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The safety chain: A delusive concept

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ABSTRACT

Various governments have defined a so-called safety chain to structure their efforts in the field of risk management for low-probability disasters. The safety chain typically consists of the following components: proaction, prevention, preparation, repression. While the terminology suggests that the safety chain should be interpreted a series system, the safety chain more closely resembles a parallel system. This has important implications: the safety chain is not as weak as its weakest link; unreliable links need not always be strengthened as it will often be more efficient to rely on a few layers of protection, or just one. To avoid misguided efforts caused by the confusing terminology 'safety chain', we propose the use of the term 'layers of protection', as is currently the case in the Dutch flood safety policy. Furthermore, we show that imperfect preparedness for low-probability disasters is often perfectly defensible or rational, given the differences between the cost-effectiveness of investments in prevention and disaster preparedness.

1. Introduction

In modern societies, risk management is a complex task that involves a wide range of actors and institutions. Various governments have defined a so-called safety chain to structure their efforts to control low-probability disasters, such as floods, hurricanes and large-scale industrial accidents. This chain links the various stages of the risk management cycle. It typically consists of proaction, prevention, preparation, repression and recovery, see Fig. 1 (Ten Brinke et al., 2008; The Netherlands Ministry of the Interior and Kingdom Relations, 1999a, 1999b).

Pro-action concerns risk management at its most basic level: risks can be avoided altogether by simply avoiding hazardous situations. Prevention concerns the reduction of risks by designing socio-technical systems in a way to ensure safe performance. But the probability of an accident, however remote, will always remain. Preparation involves all activities prior to an accident to improve emergency response. Repression is the actual response to emergencies, and recovery involves all activities in the post-accident phase. A similar approach is adopted by FEMA (2003) to address safety and security issues. It consists of four phases: mitigation, preparedness, response and recovery.

The different components of the safety chain relate to the different phases in the 'disaster life cycle'. Proaction, prevention and preparation concern the pre-event phase: they concern the activities that take place before disaster strikes. Repression concerns all activities during the event. Recovery relates to the activities in the post-event phase. The dividing line between repression and recovery is not as clear as for the other components of the safety chain. In many cases, such as the tsunami and nuclear crisis in Japan in early 2011, emergency operations are carried out alongside efforts to help victims rebuild their lives; the emphasis often gradually shifts from repression towards recovery.

While this article focuses on the safety chain as a concept for structuring options for risk mitigation, it should be noted that numerous alternative frameworks exist. Examples include the ten strategies for risk reduction (Haddon, 1980), Leveson's systematic accident model for engineering purposes (Leveson, 2004), and the various guidances that have been published by professional organizations (e.g. COSO, 2004; IRGC, 2008) and governments (UK Cabinet Office, 2002; Treasury Board of Canada, 2001).

This article is organizes as follows. In Section 2, the safety chain is analyzed using basic reliability engineering theory. Section 3 discusses the economics of the safety chain. More specifically, it discusses the cost-effectiveness of policy alternatives, such as spending an available budget on prevention, disaster preparedness, or a combination of both. Section 4 links the theoretical results of the preceding sections to the realities of risk management. Section 5 then presents some concluding remarks. Our overall objective is to demonstrate that the so called 'safety chain' can easily be interpreted in a way that confuses rather than aids the policy making process, with costly consequences.

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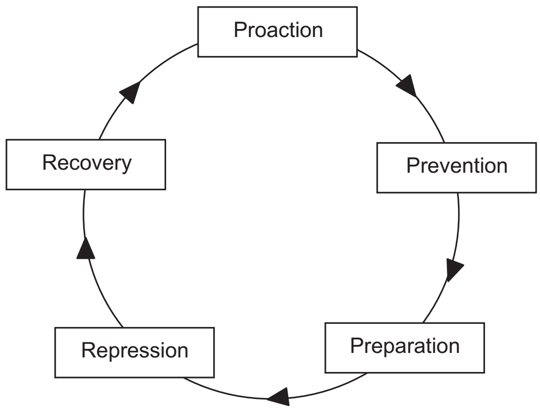


Fig. 1. Graphical representation of the safety chain.

