Use of safety-related indicators in resilience assessment of Smart Critical Infrastructures (SCIs)

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ABSTRACT

This paper tackles the issue of proactively using safety-related indicators in resilience assessment of critical infrastructures in the European project SmartResilience. The project addresses the assessment of resilience by means of resilience indicators. The paper describes a new, advanced, resilience assessment methodology, which takes into account the vulnerability and early risk warnings of Smart Critical Infrastructures. The methodology is based on the identification of existing and new smart resilient indicators, providing the possibility to assess and monitor the resilience over the phases of the resilience cycle ("Understand Risk", "Anticipate/prepare", "Absorb/Withstand", "Respond/recover, and "Adapt/learn"). The results presented in the paper suggest that the safety-related indicators are of particular importance for the phases "Understand Risk" and "Anticipate/prepare". The indicators from the sources usual in the area of safety are adapted to the needs of resilience assessment and inserted into the SmartResilience database of indicators.

1 INTRODUCTION

The prevention of accidents and ensuring safety has for a long time being focused on technical issues and one of the ways for achieving this goal has been the introduction and use of the safety performance indicators. To this end, different guidelines help in the identification and reporting of safety indicators, such as e.g. OECD (2003), ANSI/API RP 754 (2008), CCPS (2007), and OGP (2011). However, the safety related interest in recent years is more and more including the resilience aspects and these considerations necessarily lead to the question: "Which indicators one can or should use for assessing resilience?."

The issue is in the focus of the EU supported project SmartResilience (Smart Resilience Indicators for Smart Critical Infrastructures, Grant Agreement No. 70062). The project focuses on the development of a new methodology allowing to derive resilience indicators and use them for resilience assessment. The methodology is to be applied to Critical Infrastructures (CIs) which use smart technologies to enhance their performance and quality of service (The SCIs – Smart Critical Infrastructures). In addition, the methodology being developed in the project considers that the events challenging these SCIs can potentially be the emerging (new) risks.

The first results of the project are the resilience curve concept, the resilience matrix (resilience cycle vs the resilience dimensions) and the methodology.

In particular, this paper explores the suitability of process safety indicators to measure resilience of SCIs. Here, the indicators from process safety are used to assess resilience to the city of Pančevo (Serbia). The city contains an industry area with multiple SCIs such as chemical production plants and a refinery, subjected to possible threats such as terrorist attacks, cyber-attacks and/or natural disasters. Preliminary results of the application of the SmartResilience methodology suggest that safety indicators can be useful for each phase of the resilience cycle. The safety indicators seem to be of particular importance during the first two phases: Understand risk and Anticipate/Prepare (Fig.1). The indicators help to measure whether an organization is able to identify what could the "adverse event" be and what kind of measures are needed to prepare to such events. However, in order to guarantee overall resilience of the critical infrastructure additional indicators are needed to efficiently cover also the remaining phases.

2 RESILIENCE CONCEPT

In SmartResilience Project, resilience of an infrastructure is defined as "*the ability to anticipate possible adverse scenarios/events (including the new/emerging ones) representing threats and leasing to possible disruptions in operations/functionality of the infrastructure, prepare for them, withstand/absorb their impacts, recover from disruptions caused by them and adapt to the changing conditions*" (Jovanovic et al. 2016a). Based on this definition the new approach proposed is built upon the five phases of the resilience cycle containing: Understand risks, Anticipate/Prepare, Absorb/Withstand, Respond/Recover and Adapt/Learn (Fig. 1).

The Phase Understand risks, analyzes the SCI prior to an adverse event. It emphasizes the emerging risks and includes their early identification and monitoring. This is followed by the phase Anticipate/Prepare, also looking at the time before the occurrence of an adverse event. It includes planning and proactive adaptation strategies, possibly also "smartness in preparation". The phase Absorb/Withstand, is the one during the initial phase of the adverse event and it includes the vulnerability analysis and the possible cascading/ripple effects; e.g. "how steep" is the absorption curve, and "how deep" down will it go? The phase Respond/ Recover, is related to the question "how steep" is the recovery and normalization of the functionality. It is followed by phase Adapt/Learn looking at the post event recovery. It encompasses all kinds of improvements made on the infrastructure and its environment; e.g. affecting "how well" the infrastructure is adapted after the event. The activities in this phase also lead to preparation for the future events and hence, this resilience curve also exhibits a reoccurring cycle (Jovanovic et al. 2016b).

Further, the activities and events can be analyzed along five "resilience dimensions" thus forming the 5×5 resilience matrix shown in Figure 2.
The dimensions are system/physical, information/data, organization/business, societal/political, and cognitive/decision-making. The dimensions provide additional help in identifying and categorizing the indicators.

