karl Marbe. Marbe is a psychologist from the Würzburg University, using the accident reports of the Berufsgenossenschaften, the German accident insurance (Burnham, 2008; Farmer, 1925; Hale and Hale, 1972; Marbe, 1925). Both Marbe and Farmer are developing tests to select the unfäller, or the accident prone workers, and to exclude them from dangerous work. This method of selection has become possible through developments in psycho-technique, an applied form of psychology. During World War I their tests have been utilized on a larger scale for pilot selection and have found applications in trade and industry (Anonymous, 1973; Hoorn van et al., 1980; Lochem, 1943). Farmer and colleagues have developed a so-called aesteto-kinetic battery of tests, testing the capacity of coordination and concentration of workers. These accident prone workers are acting faster than they think, and tests can detect this impulsive behaviour which is an important cause for accidents (Farmer and Chambers, 1926, 1929, 1939; Farmer et al., 1933; Farmer, 1940, 1942). These tests have been applied in various populations, like apprentices of the marines and the army, London bus drivers, shipwrights, mechanics, and electricians. With an exposed population, varying between 650 and 1843 workers, and a sample time between 12 weeks and 5 years, the results only showed a rather low correlation of 0.2–0.4 between the test results and accidents. Researchers could not conclude otherwise that accident proneness is dependent on many different factors, which are not quite well understood.

3.5. British reference books during the interbellum, Horace Middleton Vernon (1870–1951)

The title of Vernon’s reference book ‘Accidents and their prevention’ (Vernon, 1936) refers to an engineering approach. But Vernon is not an engineer. He has academic qualifications in chemistry, physiology, biology and medicine. In 1915 he has worked in a munitions factory at Birmingham, which has raised his interest in occupational safety. He has joined the Health of Munitions Workers Committee, as well as its later successors. His work is remarkable, because not only industrial and mine safety is the topic of his book, but also the transport sector, including road transport, and safety at home. The contribution to lethal accidents of these last two sectors is much higher than industry. Of the 17,000 registered fatalities in 1932, 43% is accounted for by the transport sector, one third is domestic and only 9% industrial.

The influence of environmental causes of accidents is an important theme of Vernon’s research and his book, like the influence of temperature, fatigue, speed of production, ventilation and alcohol consumption (Bedford, 1951; Osborne et al., 1922; Smith, 1951; Vernon, 1919, 1920). He is referring to Marbe’s work as well as to Heinrich, but is rather critical on tests developed by Farmer. For workers these tests are not reliable at all, while for traffic and railway the results are much more positive. But he still has the opinion the human factor is a major contributor to accidents. Defects on machinery are relatively easy to repair, and also his work provides detailed information on safety technique. The influence of human behaviour is much more complicated and the organisation of work should be a starting point for prevention, more specifically the safety committees, as introduced in the United States. These safety committees should keep the interest of safety alive amongst managers and workers, train workers in safe-working methods, and conduct safety inspections at the shop floor. Especially this last point is important to Vernon, because legislation without any form of inspection hardly makes any sense at all.

3.6. Criticism on the accident proneness theory

The accident proneness theory has encountered many comments in scientific literature. This is not only limited to comments on low correlations between test results and accident figures, or the fact that a correlation is not a proof of a causal relation. The comments focus on the statistical approach chosen. The distribution of accidents of a group of people in a period of time normally follows a J-curve. By a chance distribution one expects that some persons will experience a more than average number of accidents, while amongst others much less accidents will occur. Most probably the number of accidents will be lower than the number of workers if the exposed population is large – a few hundred workers and a survey period limited to weeks or a few years. One expects that a limited number of workers will experience a large part of the accidents, and there is no psychological factor involved what so ever. The length of the survey period is one of the main points of criticism. Also the research is retrospective by definition, based upon accident registrations of companies. The reliability of the information of these registrations is limited. Another argument is the vagueness of the definitions used. An accident prone worker is very difficult to define in scientific terms, and this problem becomes apparent in the low correlations between the different tests. Furthermore the individual hypothesis is using the concept of homogeneity, both for groups studied as for exposure to hazards and risks. This concept is disputed, and it is very unlikely that workers with the same job will encounter the same hazards, and identical risks. This argument hits a rather fundamental point. Only one factor has been taken into account as an explanation for accident causality. None of the research reports on accident prone workers provide any information on the accidents considered. The focus is only on the consequences of accidents, bodily harm, and the psychological stability of the victim. These comments appear in the scientific press just before and after World War II and discredit the individual hypothesis (Anonymous, 1952, 1964; Arbous and Kerrich, 1951; Burger et al., 1974; Cameron, 1975; Froggatt and Smiley, 1964; Guarnieri, 1992; Hale and Hale, 1970, 1972; Vernon, 1936; Webb, 1955; Winsemius, 1951).

