Special Issue Article

Institution of MECHANICAL ENGINEERS

Journal of RISK AND RELIABILITY

Proc IMechE Part O:
J Risk and Reliability
226(6) 666–676

DOI: 10.1177/1748006X12466371
pio.sagepub.com
SAGE

Quantitative modeling of organizational resilience for Dutch emergency response safety regions

John MP van Trijp[1], Mihaela Ulieru[2] and Pieter HAJM van Gelder[3]

Abstract

Resilience is an important concept to determine how well a Dutch Emergency Response Safety Region behaves under stress. The main objective of this study is to determine the intrinsic value of "resilience" for Dutch Emergency Response Safety Regions. In this study it is concluded that the concept of "resilience" can be best described by the generic approach "operational resilience". A large scale survey among safety stakeholders in The Netherlands was conducted where the following items describing operational resilience were explored: situation awareness (***awa***); management of keystone vulnerabilities (***kv***); adaptive capacity (***ac***) and quality (***q***). Results show resilience of an emergency response organization can be described by a unique dynamic operational resilience $f(R_{ero})_{UV}$ factor. A simplified approach of unique dynamic operational resilience is suggested by using a quick scan method to speed up the process of assessment.

Keywords

Adaptive capacity, awareness, emergency response organization, keystone vulnerabilities, management, operational resilience, resilience, risks

Date received: 16 Mar 2012; accepted: 10 Oct 2012

Introduction

In recent years a scale increase of emergency response organizations in The Netherlands has occurred or is still in progress. This scale increase is strongly favored by the Dutch Government and by 1 October 2010 this was enforced by law as well. Local Fire Departments, municipal Medical Departments, Medical Emergency Services, etc., will be working together in a new structure: The Safety Region. Today, the greater part of the Safety Region consists of the Regional Fire Service, which in turn is a body created from amalgamated Municipal Fire Departments. A huge shift in political responsibility has occurred as local Mayors lost their direct control over the originally locally based Fire Departments. The law is expected to be changed during the course of 2012 requiring amalgamation of the Municipal Fire Departments into Regional Fire Services.

As a Safety Region encompasses a multitude of Municipalities and Emergency Response Organizations, a complex structure is drawn to ensure democratic control by the individual municipalities. Figure 1 shows this complex structure (Situation February 2012).

The Safety Region holds the Regional Fire Service and the Regional Medical Service. The members of the Board of the Safety Region are the individual (Lord) Mayors of the municipalities. The Chair is held by the Mayor of the so-called "center-municipality", usually the largest one and is named "Coordinating Mayor".

The individual municipalities have operational representatives working inside the Safety Region to ensure proper disaster and crisis planning and response. The regional Police and the Department of Defense work closely together with the Safety Region on safety issues, but are not controlled by it. The Regional Police has its own Board with the same (Lord) Mayors, of which the Chair is labeled Administrator of Police and the Regional Police work with the Safety Region on the basis of a signed Memorandum of Understanding. The

[1]Libertas in Vivo vof, Utrecht, Netherlands
[2]Impact Institute for the Digital Economy and Carleton University, Ottawa on, Canada
[3]Delft University of Technology, Delft, Netherlands

Corresponding author:
John MP van Trijp, Libertas in Vivo vof, Purpervlinderstraat 27, Utrecht, VZ 3544, Netherlands.
Email: john.vantrijp@libertasinvivo.com

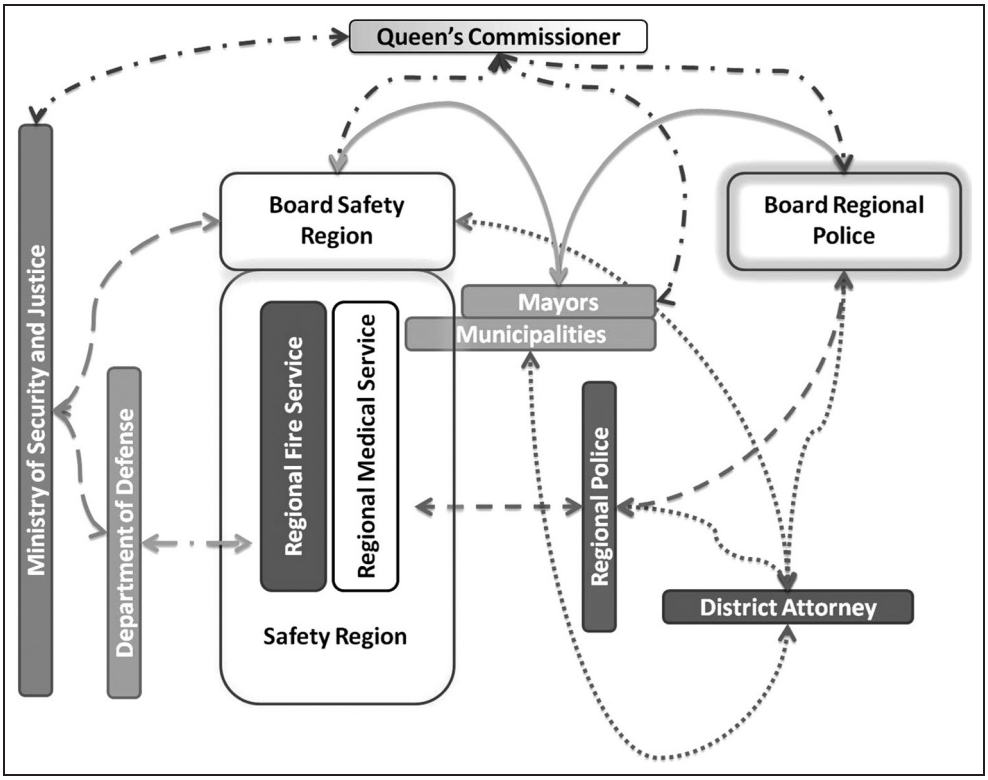

Figure 1. A Safety Region and its relationships in The Netherlands.
Source: Reproduced with permission from Van Trijp et al.[1]

Office of the District Attorney works closely together for criminal law issues (this officer may be present in the Board Safety Region as well) with the Safety Region and the Regional Police. The role of the Queen's Commissioner is rather complex and the Commissioner acts on behalf of the Government by providing a safety directive in the rare case the Coordinating Mayor fails to act adequately. It will suffice to note the Queen's Commissioner is not the Commander-in-Chief of the Safety Region (the Coordinating Mayor is), but there are distinct functional and operational lines visible.

