Quantitative approach of organizational resilience for a Dutch emergency response safety region

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ABSTRACT:

Resilience of an Emergency Response Organization 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 "Resilience" in case of a Dutch Emergency Response Safety Region. In this study it is concluded that according to literature 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* $\boldsymbol{f(R_{ero})_{UV}}$ factor. A simplified approach of *Unique Dynamic Operational Resilience* is suggested by using a Quick Scan method to speed up the process of assessment.

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 October 1, 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 is formed by the Regional Fire Service which in its turn is a body made created by fused Municipal Fire Departments. A huge shift in political responsibility has occurred as local mayors have lost their direct control over the originally local Fire Departments. In some parts of the country, a debate is still running whether this is the proper cause to follow. In other parts this regionalization has already taken place or is underway. a Safety Region has to: Provide better protections of civilians from risks; Offer better emergency management and aftercare during disasters and crises; Act during emergencies as one administrative organization which 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". This paper explores the concept of resilience from literature and as determined from a survey by relevant Dutch Safety stakeholders and presents a quantitative approach for resilience.

Objective

The main objective is to determine the intrinsic value "Resilience" in case of a Dutch Emergency Response Safety Region. The following preliminary objectives were formulated: What is according to literature 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 which underlies this study. Te Brake *et al* (2008) describe as major characteristic for resilience "to sustain normal development despite long-term stress or adversity." This characteristic was formulated in relation to resilience of man. Wildavsky (1988) describes it as follows: "The capacity to cope with unexpected dangers after they become manifest". Rutter (1985) 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* (2009) give the following characteristic for resilience in relation to a network: "The social structure of a network determines resilience. In centralized networks, activity evolve around a small core group of people. For a more resilient and efficient community the network should become less centralized." Stolker (2008) 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* (2007) and Seville (2009) 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 (2008) combine the data (Resilience is a function of…) into a modified Bow Tie diagram which show the basic features of resilience related to the stages of "reduction", "readiness", "response" and "recovery". Amaratunga *et al* (2008) 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. In the context of this paper, resiliency is defined as the capacity of health care workers to fulfill their emergency response functions. Health care worker resiliency depends on the cumulative effects of biological, environmental, and social health determinants and the interactions among them. Stakeholders in emergency response include law enforcement, the armed forces, all levels of government, health care workers and their organizations, academic researchers and many others." Bosher *et al* (2008) 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 that should be 'mainstreamed' into developmental initiatives. The United Nations' International Strategy for Disaster Reduction (UN/ISDR 2004) 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* (2006) 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 capabilities 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 which are a function of an organization's Operational Resilience:

-Situation Awareness; -Management of Keystone Vulnerabilities; -Adaptive Capacity and -Quality.

Methodology

On the Internet a survey was designed based on a regular standardized format which was tested by pilot group of 10 individuals randomly selected from the prospective group op respondents. The survey contained questions and statements: 1.Introduction to the survey; 2. Data which collects the title of the respondent; 3.Data which collects information about the type of employer of the respondent; 4. Statements to rank by the respondent (adapted from Rutter, 1985; Stolker, 2008; Te Brake *et al*, 2008; Wildawsky, 1988). Objective is to determine definitions by relevance for Resilience; 5. Statements to rank by the respondent (adapted from McManus *et al*, 2007 and Seville, 2009). Objective is to determine different factors describing Awareness by relevance; 6. Statements to rank by the respondent (adapted from McManus *et al*, 2007 and Seville, 2009). Objective is to determine different factors describing Keystone vulnerabilities by

relevance; 7. Statements to rank by the respondent (adapted from McManus *et al*, 2007 and Seville, 2009). Objective is to determine different factors describing Adaptive capacity by relevance; 8. Statements to rank by the respondent (adapted from Brouns *et al*, 2009). Objective is to determine by relevance two factors describing Adaptation; 9. Statements to rank by the respondent (adapted from McManus *et al*, 2007 and Seville, 2009). Objective is to determine different factors describing Quality by relevancy; 10. Remarks, a maximum number of ten remarks is possible in descending order of relevancy; 11. Final where the respondent is thanked and presented with the possibility to leave an e-mail address in case the respondent is interested in the final report.

Due 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 the those were selected which all 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 e-mail 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.

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 Bowtie "Reduction + Readiness" and for the right side "Response + Recovery" according to Vargo and Seville (2008) describing Resilience $\boldsymbol{R_{ero}}$ are: -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; -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: -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.); -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: -Individual managers, decision makers and subject matter experts; -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: -Leadership and decision making structures; -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: -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; -A greater awareness of itself, its key-holders 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* (2007), Vargo and Seville (2008) and Seville (2009) the following equations may be computed: Resilience is defined by $\boldsymbol{R_{ero}}$:

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

where 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; a = The sustenance of normal development despite long-term stress or adversity; d = The readiness of an organization before the shock or disruptive event; b = The capacity to cope with unexpected dangers after they become manifest; and e = The response of the organization after the disruption has struck. This is an additive function of the left and right side of the Bowtie as both sides are regarded as of equal weight to the concept of Resilience (Vargo and Seville, 2008).