4. The Netherlands

Although there is a documented attention for working conditions and occupational safety in The Netherlands before the 1887
Parliamentary Enquête, as is described in the introduction of this article, the results of the Enquête created a chain of initiatives. One of them being the 1890 national exhibition 'To promote safety and health in factories and workplaces', organised in the Amsterdam 'Paleis van de Volksvlijt' (Palace of popular diligence) (Zwaard, 2007). With more than a million visitors the exhibition is a big success, and numerous examples of practical safety technique are shown, both from industry, agriculture and mining. Another initiative is the foundation of the Nederlandse Vereeniging tot Voorkomend van Ongelukken in Fabrieken en Werkplaatsen (Dutch Society to Prevent Accidents in Factories and Workshops), also mentioned in the introduction. This society serves as a meeting point for national and local entrepreneurs, politicians and scientists (Bakker and Berkers, 1995), and is the initiator of the Safety Museum in Amsterdam. This museum opens its gates in 1893 with a permanent exposition of safety technique, and starts around 20 years earlier than similar initiatives in the United States and the United Kingdom. Partly financed by the state, provinces and the local authority of Amsterdam, safety propaganda has been one of the first activities, followed by training programs for employers, employees, and civil servants of the Labour Inspectorate. Legal requirements of the 1895 Safety Law are one of the topics of these courses, and advice and the rationale behind adequate safety equipment, and procedures. Especially civil servants of the Labour Inspectorate are encountering resistance and difficulties with employers regularly, who find the regulations often impractical and needlessly expensive. The museum offers the opportunity to test consequences of recommendations, and to enhance the quality of their inspections (Anonymous, 1914a).

Around the turn of the century, two men have played a dominant role in the discussions on occupational safety: the engineer Frederik Westerouwen van Meeteren, and the physician and hygienist Louis Heijermans. The contribution of both men will be described in the following paragraphs.

4.1. Frederik Westerouwen van Meeteren (1851–1904)

The reference book of Westerouwen van Meeteren is a combination of occupational medicine and occupational safety. Westerouwen van Meeteren has been an independent advisor on safety and health in factories and workshops for most of his career. In 1891 he is appointed as technical advisor to the '2e afdeling van de Eerste Verzekerrinsmaatschappij op het Leven en tegen Invaliditeit' (2nd department of the First Insurance Company for Life and against Invalidity), and is responsible for factory inspections. Being a technician himself, he justifies the medical focus from an efficiency point of view. To remove health hazards is much more effective than safety hazards. Health hazards will affect much more employes than safety hazards only will have consequences for one or a very limited number of workers, only for those standing close by, and will come in contact with hazards. This point of view also reflects the position of occupational medicine, which in West European countries at the end of the 19th century is an upcoming and strong field of research compared to occupational safety. Like Calder’s reference book, Westerouwen van Meeteren’s book is full of information on legislation, and on numbers, reporting all registered fatal and non-fatal accidents in various trades, installations and machines for the period 1890–1891. While no knowledge is present on the number of workers per trade, consequently accident rates are absent and only absolute numbers are presented. Mechanical causes of accidents are mentioned, moving parts of machines, and apart from general observations on lighting, working hours, ventilation and temperature, there are quite some illustrations on various examples of safety technique. Surprisingly there is no reference to qualities of workers, like ignorance and carelessness.