In the course of the year 2012 the Regional Police will cease to exist only to be replaced by the National Police, which will be under direct control of the Minister of Security and Justice.

By law a Safety Region has to:

- provide better protection of civilians from risks;
- offer better emergency management and aftercare during disasters and crises;
- act during emergencies as one administrative organization that coordinates and addresses the Fire Service, Medical Service, Disaster and Crisis Control Service and the operational use of Police;
- enhance the administrative and operational striking capability.

To meet these criteria, a Dutch Emergency Response Safety Region should possess a certain amount of "resilience". In order to facilitate comparison between Dutch Emergency Response Safety Regions on a basis of their resilience capabilities we have chosen to develop a quantitative resilience model. We believe this model can be used to clarify and improve the administrative and operational striking capability of such regions.

This article explores the concept of resilience from literature and contains the results of a survey among relevant Dutch Safety stakeholders and finally presents a quantitative model for resilience.

The quantitative model is based on the application of a multi criteria analysis (MCA) method: the multi attribute utility theory (MAUT) as described by Goodwin and Wright.[2] In Seppälä et al.,[3] MAUT was compared with other types of MCAs like outranking methods as ELECTRE and PROMETHEE. They concluded, just as Aiello et al.,[4] Roy[5] and Figueira et al.,[6] that in outranking methods, a decision maker can express some or strong preference when alternatives are compared and when a set of alternatives has to be ranked. ELECTRE is regarded as a non-compensatory model that is unlike MAUT, where attributes can be viewed as scaling constants that relate to variations and changes to attribute levels (Rogers et al.[7]). Those scaling constants can have any value between 0 and 1 (Canbolat et al.[8]). Seppälä et al.[3] also suggest outranking methods like ELECTRE lack a strong theoretical foundation.

For the reason attributes can be used as scaling constants between 0 and 1, MAUT was the preferred

choice as MCA. It can be argued the attributes need to be independent of each other while in reality they may interact. According to Edwards and Fasolo,[9] taking this interaction into account enormously contributes to the elicitation load, while in reality the proposed user of the suggested MAUT approach is a basic level decision maker (DM) in a Dutch Emergency Response Safety Region. Edwards and Fasolo[9] argue taking interaction into account has little effect on the result. Hence, it was decided to use MAUT without taking any interaction between the attributes into account.

Objective

The main objective is to determine the intrinsic value "resilience" of a Dutch Emergency Response Safety Region. The following research questions were formulated.

- What, according to literature, is understood by the concept of "resilience"?
- In what way is this concept valid for a Dutch Emergency Response Safety Region?
- What are relevant key aspects determining "resilience"?
- Is a quantitative measure of "resilience" possible/feasible?

Concept of resilience

In literature many features are described with respect to resilience. Some of those features are used to construct the survey that underlies this study. Te Brake et al.[10] describe a major characteristic for resilience in relation to resilience of man "To sustain normal development despite long-term stress or adversity". Wildavsky[11] describes it as "The capacity to cope with unexpected dangers after they become manifest". Rutter[12] states "Resilience is the potential (of organizations and individuals) to adapt to changing circumstances in the face of adversity, and the ability to recover after a disaster or other traumatic event". Brouns et al.[13] give the following characteristic for resilience in relation to a network: "The social structure of a network determines resilience. In centralized networks, activity evolves around a small core group of people. For a more resilient and efficient community the network should become less centralized". Stolker[14] presents a generic approach to assess operational resilience. "The capabilities of operational resilience in an organization are defined as: the ability of an organization to prevent disruptions in the operational process from occurring; when struck by a disruption, being able to quickly respond to and recover from a disruption in operational processes". McManus et al.[15] and Seville[16] state "Resilience is a function of an organization's situation awareness; Management of keystone vulnerabilities and Adaptive capacity". They present a detailed description of the three items listed. They conclude "An organization with heightened resilience is able to quickly identify and respond to those situations that present potentially negative consequences and find solutions to minimize these impacts. Furthermore, resilience enables an organization to see opportunities in even the most difficult circumstances which may allow it to move forward even in times of adversity". Vargo and Seville[17] combine the data (resilience is a function of…) into a modified bow tie diagram that shows the basic features of resilience related to the stages of "reduction", "readiness", "response" and "recovery". Amaratunga et al.[18] define a concept of resiliency for the health care system: "The concept of resiliency, which emerged from ecology, is useful in examining the strength of the public health care system and its workers when exposed to the stress of a large-scale outbreak". "A resilient health care system is one that can adapt rapidly to increased demand for essential medical treatment and services. Resilience is defined as the capacity of health care workers to fulfill their emergency response functions". Bosher et al.[19] describe a more proactive disaster risk management (DRM) paradigm in relation to resilience: "The observed shift in the way disasters are being managed has been illustrated by the move away from the reactive attributes of disaster management towards the more proactive Disaster Risk Management (DRM) paradigm. "The United Nations' International Strategy for Disaster Reduction[20] has adopted a concept of DRM that can be summarized into four mutually interconnected phases being: 1. Hazard identification; 2. Mitigative adaptations; 3. Preparedness planning; and 4. Recovery (short -term) and reconstruction (longer -term) planning." According to Hollnagel et al.[21] resilience may be found on the left and right side of the undesirable event in the bow tie diagram.

From literature it is concluded the concept of "resilience" can be best described by the generic approach "operational resilience". The generic capability of operational resilience in an organization is defined as: the ability of an organization to prevent disruptions in the operational process from occurring; When struck by a disruption, being able to quickly respond to and recover from a disruption in operational processes.

To obtain and sustain these capabilities the following four items from literature are derived that are a function of an organization's operational resilience:

- situation awareness;
- management of keystone vulnerabilities;
- adaptive capacity;
- quality.