2. Formal representations of the safety chain

The word 'chain' suggests that the safety chain resembles a series system. This interpretation can be evaluated using standard techniques from the field of risk analysis and reliability engineering. For reasons of simplicity, it is assumed herein that proaction, prevention, preparation, repression and recovery have only two mutually exclusive states: failed or intact. In reality, the components of the safety chain can fail (or function) to different degrees. The success rate of a preventive evacuation can for instance range from 0% (no evacuation) to 100% (complete evacuation). While the assumption of dual states does scant justice to reality, it is harmless in the sense that it does not affect the line of thought or our overall conclusions.

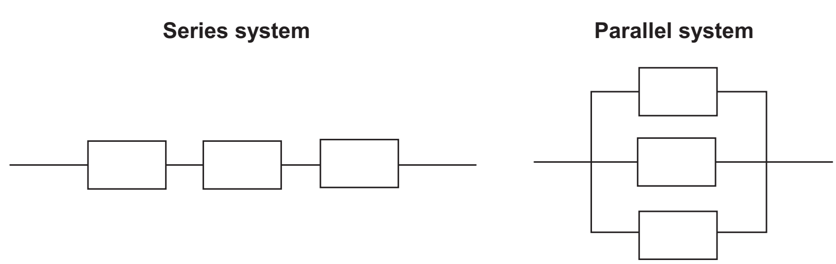
To avoid rhetorical confusion, proaction is excluded from the following discussion. This is because it seems inappropriate to speak of 'failures of proaction' since a lack thereof can be a deliberate decision. It should be noted, however, that the exclusion of proaction is immaterial to our conclusions: proaction is similar to prevention in the sense that both reduce the probability of anything bad from happening. Moving a hazardous facility to an unpopulated area (proaction) has the same effect on third party risk as making it perfectly safe (prevention) notwithstanding that, in practice, perfect prevention cannot be achieved. The left-hand side of Fig. 2 depicts the safety chain as a series system. Such a system is as weak as its weakest link. If the safety chain were to behave like a series system, each of its links should perform well for the probability of failure to be low. In practice, this would imply that emergency services should be able to cope with the consequences of a severe accident, regardless of the reliability of protection schemes.

The abovementioned outcome seems to conflict with the realities of risk management. A report by The Netherlands Hazardous Materials Council (2008) showed that none of the emergency services in the Netherlands would be able to cope with a major industrial accident. It seems that this conclusion can easily be generalized to other countries, given the track record of governments worldwide for dealing with large-scale accidents or disasters. Yet few would argue that industrial risks are untolerably high, just because disaster response is likely to fall short. The probability of severe accidents clearly plays a role. So should the safety chain be conceptualized as a series system?

Let us first assume that all links of the safety chain are perfect substitutes. This means that each component can fulfill the function of another component so that they can all prevent the same adverse consequences. In that case, the safety chain should be conceptualized as a parallel system rather than a series system. It would then be more appropriate to refer to proaction, prevention, preparation repression and recovery as 'layers of protection', instead of 'links of a chain'. After all, an adverse outcome will only obtain when all components fail. A parallel system is at least as strong as its strongest link (see also Fig. 2).

Although the safety chain seems to more closely resemble a parallel system than a series system, the former representation still seems imperfect. If, for instance, a levee system were to fail, some or many people could be saved through disaster response, but the immediate damages could not be undone, nor could disaster response bring the immediate flood victims back to life. The assumption of the links being perfect substitutes, making the safety chain work like a parallel system, only seems reasonable when it comes to proaction and prevention. These activities, that belong to the pre-event phase, can both prevent the occurrence of a critical event (e.g. flood or loss of containment) and hence prevent an adverse outcome (e.g. fatalities, economic loss) altogether. Preparation, repression and recovery can only reduce the secondary impacts of accidents and disasters, e.g. by preventing critically injured people from dying.

