Conditions of occurrence of major and minor accidents
Urban myths, deviations and accident scenario's

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Trefwoorden: accident scenario's, deviation model

Summary

In the safety world there is a general belief, traceable back to Heinrich in 1931, in the similarity of causes of minor and major accidents. This leads to the belief that one can prevent the major accidents in a company by studying and tackling the minor accidents. The objective of this paper is to show that this general belief is based on careless reasoning and is not supported by the limited research which there is. If indiscriminately applied, it can mislead companies and safety experts into seriously misdirecting safety efforts and can give them unreasonable expectations about the control of risk. Only if reasoning based on an explicit deviation model is carefully applied can clear indicators of potential major accident scenarios be derived and can this pitfall be avoided.

Samenvatting

Binnen de veiligheidskunde wordt in het algemeen aangenomen, dat de oorzaken van kleine en grote ongevallen dezelfde zijn. Dit geloof is terug te voeren op de beweringen van Heinrich in 1931. Dit leidt tot de aanname, dat grote ongevallen in bedrijven te voorkomen zijn door onderzoek naar, en maatregelen tegen kleine ongevallen. In dit artikel wordt gesteld dat deze aanname gebaseerd is op een onzorgvuldige redenering en dat het niet te staven is uit het beperkte onderzoek naar dit onderwerp. Als het onnadenkend toegepast wordt, kan het bedrijven en veiligheidskundigen leiden tot een verkeerde inzet van veiligheidsinvesteringen en tot overtrokken verwachtingen over de mate van beheersing van risico. Alleen als een redenering, gebaseerd op een expliciet afwijkingsmodel, zorgvuldig toegepast wordt kunnen duidelijke indicatoren van potentiële scenario's van grote ongevallen geïdentificeerd worden en kan deze valkuil vermeden worden.

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Origins of the belief

Heinrich [1931] was the first proponent of the similarity of causes of minor and major accidents and summarised his conclusions in his triangle, which has been endlessly copied ever since. Three such triangles are given in figure 1

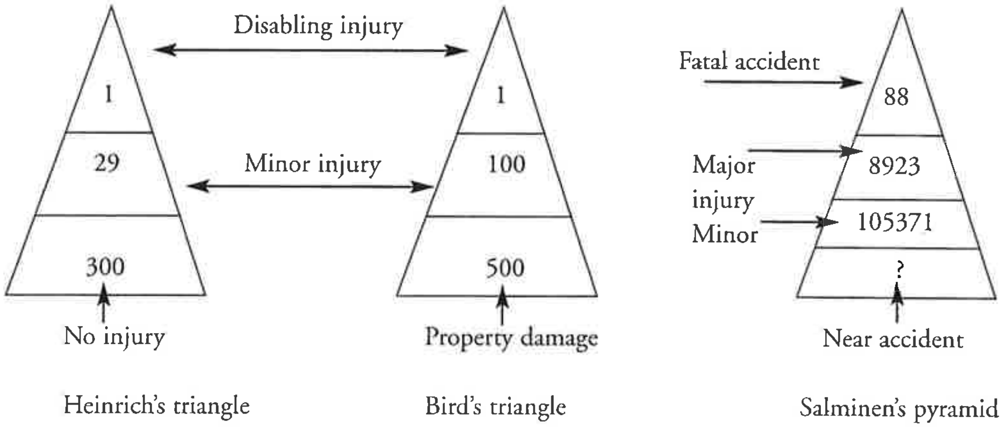

Figure 1. The relation between major, minor and near accidents

Heinrich's triangle is based on his investigations of several thousands of insurance claims of deaths and disabling injuries, the top of his triangle. For each, he looked back at the history of the activity and collected data about previous events during it – minor injuries, near misses and histories of exposure to the hazard. He always found many of these. Heinrich stated that the ratios between the three categories of major and minor accidents and near misses were very variable across all the studies he made, but averaged to the figure he quoted. Bird's triangle [Bird, 1966] is based on accident statistics of all reported events in each category for a whole department or works. The pyramid of Salminen et al. [1992] is for all reported occupational accidents in Finland in one year. Note the shift from thinking in scenarios leading to one major accident to thinking purely in ratios.