These items are defined by McManus et al.[15] and Seville[16] as "Situation Awareness is a measure of an organization's understanding and perception of its entire operating environment"; "Management of Keystone Vulnerabilities defines those aspects of an organization, operational and managerial, that have

the potential to have significant negative impacts in a crisis situation"; "Adaptive Capacity is a measure of the culture and dynamics of an organization that allow it to make decisions in a timely and appropriate manner both in day-to-day business and also in crises"; "Quality comprises Planning Strategies; Culture and Communication and Day-to-Day Resilience".

Methodology

On the internet a survey was designed based on a regular standardized format that was tested by a pilot group of 10 individuals randomly selected from the prospective group of respondents. The survey contained the following questions and statements.

1. Introduction to the survey.
2. Data that collects the title of the respondent.
3. Data that collects information about the type of employer of the respondent.
4. Statements to rank by the respondent (adapted from Rutter,[12] Stolker,[14] Te Brake et al.,[10] Wildawsky[11]). Objective: to determine definitions by relevance for resilience.
5. Statements to rank by the respondent (adapted from McManus et al.[15] and Seville[16]). Objective: to determine different factors describing awareness by relevance.
6. Statements to rank by the respondent (adapted from McManus et al.[15] and Seville[16]). Objective: to determine different factors describing keystone vulnerabilities by relevance.
7. Statements to rank by the respondent (adapted from McManus et al.[15] and Seville[16]). Objective: to determine different factors describing adaptive capacity by relevance.
8. Statements to rank by the respondent (adapted from Brouns et al.[13]). Objective: to determine by relevance two factors describing adaptation.
9. Statements to rank by the respondent (adapted from McManus et al.[15] and Seville[16]). Objective: to determine different factors describing quality by relevancy.
10. Remarks: a maximum number of ten remarks is possible in descending order of relevance.
11. Final: where the respondent is thanked and presented with the possibility to leave an email address in case the respondent is interested in the final report.

Owing to the nature of the research, higher ranking officials employed by safety regions, regional and municipal fire services, regional police services; district attorneys; fire service-related branch organizations/institutions, and regional and municipal medical services in The Netherlands were chosen as prospective respondents. From the municipalities, those were selected which have more than 100,000 inhabitants. In addition all (Lord) Mayors of the municipalities and the Chair of the Boards of Safety Regions were invited as well. A comprehensive list of 455 respondents was compiled from relevant available data.

Results

Survey response

In total 454 (100%) requests (total subset) to fill out the survey were sent by regular mail and 112 (24.7%) respondents (starter subset) started filling out the survey and 84 (18.5%) made it through the entire survey (final subset). Of these last respondents 45 (9.9% of the total subset and 53.6% of the final subset) left their email address on a voluntary basis to be used to send the final thesis. The survey was conducted anonymously, only IP addresses were collected to make certain no respondent would take more than one opportunity to fill out the survey. No such misuse was reported. In total, 29 (6.4% of the total subset and 25.9% of the starter subset) respondents aborted the survey at different questions or statements, no specific reason was given or could be determined. The collector was open for a period of 43 consecutive days.

Functional title of the respondent

As there are 25 Safety Regions in the Netherlands, 25 is the absolute response count for the first five mentioned titles, contrary to the other four titles that have no maximum (N/A = not applicable). Only one Coordinating Mayor filled out the survey and, therefore, is considered not to be representative for all Coordination Mayors, the result was added to "other". The category "other" contained a multitude of titles ($n = 39$), including an Alderman, District Attorneys, CEO's of Municipal Medical Departments, Operational Senior Fire Officers, CEO of a Branch Organization and Military Officers (Army), of which some were transferred to better suited groups. Owing to the heterogenic mix of titles, it was decided to combine the group "other" to one entity.

See the column "corrected response percentage" in Table 1 for the final result.

Identifying attributes

According to the results from the survey, the two most important identified attributes (these attributes make up the separate items of operational resilience as identified in literature and are labeled for the left side of the bow tie "reduction + readiness" and for the right side "response + recovery" according to Vargo and Seville[17] describing resilience $\boldsymbol{R_{ero}}$ are: (a) the potential (of organizations and individuals) to adapt to changing circumstances in the face of adversity, and the ability to recover after a disaster or other traumatic event; (b)

Table 1. Function of the respondent.

Functional title	Response percentage ($n = 113$)	Response percentage (max 100% = > 25)	Corrected response percentage ($n = 113$)
Coordinating Mayor/Chair Safety Region	0.9	4.0	N/A
Managing Director/Chief Executive Officer Safety Region	4.4	20.0	4.4
Regional Fire Chief Regional Fire Service	9.7	44.0	10.6
Chief Medical Officer Regional Safety Service	5.3	24.0	6.2
Chief of Regional Police	2.7	12.0	2.7
District Fire Chief Regional Fire Service	4.4	N/A	4.4
(Deputy) Fire Chief Municipal/local Fire Department	6.2	N/A	6.2
Manager	37.2	N/A	38.1
Other, please specify	34.5	N/A	32.7

the capacity to cope with unexpected dangers after they become manifest.

The two most important identified attributes describing resilience ($\boldsymbol{R_{awa}}$) as a function of awareness are: (a) the level of enhanced awareness of expectations, obligations and limitations in relation to the community of stakeholders, both internally (staff) and externally (customers, suppliers, consultants, etc.); (b) the ability to look forward for opportunities as well as potential crises.

The two most important identified attributes describing resilience ($\boldsymbol{R_{kv}}$) as a function of keystone vulnerabilities are: (a) individual managers, decision makers and subject matter experts; (b) relationships between key groups internally and externally.

The two most important identified attributes describing resilience ($\boldsymbol{R_{ac}}$) as a function of adaptive capacity are: (a) leadership and decision-making structures; (b) the degree of creativity and flexibility that the organization promotes or tolerates.

The two most important identified attributes describing resilience ($\boldsymbol{R_{q}}$) as a function of quality are: (a) the ability to adapt to changed situations with new and innovative solutions and/or the ability to adapt the tools that it already has to cope with new and unforeseen situations; (b) a greater awareness of itself, its keyholders and the environment with which it conducts business.