4.2. Louis Heijermans (1873–1938)

Quality of workers is an item for Heijermans, known in The Netherlands for his magnum opus ‘Handleiding tot de kennis der beroepsvielkiten’ (reference book on the knowledge on occupational diseases) (Heijermans, 1908) and his big volume of publications on public and occupational health issues both in the professional and scientific press. In the beginning of his career Heijermans has written a few publications on occupational safety, ventilating a quite outspoken opinion, based upon his frequent observation in factories and workshops. He is quoting three main causes for occupational accidents in his book ‘Gezondheidsleer voor arbeiders’ (hygiene for workers) (Heijermans, 1905). The first cause is the worker himself, which is the common opinion, referring to an indifferent and careless attitude of the victim. This argument is put into perspective by Heijermans by pointing out that indifference is the consequence of daily confrontations with danger. A second cause is the tasks workers have to perform, which are so stupid and monotonous that it will kill all energy and transforms workers into machines. The last cause is the long and soul-destroying working hours, which will make workers indifferent to danger. These arguments are in line with the Eastman’s results, a few years later.

Based upon the accident information of the Factory Inspectorate a list of the categories of major accidents is presented (Table 5).

The dominant role of power tools and installations by accidents is also confirmed by the Centrale Werkgevers Risico-Bank (central employers; risk bank) (Hasselt, 1907; Valk, 2007). This private initiative of employers is one of the biggest insurers of workmen’s compensation, and has to spend approximately 50% of its payments on this type of accident.

Heijermans is warning for too much trust in messages of safety posters. The texts on the posters are badly understood by workers, who hardly have received any education and suffer from the discomfort caused by the preventive measures installed (Heijermans, 1907). Also the lack of attention during the construction and design of installations is questioned (see also Anonymous, 1909, 1911b; Vossnack, 1913). And with the engineers of the Central Employers Risk bank the employers’ role is emphasized in preventing accidents by designing or developing machinery which do not cause harm. Seventy five years later a similar vision is propagated at the Technical University in Delft, during the foundation of the Safety Science Group (Goossens, 1981).

4.3. Safety Museum

Following the examples from abroad, the Safety Museum starts to develop other safety initiatives in the 1920s, like publishing a monthly magazine ‘De Veiligheid’ (The Safety Journal), weekly radio presentations on safety related issues, the organisation of national safety conferences, and the design of safety posters. Known artists are asked to produce safety posters, and these posters have become very successful, regarding the growing demand for these

<table>
<thead>
<tr>
<th>Categories of accidents as % of total accidents</th>
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<tbody>
<tr>
<td>1 Falling from heights</td>
<td>20</td>
</tr>
<tr>
<td>2 Hit by falling objects</td>
<td>14</td>
</tr>
<tr>
<td>3 Hit by tools for manipulating metals</td>
<td>6</td>
</tr>
<tr>
<td>4 Hit by tools for manipulating wood</td>
<td>4</td>
</tr>
<tr>
<td>5 Hit by several tools, like grindstones, presses, centrifuges</td>
<td>3</td>
</tr>
<tr>
<td>6 Hit by lifts, winches, cranes</td>
<td>2</td>
</tr>
<tr>
<td>7 Gripped by driving gear, shafts, belts, pulleys, transmissions</td>
<td>2</td>
</tr>
<tr>
<td>8 Gripped by power tools and installations, steam engines, gas engines, etc.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5
Reported accidents (fatal and non-fatal), annual report Dutch Labour Inspectorate 1902 (n = 7400)
items (Anonymous, 1940a). The metaphors in these posters are referring to fear, shame and guilt, and point the audience to the consequences of negligent, reckless and immoral behaviour (Hermans, 2007) (Fig. 9).

With due care, hints to social class differences are being avoided. The topics of the safety posters are limited to known situations on shop floors, of factories, and at home, where safe behaviour of workers can avoid accidents. References to shortcomings of employers are being avoided too, assuming this would have a negative impact on employers' safety efforts. Just like the American posters (Fig. 6) the early posters contain quite some text. While the ones developed later in time, the text is reduced to general safety related remarks and the pictorial presentation becomes more important.

All posters stress the importance of behavioural aspects of accidents. This is in line with the assumption that occupational accidents are relatively simple events, with only one important cause; like not following instructions, or a limited use of personal protective equipment. These two causes are starting points for prevention. Human causes are getting a face by the introduction of 'Jan Ongeluk' (John Accident), a worker which creates dangerous situations frequently, both for himself as for workers around.

