National Risk Assessment in The Netherlands

A Multi-Criteria Decision Analysis Approach

Erik Pruyt and Diederik Wijnmalen

Abstract Nowadays, National Safety and Security issues receive much attention in many countries. In 2007, the Dutch government approved a National Safety and Security Strategy based on a multi-criteria analysis approach to classify potential threats and hazards. The general methodology of this Dutch *National Risk Assessment* and the specific multi-criteria-based approach developed for it are presented in this paper. Five issues are discussed here: the objectives, requirements and criteria of the risk assessment; the multi-criteria methods used; the pluralistic weighting approach; the sensitivity and robustness analyses; and the outcomes of the Dutch National Risk Assessment.

Keywords National risk assessment · National safety and security strategy · Multi-criteria decision analysis

1 Introduction

In 2007, the Dutch Council of Ministers approved a National Safety and Security Strategy (Programma Nationale Veiligheid 2007). This is a novel development in The Netherlands. Before that, risk analyses and preparation were rather fragmented and focused on specific types of crises. Hence, there was a need to consider all relevant threats and hazards systemically in a single framework at the national level in order to prioritise them for policy decision purposes.

The National Safety and Security Strategy is an annually recurring process that consists of the three stages displayed in Fig. 1:

1. In the *Government-wide analysis* stage, potential medium- and long-term threats and hazards are first of all identified. Thematic scenario groups then develop incident scenarios for these potential threats and hazards. The risk of any of these

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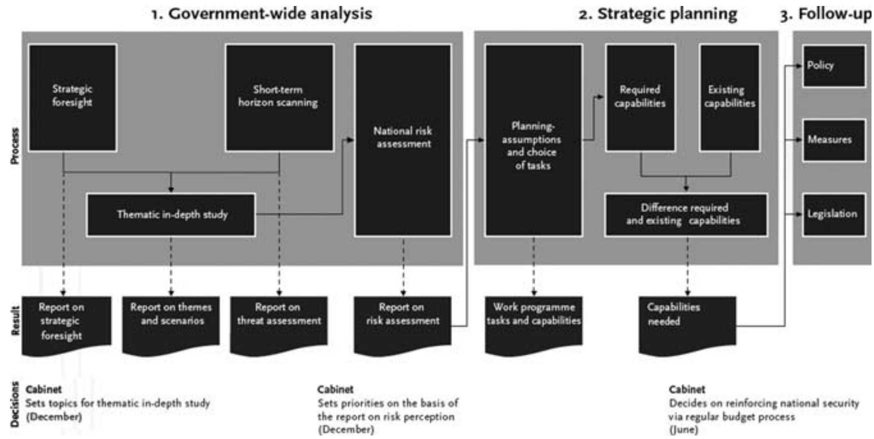

Fig. 1 The Government-wide analysis (comprising the national risk assessment), the strategic planning stage and the follow-up stage of the national safety and security strategy. Adapted from PNV (2007c, p20–21)

incident scenarios is assessed in terms of their (multi-dimensional) impact and likelihood. This information is then analysed in the *National Risk Assessment* in order to assist the prioritisation of these incident scenarios and to underpin the next two stages.

2. In the *Strategic Planning* stage, currently existing capabilities to cope with the "high-priority" risks are compared to those needed, and advice is formulated concerning policy measures that need to be taken to improve current capabilities.
3. In the *Follow-up* stage, recommended actions are implemented to augment the current capabilities to deal with "high-priority" risks.

Only the last step of the first stage, the *National Risk Assessment* (NRA), is dealt with in this paper. It focuses more specifically on the NRA methodology and the Multi-Criteria Decision Analysis (MCDA) methods used. Section 2 deals briefly with the objectives, requirements, vital interests, criteria and scoring approach. The MCDA methods used are outlined in Sect. 3. Section 4 describes uncertainty, sensitivity, and robustness analyses. NRA outcomes – and the way they are used and communicated – are discussed in Sect. 5. Section 6 contains some concluding remarks.

2 The NRA

In 2007, an "NRA methodology team" consisting of civil servants and independent scientists/consultants was established to develop the Dutch NRA methodology. Before the development of the NRA methodology started, the Dutch Ministry of the Interior and Kingdom Relations specified the objectives and requirements.

