FUNDAMENTALS OF THE FRAMEWORK FOR RISK CRITERIA OF CRITICAL INFRASTRUCTURES IN THE NETHERLANDS

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ABSTRACT

Critical infrastructures are complex societal systems. For that reason, risk criteria for critical infrastructures are also "part" of the risk criteria for complex societal systems. The questions to be resolved are

1. are the societal risk criteria of complex systems defined and quantifiable
2. is known how the risk criteria of critical infrastructures relate to the risk criteria of the complex system as a whole.

In other words, how can we be sure that the risk criteria of critical infrastructures meet the risk criteria of complex systems as a whole. A complex system in this respect may be a society as a whole, e.g. a nation. There may be large differences between both types of risk criteria.
This paper highlights the fundamentals of use of risk and risk criteria for critical infrastructures. The backgrounds are shown to be derived of cost-benefit considerations, revealed preferences, expressed preferences and for environmental risks the natural standards. A general approach is also reviewed taking into account risk aversion and the power of risk policies. This power is related to a measure of (in) voluntariness of the risks by the people exposed to it and direct benefit. Examples of handling risk criteria in the Netherlands are given for major hazards installations, airports and public transport by (high speed) trains.

KEYWORDS

Risk criteria, individual risk, Group risk, System engineering, Fundamental approach, Critical infrastructures

CRITICAL INFRASTRUCTURES

Society is a global system with many subsystems which determine day-to-day life of everyone. Parts of society are vital to our current way of living and failures of it may lead to disastrous or even catastrophic effects on mankind or its economies. Particularly when these parts referred to are embedded in larger societal infrastructures it is needed to investigate the risks of such failures and ultimately compare these against appropriate risk criteria. Apparently they are *critical infrastructures*. Examples of critical infrastructures are energy systems, transport systems (e.g., railroad systems, aviation systems, water systems, telecommunication systems, complex industrial activities, and so on).

In order to contemplate this issue of risk further, we first identify how risks are determined and which means are available to define appropriate risk criteria. Examples of some critical infrastructures developments with risk criteria in the Netherlands are presented.

USE OF RISK

The term *risk* becomes meaningful once it is associated with minimal requirements of the risk construct, e.i., it should adhere to unwanted events (or scenarios), its likelihood of occurrence given the unwanted events outcomes. Although substantiated in many text books on risk analysis this notion is well defined by Kaplan & Garrick (1981). Likelihood of occurrences is generally expressed in terms of probabilities, or frequencies over time or desired events. Unwanted event outcomes are generally expressed in number of deaths or injured or economic losses. In order to explore the risk of any systems, one should be aware that each risk assessment on the same system would have another outcome (both qualitative and quantitative). This is partly due to the fact that the data chosen for the risk models differ and the modeling itself may differ, but also largely because any risk assessment provided is constrained by choices (either made by the decision maker who warrants the assessment, or made by the risk analysts). In conclusion, one can say that any risk assessment is conditional on its choices, models and numbers used.

As said earlier, critical infrastructures are large societal systems where a lot of choices can and must be made on how to proceed with risk evaluations. Fundamentally it should be so that the risk assessments performed comply with the backgrounds of the risk criteria imposed on the risk evaluation. Otherwise, the whole exercise would be meaningless.

RISK OF CRITICAL INFRASTRUCTURES

Once we deal with risks of critical infrastructures as a whole, we should be aware that the risks of parts of the system as a whole would be evaluated against other interests as well. If we look at the risk of loss of energy supply to a large population in a country, occupational safety and health laws require to also pinpoint on worker risks associated with it. These worker risks may not be part of the overall critical infrastructure risk definition, but is relevant for the survival of the energy systems. If the risk of working on high voltage lines pillars is considered too large for workers, the labor inspection may shut down the activities, at least for a while, jeopardizing the functioning of the energy supply system.