4.4. Safety publication

Apart from De Veiligheid, publications on occupational safety either in the professional, or in the scientific press are limited. The Rijksverzekeringsbank, the organisation responsible for the implementation of the Act on industrial injuries, publishes an overview examples of safety technique (Rijksverzekeringsbank, 1914). And the professional safety journal De Veiligheid is publishing a series of articles on accident proneness, referring to German and French safety literature till halfway the 1930s, and from 1936 onwards mostly to British and American publications. There is ample attention for accident proneness and safety educational for workers (Anonymous, 1928, 1936, 1937a,b,c, 1940b; Copius Peerboom, 1941; Gorter, 1935, 1946; Patijn, 1945, 1946; Sievers, 1941; Steiner, 1939; Young, 1946). But there is also a focus on the design related aspects of safety (Copius Peerboom, 1941; Gorter, 1946; Winkel, 1936), and on the American slogan that 'safety pays off' and is equivalent to an efficient industrial production (Anonymous, 1939a,b; Winkel, 1936).

The other publications are a textbook for secondary technical education 'Industrial hygiene and safety technique' (Mesritz and Ree, 1937), and two medical PhD theses, one from the IJmuiden Steel works Hoogovens (Borg ter, 1939) and the other from the Dutch coal mines (Herold, 1945). As in American and British publications the textbook is paying attention to the accident prone worker, and to safety technique. For the first topic, references are made to British and German publications, while for safety technique German references are dominant. This combination of an individual and an environmental explanation of accident causation is also present in the Hoogovens thesis. In the research amongst miners, aesteto-kinetic test, developed by Farmer, are applied. However, the thesis does not present relations between accidents and test results. But still the author is rather positive to change an inherent or obtained disposition for accidents through company trainings and education.

5. Discussion and conclusions

Returning to the first two questions raised in Section 1, two different theories on accident causation have been developed during the first decades of the 20th century. The first theory comes from the United States, from the Pittsburgh survey. This theory, based upon an extensive scenario analysis, supported the environmental

Fig. 9. Examples of Dutch safety posters 1922–1955. 1922 Waarom droeg je geen muts als ik. Loshangende haren bij machines en drijfwerk zijn gevaarlijk (why did you not wear a bonnet, like me. Loose hair is dangerous by machines and driving gears); 1922 Omdat hij voorzichtig was (because he was cautious); 1926 Dat komt ervan als de nooddeur versperd is (that is happening when the emergency door is blocked); 1927 Afleiden leidt tot ongevallen (distraction gives accidents); 1929 Verkeerd stapelen is levensgevaarlijk (wrong piling is perilous); 1931 Er dreigt gevaar (hazard is threatening); Is uw gezin heilig? Werk dan veilig (Do you love your family? Work safely); 1939 Las veilig (weld safely); 1940 Onveilige stempelpersen stanzen, e.d.!! 546 ongevallen per jaar (unsafe stamping press, punching, and the like!! 546 accidents each year); 1942 Werk veilig, denk aan moeder (work safely, think on mother).
hypothesis of external determinants of accidents, the conditions of labour. Eastman, a sociologist, has conducted the research, making an in-depth analysis of 526 accidents in a steel district, and used an extended case study as a research design. Also research by the Industrial Fatigue Board in the United Kingdom in the interbellum has supported the environmental hypothesis. For instance the findings of two physicians, Osborne and Vernon, conducting prospective studies over longer periods of time and linking variations in accident incidence to temperature changes, as well as working hours, speed of production and ventilation. The other theory has used the individual hypothesis as an explanation, and is commonly known as the ‘accident proneness theory’. Both British Industrial Fatigue Board and the Würzburg University in German are the source of this theory. The research is conducted by Greenwood, an epidemiologist, and by Framer and Marble, both psychologists, by applying a statistical analysis to accident data from branch specific, or national accident registrations. This division between a statistical analysis, or one on accident scenarios is also seen in the metaphors developed in this period.