Modeling resilience

The preferences of the respondents were ranked and normalized and translated into weight factors, where the highest ranking has a weight of 1.0 and the lowest ranking a weight of 0.0 in arbitrary units (AU). The criteria within each separate set of definitions may be considered independent as respondents were forced to rank their preference. The sets may be dependent of each other as respondents were not asked to rank the sets. According to McManus et al.,[15] Vargo and Seville[17] and Seville[16] the following equations may be computed: resilience is defined by $\boldsymbol{R_{ero}}$

$$\boldsymbol{R_{ero}} = (1.00\mathrm{c} + 0.20\mathrm{a} + 0.10\mathrm{d})_{\text{Reduction + Readiness}} + (0.70\mathrm{b} + 0.30\mathrm{e})_{\text{Response + Recovery}} \quad (1)$$

where $\boldsymbol{c}$ is the potential (of organizations and individuals) to adapt to changing circumstances in the face of adversity, and the ability to recover after a disaster or other traumatic event; $\boldsymbol{a}$ is the sustenance of normal development despite long-term stress or adversity; $\boldsymbol{d}$ is the readiness of an organization before the shock or disruptive event; $\boldsymbol{b}$ is the capacity to cope with unexpected dangers after they become manifest; and $\boldsymbol{e}$ is the response of the organization after the disruption has struck. This is an additive function of the left and right side of the bow tie as both sides are regarded as of equal weight to the concept of resilience (Vargo and Seville[17]).

Resilience is a function of Awareness $\boldsymbol{R_{awa}}$

$$\mathrm{R_{awa}} = (1.00\mathrm{k} + 0.95\mathrm{f} + 0.60\mathrm{i} + 0.45\mathrm{g} + 0.10\mathrm{h})_{\text{Reduction + Readiness}} + (0.10\mathrm{j})_{\text{Response + Recovery}} \quad (2)$$

where $\boldsymbol{k}$ is the level of enhanced awareness of expectations, obligations and limitations in relation to the community of stakeholders, both internally (staff) and externally (customers, suppliers, consultants, etc.); $\boldsymbol{f}$ is the ability to look forward for opportunities as well as potential crises; $\boldsymbol{i}$ is the level of increased awareness of the resources available both internally and externally; $\boldsymbol{g}$ is the ability to identify crises and their consequences accurately; $\boldsymbol{h}$ is the level of enhanced understanding of the trigger factors for crises; and $\boldsymbol{j}$ is the level of better understanding of minimum operating requirements from a recovery perspective.

Resilience is a function of keystone vulnerabilities $\boldsymbol{R_{kv}}$

$$\boldsymbol{R_{kv}} = (1.00\boldsymbol{n} + 0.80\boldsymbol{o} + 0.70\boldsymbol{p} + 0.35\boldsymbol{m} + 0.25\boldsymbol{l} + 0.10\boldsymbol{q})_{\boldsymbol{Reduction + Readiness}} \quad (3)$$

where $\boldsymbol{n}$ is the level of importance of individual managers, decision makers and subject matter experts; $\boldsymbol{o}$ is the level of relationships between key groups internally and

externally; p is the level of importance of communication structures; m is the level of importance of computers, services and specialized equipment; l is the level of importance of buildings, structures and critical supplies; and q is the level of perception of the organizational strategic vision.

Resilience is a function of adaptive capacity R_{ac}

$$R_{ac} = (1.00r + 0.80t + 0.10s)_{Reduction + Readiness} \quad (4)$$

where r is the level of importance of leadership and decision making structures; t is the degree of creativity and flexibility that the organization promotes or tolerates; and s is the level of importance of the acquisition, dissemination and retention of information and knowledge.

Resilience is a function of quality R_q

$$R_q = (1.00w + 0.50u) \quad (5)$$

where w is the level of ability to adapt to changed situations with new and innovative solutions and/or the ability to adapt the tools that it already has to cope with new and unforeseen situations; and u is the level of greater awareness of itself, its key holders and the environment with which it conducts business.

The function of resilience on the defined items can be described as

$$f(R_{ero}) = R_{ero}\left(R_{awa} + R_{kv} + R_{ac} + R_q + \varepsilon\right) \quad (6)$$

where ε is the unspecified data and items that are also a function of resilience.

Maximum resilience $f(R_{ero})_{\max}$ is achieved when R_{awa}; R_{kv}; R_{ac}; R_q; ε and R_{ero} are all as high as possible. It should be noted a high score for R_{ero} alone is no guarantee the resilience of an emergency response organization is good as well. The latter is also dependent on good scores with awareness; keystone vulnerabilities; adaptive capacity and quality that are all part of REDUCTION and READINESS before the event takes place.[17] $f(R_{ero})$ may also, owing to its nature, be defined as dynamic operational resilience of a Dutch Emergency Response Safety Region as it dynamically describes the actual state of resilience of the organization.

Quantifying resilience

Stolker[14] uses a value tree based on the MAUT developed by Goodwin and Wright[2] to measure the operational resilience management performance index $\mathbf{PI}_j$, which may be considered similar to the postulated dynamic operational resilience index. The term utility *an sich* is not correctly used because utility is mostly referred to in order to deal with uncertainty; Goodwin and Wright,[2] cited in Stolker.[14] A better term is "value" instead of "utility". However, value and utility can be used in the same manner according to Weil and Apostolakis[22] as cited in Stolker,[14] and therefore utility is designated in this article as "utility value", which measures performance of the respective attribute (like the performance of w and u that are attributes of quality R_q). When MAUT is applied to the findings of this study a value tree according to Figure 2 may be constructed, Van Trijp.[23]

It is assumed R_{ero}; R_{awa}; R_{kv}; R_{ac}; R_q and ε have a weight factor equal to 1.00. The undetermined utility values (small spheres in Figure 2) can be assessed individually for each unique Emergency Response Safety Region by auditing this organization. In general when an attribute is fully implemented and operational a score of 100% is assessed and the related utility value = 1.00. An assessed score of 45% gives a utility value of 0.45, etc.