Another issue of great importance in risk evaluations are the system boundaries of the critical infrastructures. Do we look at the transport system as a whole, or do we define the railroad system as a separate critical infrastructure. Is the energy system supplying the railroad high voltage lines part of the transport system, or not. It is clear that a proper risk evaluation process very much depends on the definitions chosen for the system boundaries. It does not matter where the system boundaries are chosen as long as the risk assessment and the risk criteria are matching with each other.

One example where the risk evaluation of one critical infrastructure may be "overruled" by taking into account the consequences of decisions in the risk evaluation of another adjacent critical infrastructure. For instance, major repair activities of the railroad tracks may require no train traffic over both tracks for a large period of time. The main reason for doing so, is given by the relatively high individual risks of railroad workers in the railroad system. The individual risk criterion relates worker deaths as a result of accidents to number of railroad workers per year for one country as a whole. Shutting down all train activities along the repair tracks meets that risk criterion far better than any other decision whereby trains are still allowed albeit against certain constraints (like lower speeds).

However, no trains at all requires alternative transport modes, like transporting train passengers with hired buses. Furthermore, a large part of the passenger population will make a decision to go by car. So the safety decision in the railroad system creates higher risks in the road system. As roughly speaking, the railroad system is safer than the road system, we may eventually end up in deep trouble. Tough decisions have to be made, like trading off the worker risks of the railroads against increased passenger risks on the roads.

BACKGROUNDS OF RISK CRITERIA

At least four approaches driving risk criteria can be distinguished (see for further explanation, of each, Shrader-Frechette (1985)):

1. criteria based on risk-cost-benefit measures, like, e.g. in complex and expensive health services
2. criteria based on past performance or revealed preferences, like, e.g. in major hazards licensing and rail road safety of high speed lines
3. criteria based on societal or laymen's preferences, expressed preferences, like, e.g. in asbestos abatement or approaches to dioxin emission mitigation causing health problems, and
4. criteria based on natural standards, like, e.g. in some environmental risk criteria.

The question is how these backgrounds fit into the risk criteria used for critical infrastructures, or only for parts of the system. For instance, the health care system is not using the same risk criteria in all corners of the system. For large general population programs, like preventive breast cancers surveys under women of a certain age category, the choice of doing it at all for everyone in that category, or whether you should survey every two, three or four years, is largely driven by risk criteria based on cost weightings against the number of women to be expected to not develop a fatal breast cancer as a result of those surveys. Some unraveled discussions also take place with respect to risks due to waiting lists for expensive health treatments. Albeit ethically debatable, for certain areas risk criteria based on cost versus less fatalities can "make sense". Political and public debates try to arrange a shift towards risk criteria based on expressed preferences anyway.

Valuing human life as a base for assessing new safety measures is also based on cost-benefit-considerations. The British decision for valuing human life at about £ 600,000 at some point of time for road traffic safety measures is an example. The valuation of human life was judged scientifically to be about twice that value, but the British Treasurer prevented bankruptcy by lowering the value substantially. It would have substantially impacted the national budget as higher values of human life would justify the rebuild of very many road crossings into viaduct crossings.

Risk criteria based on past performance are also getting more attention as it offers an opportunity of going further on the same road without drastic policy changes in the short run. One can then adapt the risk criteria over the years by adding percentages of risk reduction to it. The national policy on road safety in the Netherlands is an example, whereby the Ministry of Transport and Waterways decided to go for 25 to 30 percent reduction in number of deaths and hospitalized persons over a period of 12 years from 1998 onwards.

Another area where risk criteria based on revealed preferences have been adopted is the railroad system in the Netherlands and particularly the risk criteria of the new high speed links. In here the individual risk criteria (IR: probability of a fatality for railroad workers, or for passengers, or for people living close to the railroad tracks, related to all people involved over a year) are based on past performance of the general railroad system adapted to comparable systems with existing risk criteria. For instance, the number of the IR criterion for people living close to the railroad tracks is similar to that of the IR of someone living close to a major hazards chemical facility; the IR criterion for railroad workers is similar to the fatalities to be expected among public road workers and the IR criterion for railroad passengers is derived from past experience and somewhat adapted to a lower value.