A metaphor is a figure of speech in which a name or a quality is attributed to something to which it has no literally application. They serve a purpose by revealing important viewpoints or perspectives on causes of accidents. Metaphors can stand on their own, or being a pre-theory and a starting point for further validation and leading to a theory, or being a simplification of a complex theory. The period under study has produced quite a few metaphors. One of the first is the country path, the ‘road to happiness’ of the Safety First Movement from 1913, pictured in Fig. 1. Like the ‘country path’, all posters refer to unsafe behaviour, and some are using distinct metaphors. The risk gambler is an example (Fig. 6, 1919), as well as ‘good citizenship’ and ‘family values’ (Fig. 6, 1922, 1939, 1942). The accidents proneness theory is the scientific foundation for the unsafe behaviour metaphor, but Greenwood and Woods publication (1919) does not make a reference to the American safety initiatives. Meaning it is not likely the country path metaphor played any role in the British research. The most powerful metaphor are the ones from Heinrich, his iceberg energy levels and exposure, and introduces the concepts of exposure and health hazards has increased. In this period occupational safety is becoming a topic of concern, due to the high incidence of occupational accidents and fatalities which are interfering with the speed of production, and the costs of these accidents. Occupational safety becomes a professional field of expertise. In the three countries under discussion, organisations devoted to safety start to emerge, as well as professional journals, books devoted to so-called ‘practical safety’ (safety technique), and reference books on safety.

There is a remarkable difference between the United States and the United Kingdom. In the United Kingdom, with its long tradition of Factories Acts, from the start of the 19th century onwards, governmental agencies are leading. There is a strong focus on scientific inquiries on determinants of accidents. This is most likely the reason for the much lower attention to managerial aspects of occupational safety, compared to the United States. In this country not the government, but market parties play a dominant role, like the steel industry and insurance companies. And with the exception of the work of Eastman, and DeBlois, the applied and managerial aspects of occupational safety are dominant. There are also parties involved with compassion for the social movement of that time. Eastman is an example, and her work makes reference to publications of William Hard, a journalist with strong sympathies for the organised labour movement. Also Hard in his 1910 publication refers to the work of Eastman. Lewis Hine is involved as photographer by the Pittsburgh survey, and most likely all authors have been familiar with Upton Sinclair’s book ‘The Jungle’, because of the immediate huge popularity of this book and the influence of the book on 1906 food laws in the United States.

Eastmans’ work is praised in law review journals and journals of political and social sciences, but surprisingly no reference is made to her work in American and British reference book on occupational safety, although the ideas expressed in DeBlois reference book (1926) is a continuation of her concepts. From DeBlois background it is not very likely he would share similar political sympathies. DeBlois makes a few remarkable observations. He postulates the accident process as a sequence of several separate events, describes hazards as various forms of energy, prevention as a reduction of energy levels and exposure, and introduces the concepts of exposure to hazards and probability of accidents, as two separate items. It is clear that Heinrich in the 1931 edition of his reference work, referring to DeBlois, is building on some his ideas. Surprisingly both DeBlois and Heinrich are very cautious on the consequences of the accident proneness theory, the aestheto-kinetic battery of tests to select accident prone workers. Both declare these tests are in an initial stage, and their validity is not proven yet. This means that the practical application of the accident proneness theory for practitioners and business is still under discussion.

Logically there is the question why Heinrich’s name is known even nowadays, while the names of Eastman and DeBlois have disappeared in history. There is not an easy answer to this question, apart from the fact that Heinrich’s ratio’s are easy to understand and to use for prevention and cost calculations. Another argument is the sheer volume of Heinrichs’ output. While Eastman and DeBlois only produced a few publications in a limited period of time, Heinrich is the author of 21 articles between 1927 and 1956, and his book had six editions between 1931 and 1980. He is still the first author of the 1980 edition, while he died in 1962. Apparently his name has the status of a trade mark (Gulijk et al., 2009).