The objective of the NRA is to develop a robust classification of incident scenarios in terms of impact and likelihood in order to help the Dutch government decide about what additional capabilities to organise for dealing with plausible and potentially devastating threats and hazards. That requires a comparison and classification of a multitude of different threats and hazards at the national level.

The ministry specified that the methodology needs to be able to deal with multiple criteria, and that the MCDA methods used need to be as transparent and methodologically consistent as possible. The Dutch government also predefined five national, so-called "vital interests": territorial security, physical safety (public health), economic security, ecological security, and social and political stability. According to the National Safety and Security Strategy, Dutch national safety and security is at stake when at least one of the vital interests is threatened or harmed at the national scale.

The first job of the NRA team was therefore the development of a set of criteria that would adequately represent these five vital interests when assessing the overall impact of incident scenarios. This lead – after many meetings and stakeholder consultations – to the list of ten impact criteria displayed in Table 1.

The criteria are operationalised by means of subcriteria and/or indicators. That allows the thematic scenario groups to first provide relevant information to enable assessment and, second, to assess the impact of the incident scenarios on these criteria. Some of the subcriteria are operationalised by means of a single indicator, but most of the criteria are operationalised by means of two indicators (e.g. impacted area and duration) which are combined in matrices to obtain the criterion evaluation. Some (qualitative) criteria are operationalised by means of a set of indicators and a procedure to turn the indicator evaluations into criterion evaluations (see (Programma Nationale Veiligheid 2008b) for information on the indicators, subcriteria, and transformations).

Since many of the potential incident scenarios have never actually happened, it is difficult to assess the precise impact on these criteria. If that is the case, then

Table 1 Vital interests and criteria of the Dutch NRA

Vital interest	*Criterion*	*Description*
Territorial security	f_1	Infringement of the Dutch territorial integrity
	f_2	Infringement of the integrity of the international position of The Netherlands
Physical safety (public health)	f_3	Number of fatalities
	f_4	Number of seriously injured & chronically ill
	f_5	Physical suffering
Economic security	f_6	Financial costs
Ecological security	f_7	Long-term damage to flora & fauna
Social and political stability	f_8	Disruption to everyday life
	f_9	Violation of the democratic system
	f_{10}	Social psychological impact: public (out) rage & anxiety

Table 2 The 13 NRA 2007 incident scenarios with their most likely *(0–E)* scores

	Incident scenario	Likelihood	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
S_1	Pandemic flu (mild)	likely	0	0	D	C	A	E	0	A	A	E
S_2	Pandemic flu (severe)	possible	0	0	E	D	E	E	0	E	C	E
S_3	Heat-Drought	likely	0	0	C	0	A	D	A	A	0	A
S_4	Flooding (worst credible)	highly unlikely	D	A	E	E	D	E	E	E	B	E
S_5	Flooding (DikeRing14)	highly unlikely	C	A	D	E	D	E	E	E	A	E
S_6	Nationwide blackout	likely	0	0	B	A	D	D	0	D	B	A
S_7	Intentional electricity disruption	unlikely	A	D	A	A	D	D	A	D	B	E
S_8	Oil (geopolitical)	possible	0	A	A	A	A	E	0	E	D	E
S_9	Right wing extremism	likely	0	A	A	A	0	A	0	B	B	C
S_{10}	Left wing extremism	possible	0	A	A	A	0	B	0	A	A	A
S_{11}	Animal rights activism	possible	0	A	A	A	0	A	0	A	0	D
S_{12}	Political Salafism	likely	0	A	0	0	0	C	0	C	0	E
S_{13}	Muslim extremism	unlikely	0	A	A	A	0	B	0	A	C	E

the thematic scenario groups merely have to indicate to which ordered class – with labels *0, A, B, C, D* or *E*, denoted from here on as (*0–E*)– the evaluation belongs. The label *0* is assigned if the criterion is not relevant to the scenario. Label *A* corresponds to a "limited" impact, label *B* to a "substantial" impact, label *C* to a "serious" impact, label *D* to a "very serious" impact, and label *E* to a "catastrophic" impact. The upper limit of the highest ordered class *E* is indeed the most catastrophic impact possible. All operational evaluations and measurements are transformed to the same ordinal *0–E* labels. The *0–E* labels ease, as such, the assessment and allow to take some uncertainty into account.