Risk criteria based on expressed preferences tend to come from (heavy) public debates, in which cases discussions are strongly determined by whether or not to proceed with those risky activities. In general, the public wants to stop the activity while industries or governments like to carry on. The nuclear debate after the Chernobyl accident is an example, and the asbestos case was an example. Where the Dutch government had banned new applications of asbestos, the European Commission did not want to go that far, because of its free trade policy. Public and political concerns put the judgement of the asbestos risks into the right corner. Eventually, asbestos got banned, at least for new applications.

Another important issue is meeting the risk criteria in practice. Not in all cases risky infrastructures are monitored sufficiently in the operational phase. In many cases risk criteria apply for judging the design phase (e.g. in major hazards establishments, dyke renewal or storm surge barriers against flooding) or may even be more appropriate for the demolition phase (like to be expected for nuclear energy as a whole). This requires performance of qualitative assessments next to the quantitative risk design criteria. As this may not necessarily be the case in all circumstances, "repair" strategies are warranted to meet the original design criteria, in particular, when common-cause mechanisms in safety management overrule "as designed" management and may violate the risk criteria with orders of magnitude.

To take account of safety management efficiency in risk evaluations, in particular when judged against a quantitative risk criterion is even more cumbersome in practice. One example maybe the implementation of the Seveso-II Directive of the European Union in the Netherlands. Major hazards establishments need to present a safety report in which a quantitative risk analysis is required for external safety evaluation. That concerns the risks to third parties as a result of the establishment's chemical processes. In the Netherlands a semi-prescribed method is used for which "standard" failure data are available (CPR 1999). These data are historical data, whatever the history may be. The risk calculations thereof determine the zoning areas around the establishment as well as the group risk *FN*-curves (representing frequencies *F* exceeding *N* number of deaths of all relevant accident scenarios). The competent authority's inspection teams must evaluate the risks and must agree or disagree with current practices of the company.

In many cases, the inspection teams try to force or convince establishments to take further safety mitigating measures under the ALARA regime. ALARA means As Low As Reasonably Achievable, whereby costs of proposed safety measures are traded off against its risk reduction potential. Since the efficiency of the establishment's own safety management system is not taken into account in the external risk calculations, they often argue against additional safety measures by claiming to already have a lower risk because of their well functioning safety management system. And they can often demonstrate the efficiency.

The point made in this example is, that establishments claim that the calculated risks against which the risk criteria are set, are lower in practice. If that would be true, establishments are evaluated against the "wrong" numbers of the risk criteria.

RISK POLICIES IN RISK CRITERIA

For complex societal systems as a whole, like a nation, one normally uses *individual risk* as a measure, which varies between 10^{-5} and 3.10^{-4} deaths per year for occupational, traffic and consumer risks respectively. The individual risk is then taken over the whole population at stake and a time period of one year. Although no general individual risk criteria are set for trivial risks either, one tends to measure those against the *de minimis* value of 10^{-6} or 10^{-5} deaths per year (Mumpower, 1986) indicating a potential low acceptable risk level for any individual, where everybody can live with. In some cases of critical infrastructures, like high speed train links, individual risk criteria are set in the Netherlands (Frijters *et al* 1998). These are shown in Table 1. The same is true for the zoning between hazardous chemical facilities and residential areas, at an individual risk contour of 10^{-6} deaths per year (Bottelberghs 2000).