The last question of the introduction is referring to the influence of the development in occupational safety in The Netherlands, This country has never been a frontrunner in occupational safety in the period till World War II. No Safety First Movement has started, nor a body of safety research like in the United Kingdom. The orientation on occupational safety has always been on countries around. In the time of Westerouwen van Meeteren and Heijermans, France
and the German speaking countries are the examples in the period before World War I. Only with the founding of the Safety Museum, the Netherlands is a trendsetter (Vernon, 1936). And the early start of the Dutch Safety Museum is most likely the result of its orientation towards these two countries. In political terms Westerouwen van Meeteren and Heijermans are each other's opposite. The first is the liberal, introducing safety technique in the country, and the second is a socialist, and his ideas on accident causation are very similar to Eastman. Both men only have had a limited influence on the debate on occupational safety in The Netherlands. Westerouwen van Meeteren dies early 20th century, and Heijermans main focus is not occupational safety, but occupational and public health.

Heijermans has produced a scenario analysis of the registered accidents (Table 5). Similar scenario analyses are made by Calder (Table 3), Eastman (Table 1), and Collis and Greenwood (Table 4). The similarity of dominant scenarios is remarkable, and are almost in the same order as the recent conducted survey of Dutch reported accidents (Bellamy et al., 2008). Some scenarios are specific for its time, and accidents resulting from contact with steam, gas, hot metal are only present in the late 19th and early 20th century overviews. It is somewhat dangerous to draw conclusions from this comparison. All tables are based upon absolute numbers of accidents, and not on incident rates, but it seems that dominant accident scenarios from around 100 years ago are still active today.

After World War I the orientation of The Netherlands is directed towards the Anglo-Saxon countries. The Safety Museum is starting projects and publications like oversees museums and safety councils, like the safety posters (see for instance Gorter and Zaalberg, 1926), with a similar message and a similar success as the American examples. Despite the criticism on the accident proneness theory, the theory is still adored by a large section of managers and is regarded as proven beyond any doubt. Most probably it is part of a deep rooted Western, and maybe human thinking: people are responsible for their own safety, and the victim shares the guilt for his or her deeds. Heinrich's ideas on accident causation are introduced in The Netherlands by Heinrich's colleague Lateiner. He has been invited by the director of the Safety Museum of the day in the 1950s, and continued to teach these safety principles at vocational safety education for middle management and safety experts till the 1980s. The influence of general ideas on accident proneness are also seen in the behavioural based safety programs, which have been introduced in industry for the last decades now to reduce the number of accidents. These programs differ from an accident proneness concept, because they are not dealing with congenial qualities explicitly. But their fallacy on mono-causality and their strong focus on worker's behaviour do resemble the old theory from the beginning of the last century (Hopkins, 2006; Swuste and Jongen, 2007).

Over viewing the history of occupational safety, there is of course the question why occupational health becomes a major issue in the 19th century, as stated in various publications, while occupational safety is gaining in importance only in the 20th century? Also this answer is not an easy one. Mechanisation of the production has already started in the United Kingdom during the industrial revolution, and later spreading over Europe and the United States. From the first decades of the 19th century improvements in manufacturing techniques have made machines speedier and more dangerous. And there is a vast migration of workpeople from the countryside to the ugliness of the new industrial towns, with poor housing, overcrowding and lack of sanitation. Inside factories, workshops, and mines workers are exposed to occupational hazards causing diseases and injuries, and to adverse effects of long working hours. The social movement is gaining in strength, unions are organising labour, and epidemics infest industrial areas on a regular basis. In this period, occupational safety and health is becoming a topic, driven by the results of large surveys in major towns on working and living conditions of workers. Throughout the 19th century, several surveys are executed in European countries, like the United Kingdom and The Netherlands, and the United States. It is difficult to understand the prominent position of occupational health from a point of view of exposure, or from the size of the population at risk, an argument for instance used by the Dutch engineer Westerouwen van Meeteren. Both safety and health related hazards must have been present abundantly in factories and workshops, affecting large number of workers. Based upon local and national occupational mortality statistics the influence of noxious chemicals and dusts, like lead, phosphorus, carbon disulfide and other solvents are receiving a great deal of publicity, and leading to the first steps in the causal relation between exposure and effect. Case studies are published, first by medical men known as hygienists, followed by medical researchers at universities, and to a stream of reference books on occupational medicine is emerging from the late 19th century onwards. Occupational medicine has joined in with the attention to public health coincided, once more knowledge became available on the vectors of epidemics, like cholera, occurring in overcrowded parts of towns and factories. Occupational safety, on the other hand, is studied by a more diffuse group of experts, and primarily seen as a factory and workshop problem, staying behind the walls of the premises. Another explanation might be the control measures taken to reduce safety hazards. In early publications, like Thackray's reference book from 1832, fencing, guarding and enclosing is mentioned as an effective prevention to protect workers from falling, getting hit, or stuck by. This safety technique is an example of a common sense engineering approach, based upon accident scenarios, but always combines with remarks on careless behaviour of workers. This makes occupational safety a relative simple issue, while occupational and public health are more complicated by nature, and require extensive research efforts. Not surprisingly occupational safety is the topic of one of the first Factories Acts, like the 1844 Factory Act of the United Kingdom, and the 1895 Dutch Safety Act. For obvious reasons the United Kingdom is frontrunner in these Factories Acts and The Netherlands followed much later. Although there are national differences, these Acts are enforced against a fierce opposition from employers. In the United States these Federal Factories Acts are enforced at a later date. This is not only the result of employers' opposition, which might even be stronger than in Europe, but also the consequence of the State organisation. Each State has a considerable freedom to pursue its own policies for dealing with problems of rapid industrialisation (Ashford, 1976; Schilling, 1981).