The conclusions drawn from the triangles were that:

1. There were many precursors to disabling accidents, if one looked closely enough at an activity. It was therefore not necessary to wait until that accident happened in order to start on prevention. I do not dispute this reasoning, and indeed will return to it later as being the good basis on which to plan prevention.
2. There were many more minor than major accidents. Later safety managers, particularly in the USA, who were focussing on accident costing, used this aspect of the triangles extensively. They wanted to find a shorthand way of calculating total costs for all accidents in a company. They could calculate the average costs of each severity of accident, but often faced the problem that minor accident reporting in a company was poor, and hence the actual number of small accidents was unknown. The Bird ratio was therefore used to arrive at a total sum [e.g. Fletcher and Douglas, 1970]. The larger the sum arrived at, the better for motivating senior managers to invest in prevention. Again, I do not dispute this conclusion. The reasoning has to be applied carefully, since the ratios of different severities vary very greatly between activities and industries, but it is valid. It can be used to show that minor accident prevention is economically interesting, since, in many companies the total cost of minor injury and damage far outweighs that of major injury.
3. The causes of major and minor accidents (damage, injury) were the same. This is the conclusion I wish to examine closely in the rest of this paper. It is not so much Heinrich himself as his followers who drew this conclusion in a black and white way.

Evidence

Reasoning used

Heinrich was content to draw the rather broad conclusion that the seriousness of the consequences of an accident had a strong random element and that minor accidents often preceded major accidents. Examples quoted in his book shows how loose this reasoning is for him; the minor injuries cited take place in the same activity, but have a different and only partially overlapping set of causes from the major injury described, e.g. twisting an ankle tripping over the rail tracks when taking a short cut into the works vs. getting crushed to death between two trucks shunted on those tracks. Nowhere is the original data published, which Heinrich used. It is only quoted anecdotally. Hence we cannot check his reasoning in detail. However, the example which is often quoted later to prove the point is of an accident caused by an object falling from a crane, which may hit and kill, graze and slightly injure, or miss a person standing underneath. This anecdote is instantly recognisable and seems to 'prove' the principle of similar cause for major and minor incidents. Heinrich himself takes the argument further in quoting the results of his later study into accident prevention in 100 manufacturing plants [Heinrich et al 1980].

> 'The causes of serious injury accidents did not fairly picture the unsafe practices and conditions needing attention. Accident-prevention work in these plants was misdirected, since it was based upon the investigation of major injuries, and many other serious injuries of a slightly different nature later occurred '

This was taken by his followers as showing that attention to minor accidents would be more successful in directing prevention. However, that goes far beyond the evidence, and note also that Heinrich himself does not mention minor accidents, only near misses. He only claims that removing the causes of past serious injuries does not prevent future serious injuries. This may have been true in his case, but may only show that a small sample of major accidents is not representative of the total possible. One can ask whether his time scale was long enough to demonstrate his point. Studies done over the past 10 years at a steelworks [Swuste et al., 2002a, 2002b] indicate that such a reactive policy based almost exclusively on lost time accidents can produce good results: a reduction in the lost time accident rate of 30% and of total accident rate of 60% in 9 years, not dramatic, but a steady improvement. It is, however, clear that such an approach will only work in a relatively stable workplace and technology, which is not introducing new hazards faster than they are being removed by this incremental prevention.

What is surprising is the strength of the belief in identical causes of major and minor accidents which, subsequent to Heinrich's original work, grew up among safety practitioners, and apparently also among researchers. The persistency of this belief is shown by the vigour with which the dissenting voices have had to express themselves to counter this belief [Petersen, 1971, 1989; Hale and Hale, 1972; Salminen et al., 1992, Saloniemi and Oksanen, 1998]. Even the 5th edition of Heinrich's book found it necessary to state that:

> 'There has been much confusion about the original ratio in industrial accident prevention. It does not mean, as we have too often interpreted it to mean, that the causes of frequency are the same as the causes of severe injury. National figures show that different things cause severe injuries than the things that cause minor injuries. Statistics show that we have been only partially successful in reducing severity by attacking frequency' [Heinrich et al., 1980].