Now, let us relax the assumption that all links of the safety chain are perfect substitutes to come to an even more realistic representation. Preparation, repression and recovery can prevent



	Series System	Parallel system
Independent Elements	$1-\prod_{i=1}^{n}(1-P_i)$	$\prod_{i=1}^{n} P_i$
Dependent Elements	max(Pi)	min(Pi)

Fig. 2. The failure probabilities of a series and a parallel system (P_i represents the failure probability of a single component and n is the number of components).

some, but not all of the consequences of a critical event. When the components of the safety chain are imperfect substitutes, it can no longer be conceptualized as a pure parallel system that only fails when all its components fail. While no damages will occur as long as preventive schemes remain intact, only part of the damages can be avoided through emergency response and recovery when prevention fails. This is the case for a wide variety of disasters, ranging from floods to nuclear and chemical accidents. The corresponding schematization of the safety chain is shown in Fig. 3. When the preventive layer fails, there will be some immediate damages (D_1) that cannot be reduced by the other layers.

For reasons of simplicity, it is assumed in Fig. 3 that the performance of layer $i+1$ is dependent on the performance of layer i, in such a manner that the failure probability of layer $i+1$ is zero when layer i functions (this corresponds to a situation in which there is no demand on layer $i+1$ as long as layer i functions). This assumption seems broadly reasonable: preparedness only becomes relevant when preventive measures fail and repression is unlikely to fail when preparations are successful. The extent of damage depends on the type and number of layers that fail. It seems uncontroversial to assume that the disutility (U), or pain or discomfort, associated with an accident is positively related to the extent of damage (D): $dU(D)/dD > 0$. Damage D could be the number of fatalities, the severity of economic loss, or a combination or vector of different types of consequences.

As shown on the right-hand side of Fig. 3, the subsequent failures of preparation and repression will lead to subsequent increases of the extent of damage, and hence the disutility associated with the consequences of an accident. The increase in disutility is expressed by a factor α_i, where $\alpha_2 = U(D_{1,2})/U(D_1)$ and $\alpha_3 = U(D_{1,2,3})/(D_{1,2})$, with $\alpha_2 \geqslant 1$ and $\alpha_3 \geqslant 1$ (see also Fig. 3 – right). Note that the α_i-values indicate to what extent subsequent layers are substitutes when it comes to avoiding damage and hence an increase in disutility. When layer i is a perfect substitute for layer $i-1$, $\alpha_i \to \infty$. When $\alpha_i = 1$, layer i is wholly ineffective, in the sense that it does not influence the decision maker's well-being.

Note that, by considering the subjective valuation of the consequences of accidents, whatever they may be and however they are valued, we avoid the issue of having to define a consequence type or risk metric that is deemed meaningful to all. This is done because our objective is merely to demonstrate that incorrect conceptualizations of the safety chain may lead decision makers to make choices that are inconsistent with their own preferences. Defining universally applicable measures or valuations of risk would be an impossible task given the differences between the characteristics of risks that people find meaningful (e.g. Slovic, 1999). This is illustrated by the wide variety of risk metrics that are used in different fields, ranging from expected loss, societal risk (a cumulative fatality distribution) to probability-weighted sums of non-linearly valued consequence types (for an overview, see, e.g. Jonkman et al., 2003; Vrijling and van Gelder, 1997; Bedford, 2005).

3. The economics of the safety chain

Cost-benefit analysis is a method for structuring complex decision problems (e.g. Arrow et al., 1996) and it has long been used in the Netherlands to inform policy debates about the safety of flood defenses (Van Dantzig, 1956; Eijgenraam, 2008). The ability of cost-benefit analysis to produce morally relevant outcomes has however often been questioned (e.g. Adler and Posner, 1999), especially when it comes to matters of health and safety, where other factors than costs and benefits influence people's moral judgments (e.g. Fischhoff et al., 1981; Slovic, 1999). Here, we do not aim to reduce the multiple dimensions of risk to a dollar figure to calculate some efficient balance between risk and return. We merely aim to show how different investment strategies will influence the probability of adverse consequences, whatever they may be, and however they may be valued (but note that we do assume that smaller losses are preferred over greater ones).