When adding utility values (UV) to equation (6) the following may derived

$$f(\mathrm{R_{ero}})_{\mathrm{UV}} = (\mathrm{R_{ero}})_{\mathrm{UV}}\left(\mathrm{R_{awa}} + \mathrm{R_{kv}} + \mathrm{R_{ac}} + \mathrm{R_q} + \varepsilon\right)_{\mathrm{UV}} \quad (7)$$

where $f(R_{ero})_{UV}$ is the unique dynamic operational resilience of an Emergency Response Safety Region; and UV is the utility value.

It is clear from the designed value tree maximum achievable dynamic operational resilience is reached when all utility values equal 1.00.

When ε is nullified

$$f(R_{ero})_{max} = 22.31\,\mathrm{AU} \quad (8)$$

where $f(R_{ero})_{max}$ is the maximum achievable dynamic operational resilience.

In reality, such a score will not be realized as it can readily be imagined no Emergency Response Organization scores 100% on all attributes. For quick scan purposes to determine dynamic operational resilience in case of an Emergency Response Organization like a Safety Region; it is suggested to use a simplified version of equation (7) by just assessing the two most important items containing attributes with the highest weight factor

$$f(R_{ero})_{QSmax} = 11.99\mathrm{AU} \quad (9)$$

where $f(R_{ero})_{QSmax}$ is the maximum achievable dynamic operational resilience by quick scan, which is 53.72 % of $f(R_{ero})_{max}$. Hence, taking all uncertainties into account, it is proposed to use the quick scan approach and multiply the computed result by a factor of two to obtain the unique dynamic operational resilience $f(R_{ero})_{UV}$ of a Dutch Emergency Response Safety Region. The advantage of using the quick scan is a lower administrative burden combined with a shorter time consumption establishing resilience: a less expensive approach.

Sensitivity analysis

Sensitivity analysis of the proposed model in quick scan mode is performed by varying the input on the most important variables (variables with the highest weight factors) in $f(R_{ero})_{UV}$ equation (7) in quick scan mode

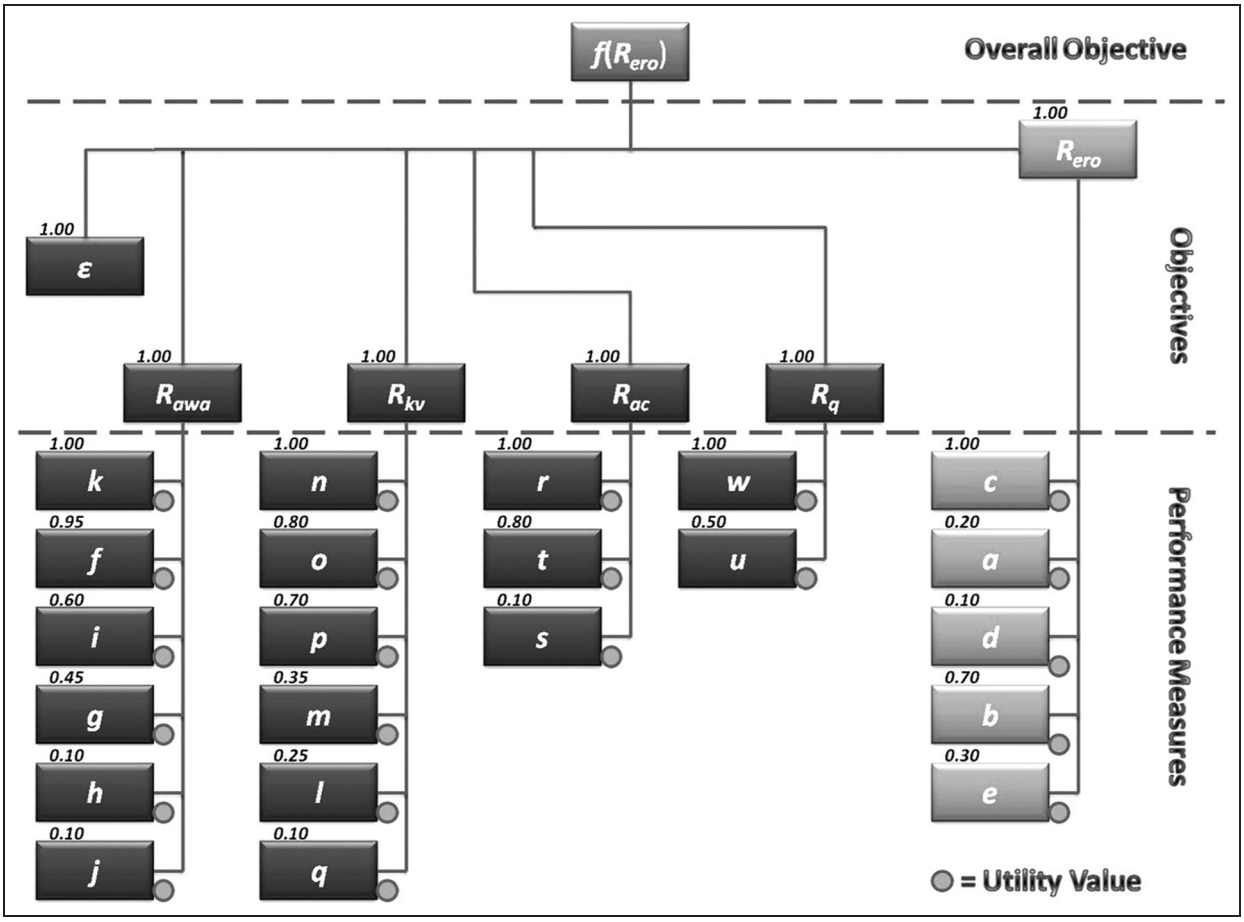

Figure 2. Value tree describing dynamic operational resilience $f(R_{ero})$ with weight factors (figures) and undetermined utility values (spheres). Maximum achievable dynamic operational resilience is reached when all utility values equal 1.00. When ε is nullified: $f(R_{ero})_{max}$ = 22.31 AU; $f(R_{ero})_{max}$ = maximum achievable dynamic operational resilience.
Source: Reproduced with permission from Van Trijp et al.[23]

Table 2. Sensitivity Analysis of $f(R_{ero})_{UV}$ equation (7) in quick scan mode.