Table 2 contains the *(0–E)* scores of 13 scenarios of specific incidents developed for, and used in, the NRA 2007 (Programma Nationale Veiligheid 2008a, p35).

3 Multi-Criteria Methods Used

Apart from the objectives and requirements discussed in Sect. 2, the MCDA methods need to be suitable for ranking/classifying a countable number of alternative scenarios ranging from about a dozen in 2007, 34 in 2008, to many more in subsequent years. Given the requirements, the methodological team decided to start with three different MCDA methods: the quantitative "Weighted Sum" method (Multi-Attribute Value Theory), the ordinal Medal Methods (ordinal in terms of intercriteria and intracriterion information), and the ordinal variant of the Evamix method (ordinal in terms of intracriterion information). Combining these three methods allowed the team to test different MCDA methods in this new context, to keep the overall approach as transparent and consistent as possible, to keep each of the MCDA methods simple and understandable, to exploit the advantages of the MCDA methods, to generate different insights (complete and partial pre-orders, influence of the compensational character, etc.), to triangulate results obtained with different MCDA methods, and to test the methodological robustness of the classification reported to the Minister.

The use of the fully compensational Weighted Sum Method results in a complete pre-order. The Medal Methods allow to check for problems of full compensation, cardinalisation, incommensurability and incomparability. Evamix allows using quantitative weights with qualitative (i.e. ordinal) assessments. And both the Evamix and Medal Methods allow to test the methodological robustness of the results of the Weighted Sum Approach.

3.1 The Weighted Sum Approach

In the Weighted Sum approach – or Multi-Attribute Value Theory (MAVT) approach (Belton and Stewart 2002) – the *0–E* scores of the scenarios on the ten criteria f_j are first of all transformed to standardised quantitative scores by means of partial value functions $v_j()$. Three different partial value functions are used: an exponential one with base 3 $\left(A \mapsto \frac{1}{81};\ B \mapsto \frac{3}{81};\ C \mapsto \frac{9}{81};\ D \mapsto \frac{27}{81};\ E \mapsto \frac{81}{81}\right)$, an exponential one with base 10 ($A \mapsto 0.0001$; $B \mapsto 0.001$; $C \mapsto 0.01$; $D \mapsto 0.1$; $E \mapsto 1$), and a linear one ($A \mapsto 0.2$; $B \mapsto 0.4$; $C \mapsto 0.6$; $D \mapsto 0.8$; $E \mapsto 1$). These quantitative scores per criterion are multiplied with the corresponding relative weights of the criteria, and subsequently summed, or:

$$N(f_1(scenario_i), \ldots, f_{10}(scenario_i)) \rightarrow \sum_{j=1}^{10} w_j * v_j(f_j(scenario_i)) \qquad (1)$$

The larger the multi-dimensional damage of an incident scenario is, the larger will be the weighted sum of the scenario. This method is simple, easy to perform, explain, and understand, and its quantitative results are easily plotted in risk diagrams and used for quantitative analyses. However, the NRA is not a standard MCDA application: the construction of value functions and weight sets that truly reflect the decision maker's actual trade-offs is complicated by the lack of a single decision maker or a small group of decision makers (all Dutch citizens are in fact concerned by the NRA), the confidential character of (some malicious) incident scenarios, the perceived incommensurability of some criteria (e.g. f_3 and f_6), and the difficulty for individuals to trade off on the national level (thousands of fatalities, tens of billions of Euros, etc.). The purely quantitative weights and scores required for the Weighted Sum Method as well as its compensational character therefore lead to the decision to use different partial value functions and MCDA methods in parallel and to perform additional analyses.

3.2 The Medal Methods

The Medal Methods (Pruyt 2007) are purely ordinal methods, based on the Argus method (De Keyser and Peeters 1994; Martel and Matarazzo 2005), that directly use the ordinal *0–E* scores and ordinal importance labels (such as "very important", "important", ...) that are assigned to the different criteria.