According to the expected utility framework by Von Neumann and Morgenstern (1944), a rational decision maker ranks risky prospects on the basis of their expected utilities. The expected utility framework rests on a number of axioms which require decision makers to be rational, i.e. able to order their preferences in a consistent manner. These axioms have been highly criticized on descriptive, empirical grounds (e.g. Kahneman and Tversky, 1974, 1979). For normative analyses, these criticisms seem less important: consistency, or rationality, seems to be a perfectly reasonable benchmark for analyzing or criticizing the decisions people make.

Based on the representation of the safety chain shown in Fig. 3, the expected value of the (dis)utility of potential damages equals:

$$\begin{aligned} E(U(D)) &= P_1(1-P_{2|1})U(D_1) + P_1P_{2|1}(1-P_{3|1,2})\alpha_2 U(D_1) \\ &\quad + P_1P_{2|1}P_{3|1,2}\alpha_2\alpha_3 U(D_1) \\ &= P_1 U(D_1)((1-P_{2|1}) + P_{2|1}\alpha_2((1-P_{3|1,2}) + P_{3|1,2}\alpha_3)) \end{aligned} \quad (1)$$

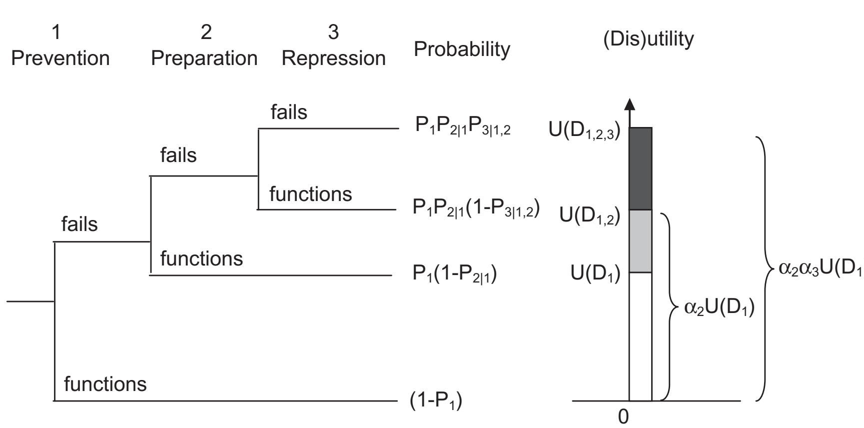


Fig. 3. Event tree showing the possible combinations of failures of layers (left) and the extent of damage (right). P_1 – failure probability of layer 1 (prevention) (probability of an accident). $P_{2|1}$ – conditional failure probability of layer 2 (preparation). $P_{3|1,2}$ – conditional failure probability of layer 3 (repression). $U(D_1)$ – the disutility (pain or discomfort) of the consequences associated with the failure of the preventive scheme that cannot be mitigated through repression or recovery. $U(D_{1,2})$ – the disutility of the consequences associated with the failures of the preventive scheme and prevention that cannot be mitigated through repression. $U(D_{1,2,3})$ – the disutility of the consequences associated with the failure of the preventive scheme, preparedness and repression.

When failure probabilities are small, this reduces to:

$$E(U(D)) = P_1 U(D_1)(1 + P_{2|1}\alpha_2(1 + P_{3|1,2}\alpha_3)) \quad (2)$$

For illustrative purposes, let us consider a system that consists of three layers of protection with failure probabilities ($P_1 = 0.01$ per year, and $P_{2|1} = P_{3|1,2} = 0.01$ per demand). Let us further assume that the extent of damage after the failure of the first, preventive layer is valued at $U(D_1) = 0.25$ and that expected disutility doubles when another layer fails ($\alpha_2 = \alpha_3 = 2$), so that $U(D_{1,2,3}) = 1$. On the basis of Eq. (1), the expected disutility value of damages equals 2.53×10^{-3} per year. This expected value depends strongly on the performance of the first layer (prevention). By strengthening the second and third layers, we can reduce expected disutility by only 2% at most. If we were to decrease the reliability of the second and third layers (preparation and repression layers) by a factor 10 ($P_{2|1} = P_{3|1,2} = 0.1$ per demand) the performance of these layers would still be relatively unimportant for the decision maker's well-being: only 20% of his or her expected disutility could then be attributed to failures of the second and third layers.