Attribute	Average $f(R_{ero})_{UV}$ AU	Standard deviation σ AU	95% confidence limits $f(R_{ero})_{UV} \pm 2\sigma$ AU
c	8.77	1.97	4.93–12.71
b	9.57	1.42	6.73–12.41
k, n, r, w	11.10	0.50	10.10–12.10
f	11.13	0.46	10.21–12.05
o, t	11.06	0.41	10.24–11.88
u	11.52	0.26	11.00–12.04

where $f(R_{ero})_{QSmax}$ = 11.99 AU. According to the US Environmental Protection Agency[24] a good approach may be to use a Monte Carlo simulation. All utility values of the attributes in the equation are set to 1.00, except for the attribute that is investigated in the range 0.00–1.00. A total of 100 simulations were run and the average, standard deviation $\boldsymbol{\sigma}$ and the average at the 95% confidence level were calculated. The results showed attributes ***c*** (the potential (of organizations and individuals) to adapt to changing circumstances in the face of adversity, and the ability to recover after a disaster or other traumatic event) and ***b*** (the capacity to cope with unexpected dangers after they become manifest) present the greatest variations in output while ***u*** (the level of greater awareness of itself, its key-holders and the environment with which it conducts business) presents the smallest variation in output, see Table 2.

Comparison of the invited subset of experts and the subset of respondents

When the composition of the subset of respondents (experts) was compared with the composition of the invited original set of experts, the following may be noted (Table 3).

Table 3. Comparison of the composition of the invited subset of experts and the subset of respondents.

Functional title	Percentage composition of the invited original set of experts ($n = 454$)	Percentage composition of the subset of respondents ($n = 113$)	Corrected percentage composition of the subset of respondents ($n = 113$)
Coordinating Mayor/Chair Safety Region	5.5	0.9	N/A
Managing Director/Chief Executive Officer Safety Region	5.5	4.4	4.4
Regional Fire Chief Regional Fire Service	5.5	9.7	10.6
Chief Medical Officer Regional Safety Service	11.0	5.3	6.2
Chief of Regional Police	5.5	2.7	2.7
District Fire Chief Regional Fire Service	3.7	4.4	4.4
(Deputy) Fire Chief Municipal/local Fire Department	6.6	6.2	6.2
Manager	38.1	37.2	38.1
Other, please specify	17.2	34.5	32.7
Total Fire Service	59.4	61.9	63.7

Based on the presented results in Table 3, it is concluded the subset of respondents is valid for Fire Service officials, including the Managing Director/Chief Executive Officer Safety Region. Of the respondents with the functional title of "Manager" 90.8% belong to a Fire Service, hence increasing the reliability of the result from a Fire Service focal point. In The Netherlands, Safety Regions consist mainly out of a Regional Fire Service as the Regional Medical Service is relatively small in comparison; exact figures are not available but the organization chart of the *Veiligheidsregio Utrecht – VRU*, or Safety Region Utrecht, presents a good indication.[25] This was also confirmed in a personal conversation with one Regional Fire Chief not belonging to the VRU (2010). Hence, it is concluded the subset of respondents is representative for the whole original set of experts of a Safety Region. In hindsight, it would have been sufficient to question Fire Service experts only.

Discussion

The desired $f(R_{ero})_{UV}$ is a different factor for each Emergency Response Organization, or in the Dutch situation, a Safety Region. This factor is influenced by the risks that are located in the Safety Region. These risks can be categorized in a risk matrix[26] where the vertical line indicates the level of impact and the horizontal line indicates the probability of risk. The higher the impact of the risk, the more resilient an Emergency Response Safety Region should be to cope with the incident at hand: the impact of the risk should not exceed the load limit of the organization as described by the functional resonance model according to Ale,[27] cited from Hollnagel.[28] The unique dynamic operational resilience $f(R_{ero})_{UV}$ should focus on "high impact, low probability risks" and "high impact, high probability risks" from the risk matrix as they have the greatest impact on the organization and its resilience. It is assumed a risk with a low impact is covered as well when high impact risks can be coped with. When the impact or load exceeds the load limit or $f(R_{ero})_{UV}$ of an Emergency Response Safety Region; loss of resilience or "the capability to react adequately" of this organization starts to occur. Safety Regions are required by Dutch law to make an inventory of all the risks involved in their Region: risk profile. From this inventory an assessment of high impact risks and probabilities should be made. The Safety Region can use this assessment in comparison with their own unique dynamic operational resilience $f(R_{ero})_{UV}$ factor to decide whether it is capable or not to deal with the identified risks, and consequently, it should and/or is able to increase operational resilience or not. First, linking equation (7) to the derived risk profiles of all Dutch Emergency Response Safety Regions is needed to validate and normalize equation (7).

Hence, the derived unique dynamic operational resilience factor is proposed after validation and normalization to be an invaluable decision support tool for (chief) executives of a Dutch Emergency Response Safety Region, in order to proactively assess and optimize resilience of their organization with respect to identified risks.

In Ulieru,[29] the concept of a self-organizing security (SOS) network is introduced. This network acts as a resilient architectural foundation on which an operational mechanism can be evolved for Emergency Response Organizations that have to react to emerging crises. This concept is a model (simulation test bed) based upon the design of holistic security ecosystems.[30,31] These holistic security ecosystems act as an operational layer enabling the deployment of dynamic, short living emergency response organizations capable of reacting quickly to emerging crisis situations and which possess a certain resemblance with the interconnected phases of DRM according to Bosher et al.[19] who suggest a DRM needs to be holistic. It is postulated by Ulieru[29] that sharing an overall operational picture through a reliable communications backbone within a holistic security ecosystem provides for a harmonious inter-organizational coordination between emergency response organizations and/or stakeholders.

As such, achieving a total effect greater than the sum of the individual parts when response to emerging crisis is concerned.

Within the described concepts of holistic security ecosystems and self-organizing security network, it should be of importance that the individual nodes in these ecosystems and networks (the emergency response organizations and/or stakeholders) possess a minimum amount of operational resilience (unique dynamic operational resilience $f(R_{ero})_{UV}$) to function properly within the network as such and as a whole.