First, the ordinal *0–E* scores and ordinal importance labels need to be set out respectively in the top row and first column of a matrix. "Medals" need to be assigned in a consistent way to all cells of this "medal matrix". The impact scores of the incident scenarios are then converted, using the medal matrix, to a set of medals. Sets of medals can be – and are in different variants of the Medal Methods – ranked in different ways:

- as partial pre-orders, by means of a pairwise comparison between all pairs of scenarios S_k and S_l, exploiting the information contained in their respective numbers of gold (G), silver (S), and bronze (B) medals. An interesting way to do this, is by checking whether there is an *outranking* relationship ($\mathcal{P}$), an *indifference* relationship ($\mathcal{I}$), or an *incomparability* relationship between them:

$$S_k \mathcal{P} S_l \;\Leftrightarrow\; \begin{cases} \wedge \; G^{S_k} \geq G^{S_l} \\ \wedge \; (G^{S_k} + S^{S_k}) \geq (G^{S_l} + S^{S_l}) \\ \wedge \; (G^{S_k} + S^{S_k} + B^{S_k}) \geq (G^{S_l} + S^{S_l} + B^{S_l}) \end{cases}$$

$$S_k \mathcal{I} S_l \;\Leftrightarrow\; \begin{cases} \wedge \; G^{S_k} = G^{S_l} \\ \wedge \; (G^{S_k} + S^{S_k}) = (G^{S_l} + S^{S_l}) \\ \wedge \; (G^{S_k} + S^{S_k} + B^{S_k}) = (G^{S_l} + S^{S_l} + B^{S_l}) \end{cases}$$

  $S_k \mathcal{R} S_l$ else.
- as complete pre-orders by adding information about the relative importance of different types of medals, from an equal preference system (1 gold medal = 1 silver medal = 1 bronze medal), over an infinity of exponential preference systems (e.g. base 3: 1 gold medal = 3 silver medals = 9 bronze medals), to a lexicographical preference system (gold medals are infinitely more preferable than silver medals, which are infinitely more preferable than bronze medals).

Advantages of the Medal Methods are that they can deal with ordinal intercriteria and intracriterion information, that they do not necessarily lead to full aggregation/compensation, that they generate insights related to combined compensatory effects of evaluations and preferences, and that the ordinal variant deals with qualitative information in a methodologically consistent way. But the Medal Methods are also less transparent and simple than the Weighted Sum approach, they require additional information in the form of a medal matrix and the ranking system chosen, and partial rankings as generated by the ordinal variant of the Medal Methods are less useful for large sets of scenarios due to the larger number of incomparabilities.

3.3 The Evamix Method

The third method used is the ordinal variant of the Evamix method (Voogd 1983), a popular method in The Netherlands (Janssen 2001). The ordinal variant of the Evamix method constructs an outranking flow and an outranked flow based on the quantitative weights assigned to the criteria and the information generated by the purely ordinal comparison of the labels *0–E* of all pairs of scenarios. This pairwise comparison leads to difference values of -1, 0 or $+1$ (corresponding to the ordinal differences of "more", "equal" and "less"). The flow values are calculated using a weighted sum of the difference values and the quantitative weights. The difference of the outranking and outranked flow values results in a quantitative score for each of the scenarios and thus a complete pre-order of the scenarios. This MCDA method also treats the ordinal evaluations (ordered classes *0–E*) in a methodologically consistent way and is used to triangulate the results together with the Medal Methods. Where the Medal Methods are characterised by assumptions that are rather different from those of the Weighted Sum method, the Evamix method is similar to the Weighted Sum method, with the difference that it is able to deal with the ordinal labels (*0–E*) without having to transform them to cardinal values. This is the main reason for using Evamix in addition to the other two methods.