This belief seems to be an example of an urban myth; a belief which seems so plausible that it commands immediate acceptance without proof[1]. Clearly such a belief is so convenient for safety practitioners that they hardly stop to question it. The strength of the belief can be understood from the viewpoint of a company where minor accidents occur relatively frequently and major accidents are rare. They see their efforts and success in reducing minor accidents. They see no major accident. The temptation is to draw a cause-effect link, without questioning whether there would have been major accidents even without the efforts in preventing minor accidents. What is then the direct research evidence?

Empirical and statistical evidence

There are only a handful of studies dealing directly with the question of identity of causes, which I have been able to find after a search of the research literature. This lack of research can perhaps be seen as an indication of the strength of the urban myth. Why bother to research what is 'obviously' true?

Salminen et al. [1992] quote one study in favour of identical causes [Lozada-Larsen and Laughery, 1987] and two others which showed different causal patterns. Finnish research [Saloniemi and Oksanen, 1998] showed that fatal accident and lost time injury rates at company and national level showed opposing trends over time and different correlation's with macro-economic variables.

Tinline and Wright [1993] analysed loss of containment incidents and lost time accidents in chemical plants and showed that there was little or no correlation between the frequencies of occurrence of the two types either within or between companies. They concluded that lost time injuries (LTIs) could not be used in any way as indicators of major hazard safety for a plant. Most lost time accidents in the chemical industry occur in activities such as walking around the site, or in transport accidents. We are not going to get very far in preventing major chemical industry disasters by encouraging people to hold the handrail when walking down stairs. However, many chemical plants use LTIs as overall safety performance indicator, with at least the implicit belief that this also indicates success in major hazard control. This is like the drunk looking for his lost door key under the street lamp, because it is light there, rather than where he dropped it.

Van der Horst [1991] compared observed traffic conflicts, such as emergency braking and avoidance manoeuvres, with actual accidents at the same spot and concluded that only conflicts with a time to collision[2] of less than 1.5 seconds could predict accidents. Less immediate conflicts showed a poor correlation in both manoeuvre being undertaken and cause.

There appears to be no research which has looked at the correlation between the frequencies of major and more minor accidents across companies. But there is anecdotal evidence from disasters like the Exxon Valdez and Esso Longford [Hopkins, 2000] and the NASA Challenger accident [Vaughan, 1996] that disaster can strike organisations with a good safety reputation.

Against this negative evidence there is the critical incident study of Flanagan [1954] which did show roughly the same distribution of injury types and accident locations between what workers recalled in critical incident interviews[3] and the pattern of accidents over the last year in the factory department. This study used recall and not observation of the critical incidents, however. We must therefore ask whether this result can be explained by the memory of the types of accidents which had actually happened, giving selective recall of near misses.

Besides these few empirical studies, which provide more denial than support of the 'similar cause' hypothesis [see also Bari, 2000; Hopkins, 2000], there is an almost endless supply of accident statistics which show very easily explicable differences between fatal, major and minor injuries. The ratio of fatal to lost time injuries differs widely across industries, indicating that some technologies have a higher potential for fatality than others. The part of the body injured in fatal accidents is more often the head or trunk, while in less major ones it is more often the arms. The percentage of fatal and permanently disabling injuries from electricity, vehicles, and falling objects is much higher than the percentage of temporary disabilities caused by these contacts. Handling of materials constitutes a much higher percentage of temporary disability than it does of permanent disability and fatalities. So locations, activities and other proximal factors in national and industry statistics of major and minor injuries do not offer much in the way of similarities. This should not be surprising. The amount of energy locked up in a process and released by the accident process will significantly determine the amount of damage which can be done [Haddon, 1973; Heinrich et al., 1980] and damage is usually taken as the measure of how major or minor an accident is. There is only a limited degree of arbitrariness about what the energy touches before it dissipates, despite what the anecdote of the crane accident quoted above appears to say. A large release of flammable chemicals will, on average, produce more fatalities than objects dropped from scaffolding. So at this level of cause there is only a very limited overlap between major and minor injuries.