Hence, it is proposed in addition to proactively assessing and optimizing resilience of an Emergency Response Organization with respect to identified safety risks; to consider defining a minimum $f(R_{ero})_{UV}$ for an Emergency Response Organization as part of the development of a SOS network.

In the Netherlands Branch Organization of Fire Services, NVBR,[32] in 2008 a project "Aristoteles" under the supervision of the Council of Regional Fire Chiefs was started to define a large number of organizational impact indicators to assess the current organizational status of the Regional Fire Service and the Regional Medical Service of a Dutch Emergency Response Safety Region. All indicators are collected and represented in a dashboard design with so-called "traffic light" colors: "green" (equal or above the norm, no additional attention needed); "orange" (almost equal to the norm, but requires additional attention) and "red" (fails to comply with the norm, urgent attention needed). When observing the norm established for the different indicators and the relevant cited literature, no link could be found with the actual risk profile in the Safety Region at hand.[33] All presented indicators and norms are based on a combination of Expert Judgment, Laws and Branch Guidelines presenting the risk of using a set of indicators that may be open to subjective judgment of emergency response officials and/or members of the board (i.e. of a Safety Region). Another identified risk of the Aristoteles approach may be the possibility of performance enhancement of the organization of an emergency response organization as an identified goal as such, instead as a means of creating an emergency response organization that performs up to standards. Up to standards means in relation with the actual risk profile in the region.

In this article it is suggested "the derived unique dynamic operational resilience factor is proposed to be an invaluable decision support tool for (chief) executives of a Dutch Emergency Response Safety Region, in order to proactively assess and optimize resilience of their organization with respect to identified risks", which gives a direct link with the actual risk profile. It means every Emergency Response Safety Region has a unique value for its resilience that is independent of some of the identified risks of the "Aristoteles" approach and solely depends on objective information. When the derived resilience factor is compared with "Aristoteles" it may be seen as additional to the data from "Aristoteles", but as mentioned earlier, the resilience factor has the distinct advantage of presenting management data unique to the Dutch Emergency Response Safety Region in combination with the risk profile.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgments

The corresponding author wishes to thank Pauline Laumans for providing excellent administrative support regarding the distribution of the survey invitation. I would also like to thank Jan Beuving, (Division Chief Operations and Preparations, Fire Department of Leeuwarden) and Paul Pattynama (Regional Fire Chief, Regional Fire Service Brabant-Noord) with whom I had fruitful discussions about the implications of my findings with respect to a (Regional) Fire Service and Safety Region.

Conflict of interest statement

The Authors declare that there is no conflict of interest.

References

1. Van Trijp JMP, Ulieru M and van Gelder PHAJM. Quantitative approach of organizational resilience for a Dutch emergency response safety region. In: Bérenguer, Grail & Guedes Soares (eds) *Advances in safety, reliability and risk management. Proceedings of the European safety and reliability conference, ESREL 2011*, Troyes, France, 18–22 September 2011, pp.173–180. London: Taylor & Francis Group, 2012.
2. Goodwin P and Wright G. *Decision analysis for management judgment*. Chichester: John Wiley and Sons, 2004. Available from http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470714395.html (2004, accessed 29 March 2010).
3. Seppäla J, Basson L and Norris GA. Decision analysis frameworks for life-cycle impact assessment. *J Ind Ecol* 2002; 5(4): 45–68.
4. Aiello G, Enea M and Galante G. A multi-objective approach to facility layout problem by genetic search algorithm and Electre method. *Robotics and Computer-Integrated Mfg* 2006; 22: 447–455.
5. Roy B. The outranking approach and the foundations of ELECTRE methods. *Theory and Decision* 1991; 31(11): 49–73.
6. Figueira J, Mousseau V and Roy B. ELECTRE methods. In: *Multiple criteria decision analysis: state of the art surveys*. International Series in Operations Research & Management Science, 2005; 78(III): pp.133–153.
7. Rogers M and Bruen M. A new system for weighting environmental criteria for use within ELECTRE III. *Eur J Opl Res* 1998; 107: 552–563.