It can easily be shown that a rational decision maker will prefer a reduction of the failure probability of a preventive scheme (P_1) over equal reductions of the conditional failure probabilities of preparedness and response ($P_{2|1}$ and $P_{3|2,1}$), unless he or she has a highly unorthodox preference function, i.e. one that places less weight on greater consequences. It also follows from Eqs. (1) and (2) that rational decision makers are likely to prefer higher standards of protection over better disaster preparedness or crisis management when the immediate damages that obtain after the failure of a preventive scheme are severe.

The conceptualization of the safety chain has important implications for the allocation of the scarce resources. Strengthening a link or layer will have some impact on the overall safety level, but this also comes at a cost (causing discomfort or disutility as well). Budget constraints typically imply that we cannot strengthen all links of the safety chain simultaneously. An important question is therefore whether a decision maker should spend a limited budget on one layer or link, or to distribute it over multiple layers or links. An incorrect conceptualization or perception of the relationships between the overall level of risk and the performance of the different layers/links of the safety chain could lead to considerable suboptimization (from the decision maker's own perspective).

Regardless of a rational decision maker's utility function, his or her optimal risk reduction strategy will differ strongly for series and parallel systems. In the case of a series system with dependent (perfectly correlated) components, it will be rational to invest in such a manner that the failure probabilities of the different links are equal. This will typically imply that the available budget has to be distributed over the system's different links. But in case of a pure parallel system with dependent (perfectly correlated) components, the budget should be spent on just a single layer.

For technical systems such as dams and industrial installations, the failure probabilities of the preventive schemes will typically be more important to the overall level or risk than the quality of disaster plans or the capacity of emergency response organizations. This is because peparedness and repression are unable to undo the severe immediate damages that will obtain after a failure of the preventive scheme(s). For risks to remain low, these preventive schemes have to be highly reliable. And when they are highly reliable (so that P_1 in Eq. (1) is low), the absolute level of risk reduction that can be achieved through further investments in disaster preparedness will be limited. This implies that for these highly reliable systems, rational decision makers are likely to investment heavily in proaction and prevention while keeping investments in preparedness, repression, and recovery at relatively low levels.

It is stressed that the above does not imply that preparation, repression, and recovery should not be considered for highly reliable systems with a potential for disaster. Relatively small investments could still yield attractive returns. Emergency services are typically equipped for dealing with day-to-day (small scale) incidents. Because incidents in different localities are unlikely to occur at the exact same point in time, there continuously is a spare capacity (albeit a fluctuating one) that can be mobilized to face infrequent, extreme events (deciding on the amount of spare capacity can also be treated as an economic optimization problem, see Jongejan et al., 2011). Planning and preparing for such mobilizations is far less costly than purchasing equipment and hiring emergency responders for highly infrequent disasters. Investments in the former may well pass a cost-benefit test.

4. The realities of risk management

Political, legal and cultural factors all influence the allocation of resources in the field of risk management. The attention given to the various components of the 'safety chain' is hardly ever explicitly governed by cost-benefit analyses. Yet cost-benefit considerations do play a role, albeit often implicitly.

On the 29th of August 2005, a category three hurricane struck the Southern US Gulf coast. Wind speeds up to 200 km/h ravaged the city of New Orleans and smaller coastal towns. When hurricane Katrina had passed, the suffering was not nearly over. The levee system protecting New Orleans proved no match for the storm surge and large parts of the city were flooded. Over 1100 people lost there lives, despite preparations and efforts to evacuate the city. It took many days to reach and provide disaster relief to the inhabitants of New Orleans. It took many years to rebuild the city. Even today, the scars left by Katrina are still visible in New Orleans. Better emergency response could perhaps have reduced the suffering caused by Katrina, but it could never have avoided the severe social and economic impacts that followed the flooding of New Orleans. Even a perfect response to the disastrous event could not have been a perfect substitute for prevention.