Evidence from major accident investigation

When we look at the analysis of major accidents such as Piper Alpha, the Challenger, Bhopal or Three Mile Island, we are always struck by the fact that there were signals of impending disaster long beforehand; the misuse of permit-to-work systems, the history of limited burn through of the O-rings, the failure of sprinklers, the malfunctions of safety valves. But note that these are generally near misses, or evidence of failures of planned lines of defence. A few, such as the emergency landing of a DC10 in Canada after losing a cargo door, which foreshadowed the major disaster when another DC10 crashed two years later at Ermenonville in France, are actual accidents with (relatively) minor damage, but it is not the occurrence of the damage or not which is interesting. It is the fact that the scenario is the same, which teaches us the lesson. The conclusion I wish to draw from all this is that: major accidents can sometimes be predicted by minor accidents, but not always; that there are always near misses and deviations, which are precursors of major accidents; and that not all minor accidents could have been major accidents.

Towards a correct reasoning: the Deviation model

Heinrich in his original research [1931] looked back from a single disabling injury and noted that minor versions of it occurred much more frequently on other occasions. There is an important truth in this way of looking at the issue. Any given accident is the culmination of a process, which can be stopped at a number of points (figure 2). Time flows downwards in the model and interventions from the left stop the development of the accident and return the process back to the top.

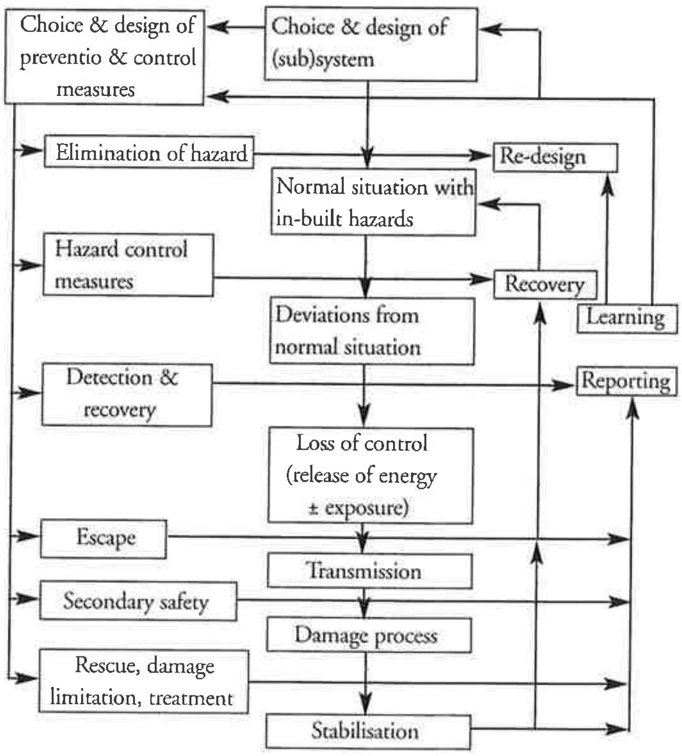

Figure 2: Accident deviation model.

The steps of the accident triangle can be defined in terms of this deviation and recovery sequence. The steepness of the sides of the triangle will be determined by the speed of the dynamics of the deviation process and the possibility of creating effective barriers and recovery mechanisms. The slower the speed of development of the scenario and the more effective the recovery mechanisms we can put in place, the flatter the triangle will be. The measures early in the sequence will prevent any damage, the later ones will only limit damage. Van der Horst's findings show that situations with a short time to collision (TTC) were good predictors of traffic accidents, whilst those with a longer TTC were not. This shows that not all deviations have the potential to lead to major loss of control and serious damage and that we are very good at some recovery steps early in the model. Hence the triangle will look more like the step pyramid of Zozer (figure 3), than the great pyramid of Khufu (figure 1).

Figure 3. A correct pyramid for a given accident scenario and its prevention

Also this reasoning is only true of one generic sequence, leading to one type of final event, with one restricted range of potential severities. Note that we also have to change the labels of the steps, by removing minor accidents and replacing them with loss of control. We end up with one pyramid per scenario. In all there are far more deviations than actual damage cases, so the conclusions drawn about needing to work on precursors rather than waiting for actual damage can stand. However, it is when we combine the pyramids into one great one that the logic goes sour. Then not all the deviations will lead to any one major accident, let alone all the minor ones. The balance of very meagre research evidence is that major and minor injuries come from different scenarios, each the top of a different set of pyramids.