TABLE 1
RISK LEVELS SET FOR HIGH SPEED TRAINS IN THE NETHERLANDS
(AFTER FRIJTERS *ET AL* 1998)

Risk group	**Personal risk (deaths per year)**
Passenger	$4 * 10^{-6}$
Train personnel	$5 * 10^{-5}$
Track side worker	$5 * 10^{-5}$
Person living near track	$1 * 10^{-6}$
Person passing-by	$1 * 10^{-6}$

For critical infrastructures sometimes also societal risks are defined. For social or group risks, the next step is to order the scenarios with increasing measure of potential consequences (mostly deaths). The cumulative probabilities (or frequencies) for exceeding a certain number of deaths is then derived from the probabilities of all scenarios contributing to that particular number of deaths. Graphically this is represented in an *FN*-curve. Orientation curves are defined for the group risk of hazardous chemical facilities (the Dutch Ministry of Environment-type of curves, with a decreasing quadratic function expressing lower accepted frequencies with increasing potential number of deaths (Bottelberghs 2000)).

Another more generic approach by which the value of risk policies are weighted has been developed by Vrijling *et al* (1995) and further elaborated by Vrijling *et al* (2001). The societal acceptable risk is judged at a national level by placing an upper-bound upon the expected number of fatalities per activity per year $E(N_{di})$. This is in line with the notion of revealed preferences (past performance is driving it). However limiting only the expected number of deaths does not account for risk aversion, which appeals to the notion of expressed preferences. This means that the risk of getting high numbers of deaths as a result of accidents should be evaluated against relatively lower risk criteria, as is for instance the case in the Dutch major hazards group risk (orientation) criteria.

Risk aversion can be represented mathematically by adding a confidence requirement $\sigma(N_{di})$ to the norm

$$E(N_{di}) + k \,.\, \sigma(N_{di}) < \beta_i \,.\, 100$$

where k is the risk aversion index (normally taken at $k = 3$) and β_i is a policy factor. The β_i policy factor varies from 0.01 for involuntary no-benefit activities to 100 for completely voluntary direct-benefit activities. In this case, the policy factor values are determined by the policy makers taking account of what they think the public wants.

Although on one hand, the risk criteria formula can be used to manipulate the (politically) wanted outcome of the risk criteria for a certain activity, it can also be positively used to identify the required minimal value of the β_i policy factor for a certain activity.

Vrijling *et al* (2001) have shown examples of how the risk criteria approach works. For airports they argue that for the crude risk calculations applied for Schiphol airport in the Netherlands a policy factor of $\beta_i > 0.5$ (meaning partly involuntary, partly voluntary and some degree of direct benefit activity) would only justify the current risks. They also argue that refined computer calculations could reduce the policy factor to the order of $\beta_i = 0.1$ (invoking less voluntariness and less benefit constraints to risk decisions). This example shows how conditional the results of handling risk criteria is on the quality of the modelling (and of course on the data used in the models).

Another example provided by Vrijling *et al* (2001) are risks of adding high speed trains to the railroad system. Table 2 gives their results in terms of minimally acceptable values of the policy factor β_i . The table shows that the high speed trains do not require additional risk considerations other than already anticipated for the HST specifically and for the whole railroad system (0.015 compared to 0.013). The table also shows the factor of 10 higher for the road system, justifying the notion of taking voluntariness more into account in judging upon road risks.

TABLE 2
PRESENT SITUATION WITH CARS AND TRAINS AND FUTURE SITUATIONS WITH HIGH SPEED TRAINS (HST) SUBSTITUTING PART OF THE CURRENT TRAINS
(AFTER VRIJLING *ET AL* 2001)

Mode	$E(N_{di})$	$\Phi(N_{di})$	$E(N_{di}) + k.\Phi(N_{di})$	B_i **(minimal value)**
Car	7.1	2.7	15	0.15
Train (now)	0.05	0.4	1.3	0.013
HST	0.05	0.5	1.5	0.015

CONCLUSIONS

The goal of this paper is to overview the fundamentals of risk criteria for critical infrastructures in the light of societal risk criteria and the life cycle of the systems at hand. It is also shown how inherently difficult risk assessments of subsystems, which are part of critical infrastructures, can be fairly judged upon against the risk criteria of the critical infrastructure as a whole.

The paper highlights the use of probabilistic risk criteria used in the Netherlands for several critical infrastructures: rail roads, major hazards installations, and airports.

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