Given the fact that preparedness and repression are grossly imperfect substitutes for prevention when it comes to the flooding of densely populated areas (α_2, α_3 close to 1), an additional investment in prevention is likely to yield a far greater return than an additional investment in disaster preparedness and/or repression. While the short-falls of preparedness and repression received considerable media and political attention after the New Orleans flood, the vast majority of the available budget to reduce future flood risks was used to strengthen the city's flood defenses rather than to expand the capacity of emergency response organizations (in line with the conclusions of the previous sections). While lessons have undoubtedly been learned, it is unlikely that the emergency response organizations are now fully prepared for another disaster on the scale of the New Orleans flood. While this outcome may sound unacceptable, it hardly seems irrational given the presence of budget constraints and the workings of the safety 'chain'.

Without its primary flood defenses, the Netherlands would be swallowed by the rivers and sea. A flood in the Netherlands could have an impact of the scale of the flooding of New Orleans (Jonkman et al., 2005). Yet interestingly, the Netherlands is poorly prepared for large-scale floods. Besides low-cost measures, would it also be efficient to invest heavily in the emergency response infrastructure and/or purchase additional helicopters to save people from their rooftops if disaster were strike? A Flood Management Taskforce was installed in 2007 to improve disaster preparedness (TMO, 2009). As part of the investigations sizeable investments in disaster planning, evacuation routes and equipment were considered. But maintaining a fleet of helicopters would require considerable annual expenditures, while the helicopters would be needed as little as (on average) once per century or millennium. And while helicopters might save some people from their rooftops, they cannot avoid the enormous economic impact of a major flood, nor can they prevent trauma and loss of life. In fact, it would be a more efficient strategy to reduce the probability of flood to a minimum. Well-intended investments in disaster preparedness could be associated with considerable opportunity cost: a dollar can only be spent once. The position taken by the Dutch cabinet (Minister of the Interior and Kingdom Relations, 2008) clearly reflects this view: it decided not to invest heavily in the capacities (boats, trucks, helicopters) needed for mass evacuation.

Needless to say, there will be exceptions. Local circumstances could yield a different optimal balance between prevention and, e.g. preparedness. Hoss (2010) for instance studied ways to reduce flood risks in the city of Dordrecht, where historic buildings line the existing flood defenses. Here, improving emergency preparedness or flood proofing buildings could be more efficient than strengthening flood defenses. This is because the costs of strengthening the flood defenses would be relatively high, whereas the area protected by these defenses is relatively small.

5. Concluding remarks

In recent years there has been considerable attention for the improvement of crisis management capabilities. This is often motivated by arguing that preventive schemes, no matter how safe, can fail so that we should always be fully prepared. Not only does such reasoning imply that preparedness and repression are fail-proof, it also violates elementary economics. 'What if'-decision making could divert resources from links of the 'safety chain' where these resources could have been put to greater use (see also Jongejan and Vrijling, 2006; Jongejan et al., 2011).

Unfortunately, the widely used term 'safety chain' falsely suggests that proaction, prevention, preparedness, repression and recovery need to be equally reliable for a hazardous system to be safe: a chain is broken when one of its links fails. This, however, is an improper representation of the relationships between proaction, prevention, preparedness, repression and recovery. The safety chain more closely resembles a parallel system. For such systems, it is typically more cost-effective to invest heavily in the performance of one component, rather than to disperse the available budget over all of them.