4 Uncertainty, Sensitivity and Robustness Analyses

4.1 Pluralistic Weighting: Using Group Preference Profiles

A pluralistic weighting approach was adopted: five different preference profiles were constructed and used instead of a single preference profile. These preference profiles (see Fig. 2) are aligned with, and assumed to correspond to, the preference profiles of different types of Dutch policy-makers who represent different sections of Dutch society, which are characterised by different world views, lifestyles, and individual value systems. Using different preference profiles allows to:

- Take value diversity explicitly into account, which is especially important for issues that cannot be openly discussed in public fora (i.e. malicious actions).
- Consider, illustrate, and communicate the effect of different world views.
- Test the sensitivity of the NRA classification for changes in relative weights. which matters for reasons of policy continuity and political and public support,
- Circumvent the impossibility to obtain *the* NRA preference set.

The first preference profile (labelled "00") simply attributes an equal weight to all criteria. The other four profiles are derived from profiles developed by the

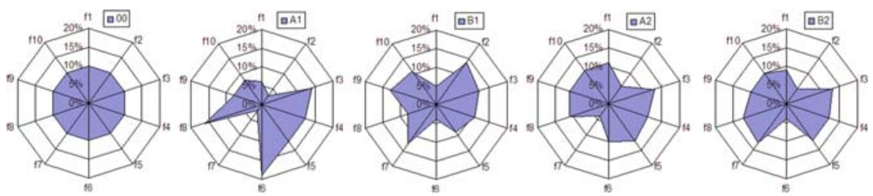

Fig. 2 Different weight profiles used in Weighted Sum approach of the NRA 2007

Milieu- en Natuurplanbureau and RIVM (2004, 2005) which are based on the four archetypical world views of the IPCC (Nakicenovic et al. 2000): Profile "A1" corresponds to an "*individualistic*" world view, "B1" to an "*egalitarian*" world view, "A2" tot a "*fatalist*" world view, and "B2" to a "*hierarchist*" world view. The corresponding relative weights of the ten criteria used in the similar Weighted Sum and Evamix approaches are displayed in Fig. 2. Ordinally equivalent "importance sets" are used in the Medal Methods, thus allowing for its different nature.

4.2 Traditional Uncertainty, Sensitivity, and Robustness Analyses

The analysis of the classifications obtained by means of the five group preference profiles already constitutes a first type of sensitivity analysis. Sensitivity and robustness of the classification is also explored by means of small changes of a single weight at a time, and simultaneous changes of all weights by means of (Monte Carlo) risk simulations. Sensitivity of the classifications to different evaluations/scores is also analysed. If evaluations are uncertain, then scenario groups are asked to provide minimum, most likely, and maximum evaluations. However, given the ordered classes (*0–E*), different evaluations may still lead to the same scores. Scores are also varied systematically (to lower and higher scores) in order to test the robustness of the classification. The effect of the combined uncertainty of the intercriteria and intracriterion information of the incident scenarios is investigated systematically too.

Finally, sensitivity of the classifications to different methods and methodological assumptions is tested too: results are calculated with the three variants of the Weighted Sum Method, the Medal Method with base 3, and the ordinal variant of the Evamix method. Combining the five MCDA methods with the five preference profiles and the three values per criterion (minimum, most likely, and maximum) leads to 75 rankings and classifications (see Fig. 3 for 25 classifications of the NRA 2007 based on the "most likely" values). In order to classify them as "catastrophic"... "limited", the rank orders of the scenarios are compared to those of five reference scenarios consisting of ten *A*-, *B*-, *C*-, *D*-, or *E*-scores respectively.

These classifications are not aggregated, but are used instead to assess the overall robustness of the classification communicated to all stakeholders in the "Report on Risk Assessment" (see (Programma Nationale Veiligheid 2008a) for the 2007 report).

The desired result of the MCDA is – as was mentioned before – a *policy robust* classification. A classification is policy robust if the classification and the policy recommendation derived from it remain the same when methods and methodological assumptions, preference profiles, and evaluations/scores are varied and challenged within reasonable limits.