There is another danger if the different pyramids are not distinguished. Measures to control one sequence may actually have an adverse effect on another sequence. The JCO nuclear criticality accident in Japan in 1999 is a good example of this[4]. New containers were introduced to reduce physical workload and back injury during the manipulation of uranium solutions. These containers allowed sufficient mass of solution to be loaded at once to produce criticality and a massive radiation dose to the workers concerned, from which two subsequently died. Recovering from a minor injury scenario opened the way for a deviation path leading to a fatal accident.

The accident model described above is commonly known in safety science as a deviation model [Hale, 2001]. There are potentially millions of deviations in any system, which can and do occur and they cannot possibly all be tackled. Some correct themselves; others do not lead to significant damage if undetected. So, should all deviations be reported? Well-organised and well-used incident reporting systems, which try to capture all deviations, such as those in aviation, are already beginning to grow so large that it is not possible to see the wood for the trees. They need filters added to them to distinguish precursors of major events.

Using the deviation model, the question about the similarity of major and minor injury causes can be divided into two parts.

1. Is there enough energy involved that the damage will be great if the sequence progresses to completion?
2. Will the sequence get as far as the damage, or will it get diverted by a recovery mechanism? And if so, are there different recovery mechanisms for sequences leading to minor than to serious accidents. Are the early recovery mechanisms different from the later ones? The main difference between near misses and significant damage would then be located, by definition, in the steps "transmission" and "damage process".

The amount of energy locked up in a process is relatively easy to indicate. Most office processes for instance have only minor potential. Question 1 helps to make a first filtering of incidents at the reporting stage and to discriminate minor from major potential. Koornneef [2000] uses this question in his incident reporting and analysis system, to decide the amount of information needed about an incident. The maximum potential for harm is also used to fix the number of incidents tolerable before additional preventive action is required.

However, there are many workplaces and activities where there is plenty of energy or harmful substances around to kill or maim. Then question 1 does not discriminate sufficiently and question 2 is crucial. Humans are naturally variable in their performance and are good at detecting deviations. Error with recovery leads to learning and learning is hard to imagine without that mechanism. So we cannot and should not try to prevent all deviations. We should try only to prevent those which will not be detected and recovered. Books such as that by Reason [1990] give the basis for distinguishing the reliable from the vulnerable human mechanisms for detecting and recovering initial error. Luckily the vast majority of the expected and recoverable deviations which people make will automatically be filtered out of any incident reporting scheme, because the perpetrators will not see them as surprises and they will not bother to mention them. Koornneef uses this concept of surprise as the basis for his reporting system for interesting incidents. This concept is of course elastic. It seems likely, however, that people would be more likely to both report and make efforts to recover from accident sequences with major than minor consequences.

Defence in depth

The 'defence in depth' strategy is also relevant in this context. The more carefully constructed the barriers which are in place, and maintained, the less chance that the accident sequence will progress to its ultimate damage stage. It is reasonable to assume that organisations will want to spend more time and money on the barriers to prevent potentially serious consequences than minor ones, other things being equal. They may not always succeed in this. Organisations have to have a clear view of all potential scenarios and be able to distinguish minor from serious ones, otherwise they may focus their prevention work on relatively unimportant scenarios. The importance of the debate on the similarity of causes between major and minor accidents lies in this danger. If companies think the causes are the same and they are not, they are betting on the wrong horse (and vice versa). However, if an organisation is well calibrated in its response to the seriousness of the potential damage, the system starts to operate as a closed loop system. The more serious the consequences, the better the barriers, and the lower will be the chance that events will reach the damage step. The serious accidents will then be associated with barriers which fail in unexpected ways, or with scenarios which were not considered, or were considered incredible. The minor accidents will result from the lack of barriers, or from trading off against other goals like production. This will be particularly true of sophisticated safety systems with defence in depth. We can postulate that, as the preventive system gets more and more sophisticated, the minor and serious accidents will get less and less similar to each other in causal sequences. In other words it will be only the poor or newly developing organisations and systems which can learn to prevent serious injuries by looking at minor ones.