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References

Adler, M.D., Posner, E.A., 1999. Rethinking cost benefit analysis. Yale Law Journal 109 (2).
Arrow, K.J., Cropper, M.L., Eads, G.C., Hahn, R.W., Lave, L.B., Noll, R.G., Portney, P.R., Russell, M., Schmalensee, R., Smith, V.K., Stavins, R.N., 1996. Is there a role for benefit-cost analysis in environmental, health and safety regulation? Science 272, 221–222.
Bedford, T., 2005. Keynote lecture: multi-attribute utility theory and FN-criteria. In: Proc. Of ESREL 2005, Tri City, Poland, pp. 157–166.
COSO, 2004. Enterprise risk management – Integrated framework. Committee of Sponsoring Organizations of the Treadway Commission (COSO).
Eijgenraam, C.J.J., 2008. An optimal flood protection standard for dike-ring areas. In: Fourth International Symposium on Flood Defence, Toronto, Ontario, Canada.
FEMA, 2003. A Nation Prepared. Federal Emergency Management Agency Strategic Plan 2003–2008.
Fischhoff, B., Lichteinstein, S., Slovic, P., Derby, S., Keeney, R., 1981. Acceptable Risk. Cambridge University Press, Cambridge.
Haddon, W.J., 1980. The basic strategies for reducing damage from hazards of all kinds. Hazard Prevention September–October, 8-12.
Hoss, F., 2010. A Comprehensive Assessment of Multilayered Safety in Flood Risk Management. Msc thesis. Delft University.
IRGC, 2008. An Introduction to the IRGC Risk Governance Framework. International Risk Governance Council, Geneva.
Jongejan, R.B., Vrijling, J.K., 2006. To prevent or to cure? Emergency response as an exchangeable risk reduction strategy'. In: Proc. ESREL2006 Estoril, Portugal.
Jongejan, R.B., Helsloot, I., Beerens, R.J.J., Vrijling, J.K., 2011. How prepared is prepared enough? Disasters 35 (1), 130–142.
Jonkman, S.N., van Gelder, P.H.A.J.M., Vrijling, J.K., 2003. An overview of quantitative risk measures for loss of life and economic damage. Journal of Hazardous Materials A 99, 1–30.
Jonkman, S.N., Stive, M.J.F., Vrijling, J.K., 2005. New Orleans is a Lesson to the Dutch. Journal of Coastal Research 21 (6), 1085.
Kahneman, D., Tversky, A., 1974. Judment under uncertainty: heuristics and biases. Science 185, 1124–1131.
Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47 (2), 263–291.
Leveson, N., 2004. A new accident model for engineering safer systems. Safety Science 42, 237–270.
Minister of the Interior and Kingdom Relations, 2008. Nationale Veiligheid; Brief van de Minister van Binnenlandse Zaken en Koninkrijksrelaties (letter of the minister of Interior Affairs to Parliament on national security), 0708tkkst30821-6.
Slovic, P., 1999. Trust, emotion, sex, politics, and science: surveying the risk-assessment battlefield. Risk Analysis 19 (4), 689–701.
Ten Brinke, W.B.M., Saeijs, G.E.M., Helsloot, I., van Alphen, J., 2008. Safety chain approach in flood risk management. Municipal Engineer 161, 93–102.
The Netherlands Hazardous Materials Council, 2008. Risicobeleid en Rampenbestrijding. Adviesraad Gevaarlijke Stoffen, The Hague.
The Netherlands Ministry of the Interior and Kingdom Relations, 1999a. Workshop Safety Chain, Rotterdam, The Netherlands.
The Netherlands Ministry of the Interior and Kingdom Relations, 1999b. Rampenbestrijding: de veiligheidsketen gesmeed; Beleidsnota rampenbestrijding 2000-2004.
TMO (Taskforce Management Overstromingen), 2009. Rapport van bevindingen.
Treasury Board of Canada Secretariat, 2001. Integrated Risk Management Framework.
UK Cabinet Office, 2002. Risk: Improving Government's Capability to Handle Risk and Uncertainty. Strategy Unit Report. UK.
Von Neumann, J., Morgenstern, O., 1944. Theory of Games and Economic Behavior. Princeton University Press, Princeton.
Vrijling, J.K., van Gelder, P.H.A.J.M., 1997. Societal risk and the concept of risk aversion. In: Guedes Soares, C. (Ed.), Advances in Safety and Reliability. Proc. Of ESREL 1997 Lissabon, vol. 1, pp. 45–52.