	Reference scenarios					Incident scenarios												
Expected Values	All A	All B	All C	All D	All E	S4	S5	S2	S13	S1	S6	S11	S12	S7	S3	S10	S8	S9
Profile 00 MAVT Exp PVF base 3	17	15	11	6	1	2	3	4	5	7	8	9	10	12	13	14	16	18
Profile A1 MAVT Exp PVF base 3	18	14	11	7	1	2	4	3	5	6	8	10	12	9	13	15	16	17
Profile B1 MAVT Exp PVF base 3	17	14	11	5	1	2	3	4	6	8	7	10	9	12	15	13	16	18
Profile A2 MAVT Exp PVF base 3	17	15	12	6	1	2	4	3	5	7	8	9	10	11	13	14	16	18
Profile B2 MAVT Exp PVF base 3	17	14	11	5	1	2	3	4	6	8	7	9	10	12	15	13	16	18
Profile 00 MAVT Exp PVF base 10	18	16	14	10	1	2	3	4	5	6	7	8	9	11	12	13	15	17
Profile A1 MAVT Exp PVF base 10	18	16	13	8	1	2	4	3	5	6	7	9	10	11	12	14	15	17
Profile B1 MAVT Exp PVF base 10	18	16	13	10	1	2	3	4	5	6	7	9	8	11	14	12	15	17
Profile A2 MAVT Exp PVF base 10	18	16	14	10	1	2	4	3	5	6	7	8	9	11	12	13	15	17
Profile B2 MAVT Exp PVF base 10	18	16	13	10	1	2	3	4	5	6	7	8	9	11	14	12	15	17
Profile 00 MAVT Linear PVF	16	9	6	3	1	2	4	5	8	9	7	13	12	11	14	17	14	18
Profile A1 MAVT Linear PVF	16	11	6	5	1	2	3	4	8	9	7	13	14	10	12	18	15	17
Profile B1 MAVT Linear PVF	15	9	6	2	1	3	4	5	8	10	7	14	12	11	17	16	13	18
Profile A2 MAVT Linear PVF	16	11	6	3	1	2	4	5	8	9	7	13	12	10	15	17	14	18
Profile B2 MAVT Linear PVF	16	9	6	3	1	2	4	5	8	10	7	14	12	11	15	17	13	18
Profile 00 Evamix ordinal	13	9	6	3	1	1	2	3	5	6	4	10	8	7	11	13	9	12
Profile A1 Evamix ordinal	16	11	7	5	1	2	4	3	6	9	8	12	13	10	14	18	15	17
Profile B1 Evamix ordinal	13	8	5	3	1	2	4	6	9	10	7	15	11	12	16	17	14	18
Profile A2 Evamix ordinal	14	9	6	4	1	2	3	5	8	10	7	13	12	11	16	18	15	17
Profile B2 Evamix ordinal	13	8	6	4	1	2	3	5	9	10	7	14	12	11	16	17	15	18
Profile 00 Medal Method base 3	15	6	6	6	1	2	3	4	5	10	9	13	11	12	15	18	14	17
Profile A1 Medal Method base 3	16	12	6	5	1	2	3	4	8	9	6	11	14	10	12	17	15	18
Profile B1 Medal Method base 3	13	9	6	5	1	2	3	4	7	11	7	13	10	12	16	18	15	17
Profile A2 Medal Method base 3	16	10	8	5	1	2	3	4	5	7	9	13	11	12	13	18	15	17
Profile B2 Medal Method base 3	15	10	6	5	1	2	3	4	8	9	7	15	11	13	12	17	14	18

Fig. 3 25 rankings (rank orders in cells) and classifications (*shades of grey*) of the 13 NRA 2007 scenarios based on their "most likely" evaluations. *Dark grey* refers to the "Catastrophic" class, *medium grey* to the "Very serious" class, *light grey* to the "Serious" class, and *white* either to "Substantial" or the "Limited" class. The five reference scenarios (each having identical labels on all criteria) are displayed too

5 NRA Outcomes, Use and Communication

The thematic scenario groups do not only assess the impact of the incident scenarios on multiple criteria, they also assess the likelihood of them occurring in the next 5 years in classes *A* to *E* (see (Programma Nationale Veiligheid 2008b)). *A* stands for "highly unlikely", *B* for "unlikely", *C* for "possible", *D* for "likely", and *E* for "highly likely". The two pieces of information – the classifications in terms of impact (*0*–*E*) and likelihood (*A*-*E*) – are combined and plotted in a risk diagram (see Fig. 4).