8. Canbolat YB, Chelst K and Garg N. Combining decision tree and MAUT for selecting a country for a global manufacturing facility. *Omega* 2007; 35: 312–325.
9. Edwards W and Fasolo B. Decision technology. *Annu Rev Psychol* 2001; 52: 581–606.
10. Te Brake H, van de Post M and de Ruijter A. Resilience from concept to practice – the balance between awareness and fear; citizens and resilience, impact. Amsterdam: Dutch knowledge and advice centre for post-disaster psychosocial care, 2008.
11. Wildavsky A. Playing it safe is dangerous. *Regulatory Toxicol Pharmacol* 1988; 8(3): 283–287.
12. Rutter M. Resilience in the face of adversity: Protective factors and resistance to psychiatric disorder. *Br J Psychiatry* 1985; 147: 598–611.
13. Brouns F, Berlanga AJ, Van Rosmalen P, et al. *ID8.16 – Policies to stimulate self-organisation and the feeling of autonomy in a network*. Heerlen: Open University of the Netherlands, TENCompetence. Available from http://hdl.handle.net/1820/1944 (2009, accessed 10 August 2009).
14. Stolker RJM. A generic approach to assess operational resilience. Eindhoven: Technische Universiteit Eindhoven (TUE), Capaciteitsgroep Quality and Reliability Engineering (QRE). Available from http://library.tue.nl/catalog/LinkToVubis.csp?DataBib=6:639658 (2008, accessed 10 August 2009).
15. McManus S, Seville E, Brunsdon D, et al. Resilience management, resilient organizations research report 2007/01, 2007. Available from http://www.resorgs.org.nz/images/stories/pdfs/resilience%20management%20research%20report%20resorgs%2007-01.pdf (accessed 25 September 2012).
16. Seville E. The goal of resilient organizations. Keynote presentation. In: *Business continuity institute summit*, Brisbane. http://www.resorgs.org.nz. (2009, accessed 25 September 2012)
17. Vargo J and Seville E. Crisis strategic planning: finding the silver lining. In: *World conference on disaster management*, Toronto ON. http://www.resorgs.org.nz. (2008, accessed 25 September 2012).
18. Amaratunga CA, Carter M, O'Sullivan TL, et al. Lessons learned from Canada: the imperative to build a culture of preparedness for health care providers as first responders. In: *i-Rec 2008*, Christchurch, 2008.
19. Bosher L, Dainty A, Carrillo P, et al. A proactive multi-stakeholder approach to attaining resilience in the UK. In: *i-Rec 2008*, Christchurch, 2008.
20. UN/ISDR. 2004. International strategy for disaster reduction, living with risk: a global review of disaster reduction, 2004 version. Geneva: UN Publications.
21. Hollnagel E, Woods DD and Leveson N. *Resilience engineering, concepts and precepts*. Farnham: Ashgate Publishing Limited, 2006.
22. Weil R and Apostolakis G. A methodology for the prioritization of operating experience in nuclear power plants. *Rel Engng Sys Saf* 2001; 74: 23–42.
23. Van Trijp J. *An attempt to quantify resilience of emergency response organizations – results from a large scale survey among safety stakeholders in the Netherlands*. MSc thesis, Delft TopTech/Delft University of Technology, Delft, Netherlands, 2010. Utrecht, Netherlands: Libertas in Vivo vof.
24. US Environmental Protection Agency. Guidance on the development, evaluation, and application of environmental models. Washington DC: Council for Regulatory Environmental Modeling US Environmental Protection Agency. Available from http://www.epa.gov/CREM/library/cred_guidance_0309.pdf (2009, accessed 2 April 2010).
25. VRU. Organizational Chart, Utrecht, Netherlands (in Dutch). http://www.vru.nl/vruinontwikkeling/index.php?option=com_docman&task=doc_download&gid=137&Itemid=43 (2009, accessed 16 March 2012)
26. JISC Infonet. UK: Northumbria University. http://www.jiscinfonet.ac.uk/InfoKits/infokit-related-files/risk-matrix-pic/view (2009, accessed 11 August 2009).
27. Ale BJM. Risk: an introduction – the concepts of risk, danger and chance. 1st ed. New York, NY: Routledge, 2009, pp.28.
28. Hollnagel E. *Barriers and accident prevention*. Farnham: Ashgate Publishing Limited, 2004. Available from http://www.ashgate.com/isbn/9780754643012 (accessed 29 March 2010).
29. Ulieru M. Enabling the SOS network. In: *Proceedings of the IEEE SMC 2008 conference*, Singapore. Available from http://www.theimpactinstitute.org/Publications/Ulieru-Formatted-Final-sos.pdf (2008, accessed 25 September 2012).
30. Ulieru M. A complex systems approach to the design and evaluation of holistic security ecosystems. In: *International conference on complex systems*, Boston, MA. Available from http://www.theimpactinstitute.org/Publications/Boston-submitted.pdf (2007, accessed September, 2012).
31. Ulieru M. Towards holistic security ecosystems, Opening Keynote Address and Invited Tutorial Lecture. In: *3rd IEEE international conference on digital ecosystems and technologies (IEEE-DEST 2009)*, Istanbul. Available from http://www.theimpactinstitute.org/Publications/Keynote-Reformatted.pdf (2009, accessed 25 September 2012).
32. NVBR. Project Aristoteles. Arnhem, Netherlands: Nederlandse Vereniging voor Brandweerzorg en Rampenbestrijding (in Dutch). Available from http://www.nvbr.nl/wat_doen_we/thema-optimale/aristoteles/ (2010, accessed 25 September 2012) and http://www.brandweerkennisnet.nl/bovenbalk/zoeken/@7456/prestatiemeting_en/ (2010, accessed 25 September 2012).
33. NVBR. Handreiking Regionaal Risicoprofiel. Arnhem, Netherlands: Nederlandse Vereniging voor Brandweerzorg en Rampenbestrijding (in Dutch). http://www.nvbr.nl/algemene_onderdelen/bovenbalk/zoeken/@7306/handreiking/ (2009, accessed 25 September 2012).

Appendix

Notation

a	sustenance of normal development despite long-term stress or adversity
b	capacity to cope with unexpected dangers after they become manifest
c	potential (of organizations and individuals) to adapt to changing circumstances in the face of adversity, and the ability to recover after a disaster or other traumatic event

d	readiness of an organization before the shock or disruptive event
e	response of the organization after the disruption has struck
f	ability to look forward for opportunities as well as potential crises
$f(R_{ero})$	dynamic operational resilience of an emergency response organization
$f(R_{ero})_{max}$	maximum achievable dynamic operational resilience of an emergency response organization
$f(R_{ero})_{QSmax}$	maximum achievable dynamic operational resilience of an emergency response organization using the quick scan method
$f(R_{ero})_{UV}$	unique dynamic operational resilience of an emergency response organization dependant on utility values UV
g	ability to identify crises and their consequences accurately
h	level of enhanced understanding of the trigger factors for crises
i	level of increased awareness of the resources available both internally and externally
j	level of better understanding of minimum operating requirements from a recovery perspective
k	level of enhanced awareness of expectations, obligations and limitations in relation to the community of stakeholders, both internally (staff) and externally (customers, suppliers, consultants etc.)
l	level of importance of buildings, structures and critical supplies
m	level of importance of computers, services and specialized equipment
n	level of importance of individual managers, decision makers and subject matter experts
o	level of relationships between key groups internally and externally
p	level of importance of communication structures
PI_j	operational resilience management performance index for organization j
q	level of perception of the organizational strategic vision
r	level of importance of leadership and decision making structures
R_{ac}	level of adaptive capacity of an emergency response organization
R_{awa}	level of awareness of an emergency response organization
R_{ero}	level of resilience of an emergency response organization
R_{kv}	level of importance of keystone vulnerabilities of an emergency response organization
R_q	level of quality of an emergency response organization
s	level of importance of the acquisition, dissemination and retention of information and knowledge
t	degree of creativity and flexibility that the organization promotes or tolerates
u	level of greater awareness of itself, its key-holders and the environment with which it conducts business
UV	utility value of an attribute in a value tree
w	level of ability to adapt to changed situations with new and innovative solutions and/or the ability to adapt the tools that it already has to cope with new and unforeseen situations
ε	level of unspecified data and items which are also a function of resilience