Resilience is a function of Awareness R_{awa}:

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

where k = 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.); f = The ability to look forward for opportunities as well as potential crises; i = The level of increased awareness of the resources available both internally and externally; g = The ability to identify crises and their consequences accurately; h = The level of enhanced understanding of the trigger factors for crises; and j = The level of better understanding of minimum operating requirements from a recovery perspective.

Resilience is a function of Keystone Vulnerabilities R_{kv}:

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

where n = The level of importance of Individual managers, decision makers and subject matter experts; o = The level of relationships between key groups internally and externally; p = The level of importance of communication structures; m = The level of importance of computers, services and specialized equipment; l = The level of importance of buildings, structures and critical supplies; and q = 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 = The level of importance of leadership and decision making structures; t = The degree of creativity and flexibility that the organization promotes or tolerates; and s = 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 = 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 = 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:

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

where ε = unspecified data and items which 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 which are all part of REDUCTION and READINESS before the event takes place (Vargo and Seville, 2008). $f(R_{ero})$ may also due to its nature be defined as Dynamic Operational Resilience of a Dutch Emergency Response Safety Region as it dynami-

cally describes the actual state of resilience of the organization.

Quantifying Resilience

Stolker (pp. 46, 2008) uses a Value Tree based on the Multi-Attribute Utility Theory (MAUT) developed by Goodwin & Wright (2004) 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 & Wright, 2004, cited in Stolker, 2008). A better term is "value" instead of "utility". However, value and utility can be used in the same manner according to Weil & Apostolakis (2001) as cited in Stolker (2008), and therefore utility is designated in this paper as "Utility Value" which measures performance of the respective attribute (like the performance of $\boldsymbol{w}$ and $\boldsymbol{u}$ which are attributes of Quality $\boldsymbol{R_q}$). MAUT is chosen over other multi-criteria decision methods as we investigated a finite set of alternatives. When MAUT is applied to the findings of this study a value tree according to figure 1 may be constructed (Van Trijp, 2010).

It is assumed $\boldsymbol{R_{ero}}$; $\boldsymbol{R_{awa}}$; $\boldsymbol{R_{kv}}$; $\boldsymbol{R_{ac}}$; $\boldsymbol{R_q}$ and $\boldsymbol{\varepsilon}$ have a Weight Factor equal to 1.00. The undetermined Utility Values (spheres in figure 1) 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 etcetera).

When adding Utility Values ($\boldsymbol{UV}$) to equation (6) the following equation (7) may derived:

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

where $\boldsymbol{f(R_{ero})_{UV}}$ = Unique Dynamic Operational Resilience of an Emergency Response Safety Region; and $\boldsymbol{UV}$ = Utility Value.

It is clear from the designed Value Tree Maximum Achievable Dynamic Operational Resilience is reached