Finally there is one can ask what this historical review of occupational safety is teaching us. Apart from the metaphors and theories developed, and its context, the publications studied also show a few slogans which are still in use today. For instance, the request to translate experiences of accidents into easy "lessons learned" (Anonymous, 1913), or the saying that safety should become a habit of workers (Cowee, 1916). Another one is the remark that safety is a line responsibility for the foreman, and the success of safety campaigns in companies depend on his attitude towards the topic, because of his responsibility in the direct supervision of safe behaviour (Greenwood, 1934). These slogans are pointing towards the behavioural aspects of safety. DeBlois (1926) and also Eastman (1910) on the other hand are stressing organisational aspects of safety, which are fairly common today. Process disturbances are a main cause of accidents, and it is managements' responsibility to provide safe production lines. Also, there are many accidents occurring time after time, all following the same scenario. Here managers are to blame instead of workers, as is the case if accident figures in a company remain on a plateau. These remarks should be
a logic consequence of Taylorism, where the manager is set at the centre of decision making. But instead changing workers’ behaviour by education, training and enforcement is the dominant safety mantra of that time. The ories and metaphors from the first part of the 20th century have been the starting point for the development of the field of safety science. Nowadays much progress has been made on human factor research and on the integration of technical, human, organisational and managerial determinants of accidents. This progress is building on the failures and successes of previous times.

References


Anonymous, 1891. Het Veiligheidsmuseum te Amsterdam (The safety museum of Amsterdam). De Ingenieur 9 (41), 378.


Anonymous, 1897b. Nederlandse Vereniging ter voorkoming van ongelukken (Dutch association to prevent accidents). De Ingenieur 13, 153.

Anonymous, 1899. Adres in zake het ongeval-Odigs bij de maatschappi ’Elektra’ te Amsterdam (Address of the accident-Odigs by the company ‘Elektra’ Amsterdam). De Ingenieur 24 (10), 227–229.


Oliver, T., 1902. Dangerous Trades from the Legislative, Social and Medical Point of View. Methem & Co., London.


Sievers, Fr., 1941. Individuele opvoeding van den arbeider tot veiligheid (Individual education of workers to safety). De Veiligheid 18 (7), 120–123.


Steiner, W., 1939. Iets over de psychologie bij het opwekken tot medewerking ter bevordering der veiligheid (Something about the psychology during the call for corporation to enhance safety). De Veiligheid 16 (10), 129–133.


Villard, H., 1913. Workmen’s Accident Insurance in Germany, a Series of Articles. NY.

Vossnack, E., 1913. Het ongeval van de ‘Titanic’en de waterdichte indeling van grote mailboten (The accident of the Titanic and the waterproof compartments of big mailboats). De Ingenieur 28 (13), 223–244.


Young, A., 1946. Het voorkomen van ongevallen in een van de grootste Engelse machinefabrieken (The prevention of accidents in one of the biggest English machine factories). De Veiligheid 22(10), 77–78. 22(12), 93–95.