General audits

A danger of a sophisticated defence-in-depth strategy is its complexity. People can see less and less clearly what aspects contribute to controlling what scenarios, unless this is clearly documented. This is a situation, which we have found in auditing major hazard controls in companies with a very comprehensive safety management system [Hale et al., 1998, 1999a]. This lack of clarity is particularly dangerous where the company wants to scrap or simplify parts of the system, or to eliminate staff from the company. By not seeing the wood for the trees, it may remove a vital part of the control of major hazard scenarios. The auditors in the last mentioned study to test the IRMA audit found themselves falling into a related trap. The audit structure they were using was based on a generic checklist for assessing eight critical resources for, and controls on risk management. It was perfectly possible to use these checklists for any aspect of risk control, both major and minor. Only when the checklists were tightly focussed on the really crucial tasks for controlling major hazard scenarios did the audit say anything useful about that specific aspect of risk control. Without this focus it was easy for the company to tell a convincing generic story about management systems which were present, but which were probably only working for minor accident scenarios. A similar problem arises with the TRIPOD audit [Groeneweg, 1998]. Studies have shown that the questions used in assessing the 11 basic risk factors can also fail to distinguish between what is necessary to control major and minor hazards [Wielaard & Swuste, 2001]. The assumption of common causes between major and minor accidents seems still to haunt us, even with such sophisticated instruments. When we aggregate the many specific causal factors of major and minor accidents into a few generic management system categories, we end up with the same labels for both. So, at a generic level of a management system we can say that there is an overlap of causes. However, as soon as we start to descend into the specifics of what exactly to manage and do on a day-to-day basis, the differences emerge again.

Conclusion

Too many people working in safety seem to believe unquestioningly that the causes of major and minor injury are similar and hence that they can reduce major injuries by eliminating minor ones. The meagre research evidence, but also the extensive accident statistics, which we have, show that this is not generally correct, certainly at the level of proximal causes rooted in technology and human behaviour. At a management level the causes may be similar at a generic level of categorisation, but not at a detailed level. It would be safer to assume that the causes are different until proven otherwise. I would challenge the readers of this journal to come up with convincing empirical evidence to the contrary. Perhaps then we could resolve whether this is indeed an urban myth or a useful basis for prevention.

Above all, the question is not rightly posed. We should not think in terms of comparing major and minor injuries, but of understanding accident scenarios. We should compare completed and uncompleted accident sequences. The question is whether there are early precursors in the accident sequence which can tell us about weaknesses in the whole control of that sequence? The deviations we want to find are those that are specific to particular accident sequences leading to major harm or damage, or damage which the organisation has defined as significant enough to prevent. The conclusion is that clearly articulated and understood scenarios must drive prevention activities. We should discriminate between the scenarios that can lead to major disaster and those which can never get further than minor inconvenience. If we tackle minor injury scenarios it should be because minor injuries are painful and costly enough to prevent in their own right, not because we believe the actions might control major hazards. Above all we should understand that, although the broad structure and functioning of management systems for major and minor hazards (and for health, environment and quality) may be the same, what we do in detail under those generic headings must be scenario-specific.

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NOTES

[1] Perhaps the most famous of these is the story of the old lady in the USA who dried her poodle in her new microwave oven, since she had been used to drying it in her old electric one. The story continues that she successfully claimed against the company making the microwave, since they had not explicitly warned against putting live animals in the oven. Efforts to trace this story (e.g.Brunvand 1980, Klik 1989) have always failed to find any primary reference to it. Yet everyone connected with safety has heard it quoted at some stage as a proven fact, usually to support the argument that such ridiculous "American excesses" must not be allowed to spread over here.
Trevor Kletz (1979) entitled his inaugural lecture as Professor of Safety at Loughborough University "Shaking the Foundations" because he attacked a number of these urban myths about safety and its management and showed just how ungrounded they were.

[2] This is a measure derived from video registration of the conflicts. The paths of the vehicles are projected in the direction of movement and the time is measured to a collision with another vehicle or road feature at the instantaneous speed of movement. The time to collision quoted is that at the moment of the emergency manoeuvre.

[3] These are interviews in which the respondents are asked to recall any situations where they experienced themselves, or saw others in, a situation which was close to an accident.

[4] see special issue of the Journal of Cognition Technology & Work 2000 for a detailed presentation and discussion of this accident.