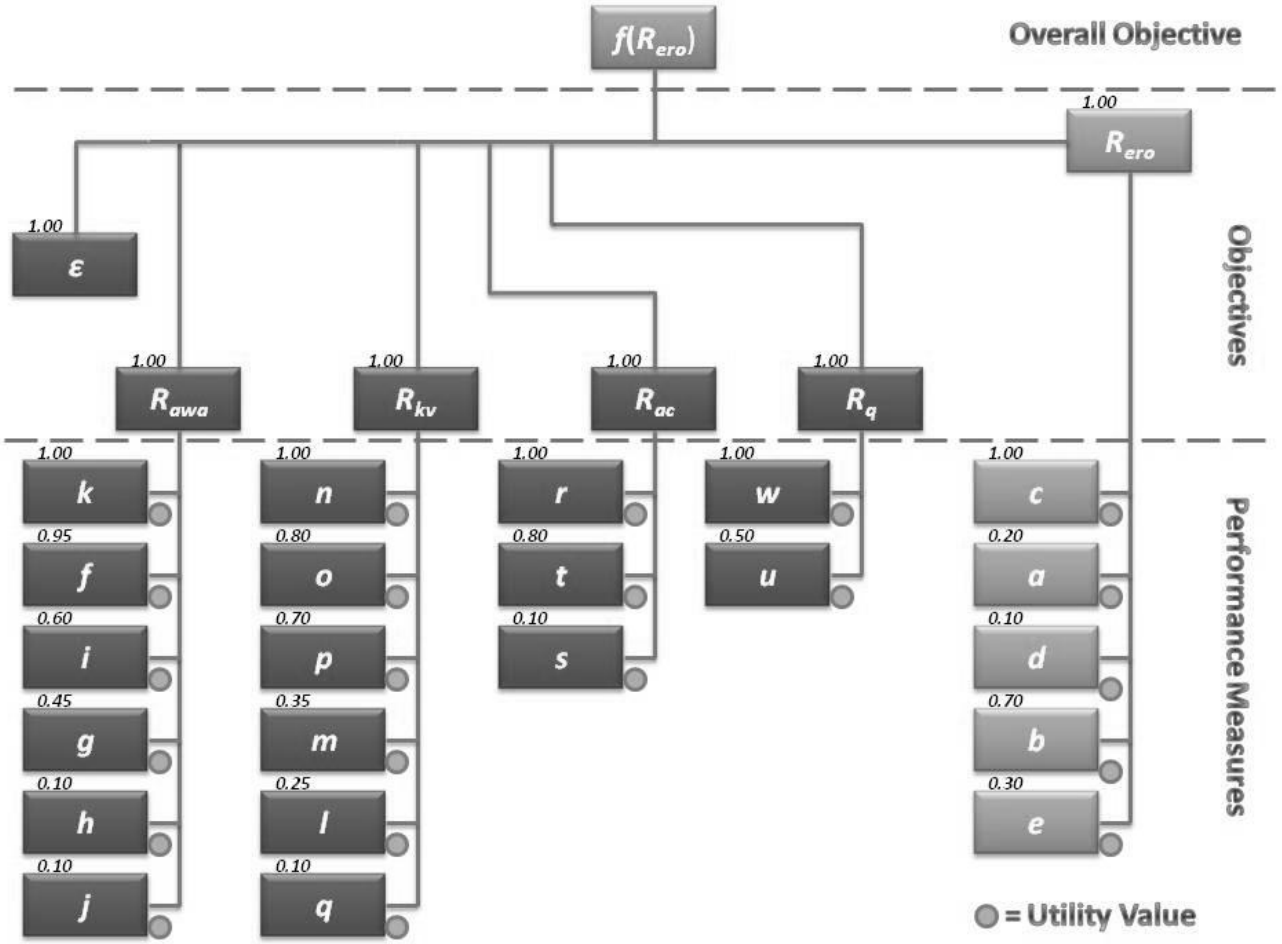

Figure 1. Value Tree describing Dynamic Operational Resilience $\boldsymbol{f(R_{ero})}$ with Weight Factors (figures) and undetermined Utility Values (spheres). Maximum Achievable Dynamic Operational Resilience is reached when all Utility Values equal 1.00. When $\boldsymbol{\varepsilon}$ is nullified: $\boldsymbol{f(R_{ero})_{max}}$ = 22.31 AU; $\boldsymbol{f(R_{ero})_{max}}$ = Maximum Achievable Dynamic Operational Resilience.

when all Utility Values equal 1.00.

When ε is nullified:

$$f(R_{ero})_{max} = 22.54 \text{ AU} \quad (8)$$

where $f(R_{ero})_{max}$ = 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:

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

where $f(R_{ero})_{QSmax}$ = Maximum Achievable Dynamic Operational Resilience by Quick Scan.

which is 53.19 % 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 is performed by varying the input on the most important variables (variables with the highest Weight Factors) in $f(R_{ero})_{UV}$ (7) in quick scan mode where $f(R_{ero})_{QSmax}$ = 11.99 AU. According to the U.S. Environmental Protection Agency (2009) 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 which is investigated in the range 0.00 – 1.00. A total of 100 simulations was run and the average, standard deviation σ 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 1.

Table 1. Sensitivity Analysis of $f(R_{ero})_{UV}$ (7) in quick scan mode.

Attribute	Average in AU	
	$f(R_{ero})_{UV}$	$f(R_{ero})_{UV}$ +/- 2σ
c	8.77	7.93 – 12.71
b	9.57	6.73 – 12.41
k, n, r, w	11.10	10.10 – 12.10
f	11.13	10.21 – 12.05
o, t	11.06	10.24 – 11.88
u	11.52	11.00 – 12.04

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 which are located in the Safety Region. These risks can be categorized in a Risk Matrix (JISC Infonet, 2009) 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

(pp.28, 2009; cited from Hollnagel, 2004). 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.

By Ulieru (2008) the concept of 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 which have to react to emerging crises. This concept is a model (simulation test bed) based upon the design of Holistic Security Ecosystems (Ulieru, 2007 and 2009). 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 Disaster Risk Management (DRM) according to Bosher *et al* (2008) who suggest a DRM needs to be holistic. It is postulated by Ulieru 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 Holistic Security Ecosystems and Self-Organizing Security network, it should be of importance 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 Self-Organizing Security (SOS) network.

By the Netherlands Branch Organization of Fire Services, NVBR, (NVBR, 2010) 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 (NVBR, 2009). 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 which 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 which performs up to standards. Up to standards means in relation with the actual Risk Profile in the region.

In this paper 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 which 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 to "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.

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