The risk diagram is one of the formal outputs of the NRA that are actively used in the Strategic Planning stage. Uncertainty/sensitivity/robustness analyses are documented in technical background reports, but high-level decision makers are not usually bothered with these analyses, the 75 rankings and classifications, the ten risk diagrams, etc. Only the most important insights generated during these analyses are communicated – together with the risk diagram based on the Weighted Sum approach with base 3, some guidelines for interpreting the risk diagrams, and some other informative diagrams – to the high-level decision-makers and the public in the Report on Risk Assessment (see (Programma Nationale Veiligheid 2008a) for the 2007 version). There, "highly likely" and "likely" scenarios with "catastrophic" or "very serious" impacts are presented as "Category I" scenarios, the rest of the scenarios with "catastrophic" or "very serious" impacts as "Category II" scenarios, and "highly likely" and "likely" scenarios with "serious" or "substantial" impacts as "Category III" scenarios. Different recommendations are provided – in view of

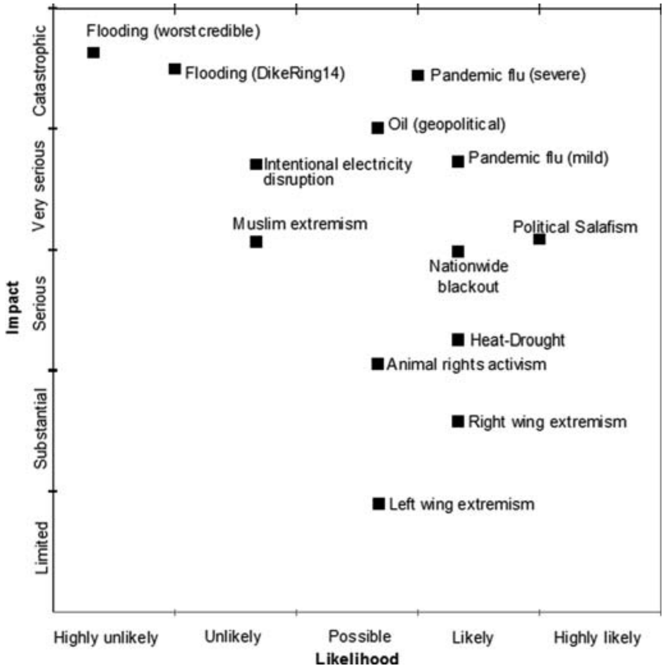

Fig. 4 The NRA 2007 risk diagram for the Weighted Sum base 3 and Profile "00"

the later stages – for dealing with scenarios from these categories. The NRA is – in that sense – a starting point: the NRA outcomes need to be informative and useful for the subsequent stages of the National Safety and Security Strategy (see Fig. 1).

6 Concluding Remarks

The objectives of the Dutch NRA are the identification of potential (malicious and non-malicious) risks, an assessment of their multi-dimensional impacts, their classification in terms of overall impact and likelihood, the investigation of the policy robustness of the proposed classification, and the generation of insights in order to underpin the Strategic Planning stage. Hence, the aim of the NRA is *not* to predict occurrences of specific disasters at specific moments in time, but to assist planning for additional or improved capabilities to face potential disasters.

The Dutch NRA is a systematic and highly standardised MCDA risk assessment approach in which different MCDA methods are used in parallel, and in which uncertainty, sensitivity and robustness analyses are always performed. Different MCDA methods are used to allow for the mixed qualitative and quantitative nature of the operational evaluations – thereby making the overall methodology as consistent as possible – and to test the methodological robustness of the outcomes, while keeping the different methods as simple and understandable as possible, and exploiting their respective strengths.

In 2007 and 2008, the NRA results were sufficiently in line with intuition to be credible, but also sufficiently "surprising" to arouse a lot of attention. The results are surprising because all hazards and threats are now analysed in a single framework, using the same set of criteria, and the results are displayed in the same graphs and tables, making them truly comparable, for the first time in Dutch history. As such, it is an innovative method for Country Risk Management (OECD 2009).

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