<table>
<tr><th>Phases →→→
vs.
Dimensions
↓↓↓</th><th>A. Understand Risks</th><th>B. Anticipate / Prepare</th><th>C. Absorb / Withstand</th><th>D. Respond / Recover</th><th>E. Adapt / Learn</th></tr>
<tr><td>a. System / Physical</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>b. Information / Data</td><td></td><td colspan="3" rowspan="3">5×5</td><td></td></tr>
<tr><td>c. Organizational / Business</td><td></td><td></td></tr>
<tr><td>d. Societal / Political</td><td></td><td></td></tr>
<tr><td>e. Cognitive / Decision-Making</td><td></td><td></td><td></td><td></td><td></td></tr>
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Figure 2. Resilience Matrix: Phases of the resilience cycle and resilience dimensions

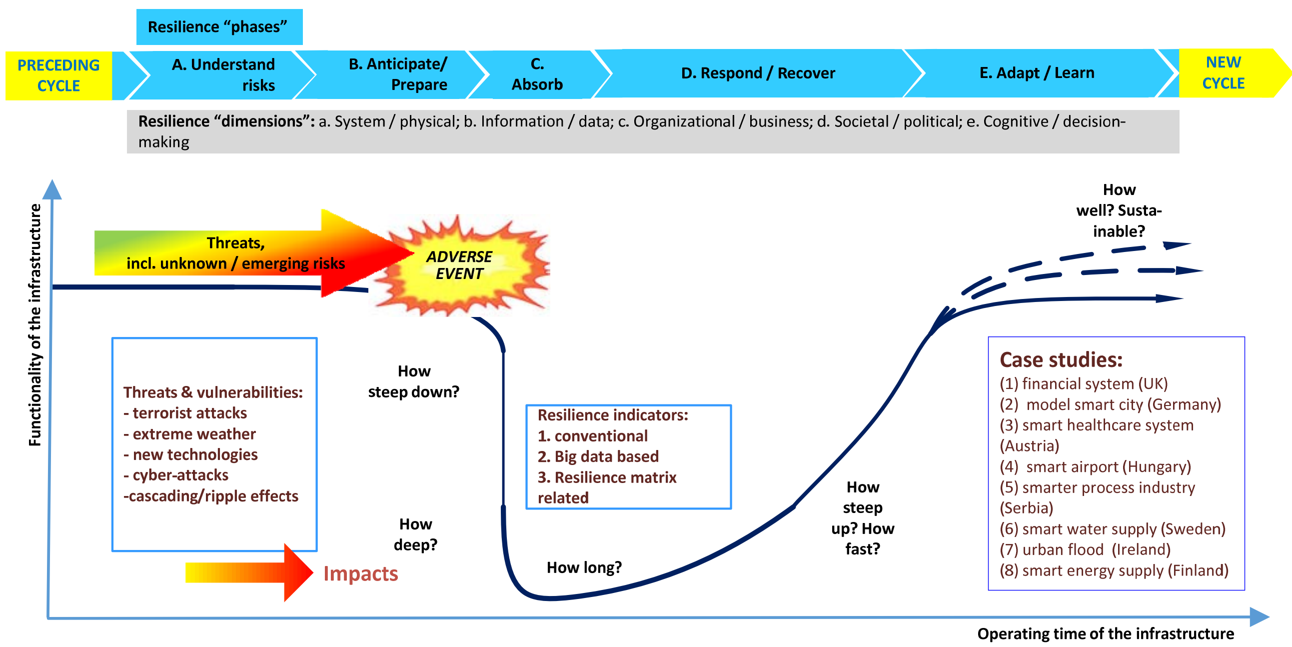

Figure 1. Resilience UV curve in SmartResilience project

3 RESILIENCE INDICATORS

The resilience indicators in the project are identified for all the phases of the resilience cycle and can potentially be based on:

1. Indicators not specifically envisaged as resilience indicators, possibly already accepted and applied in related areas, such as risk, safety, business continuity, sustainability, e.g. those proposed by OECD, GRI, API, HSE, IAEA and other organizations;
2. New resilience indicators proposed by experts (the "conventional" indicators), including those proposed in standards;
3. New resilience indicators that can be derived out of Big Data and Open Data.

As the other indicators also the resilience indicators can be, supervised or unsupervised, lagging or leading, basic or more sophisticated, more or less dynamic. Each of the above types of the resilience indicators might provide useful support to the overall resilience assessment.

4 ASSESSMENT METHODOLOGY

The methodology developed in the SmartResilience project is based on several methods proposed previously, such as the Argonne method (Fisher, 2010), the Leading Indicators of Organizational Health (LIOH) method (EPRI, 2001), and the Resilience-based Early Warning Indicator (REWI) method Øien, K., Massaiu, S., & Tinmannsvik, R. (2012). Further details can be found in the works of Øien, (2010, 2011a, 2011b, 2013), (Øien, & Nielsen, 2012).

The methodology to assess the resilience of Smart Critical Indicators uses the leveled approach. For each of the phases, the issues are identified, and indicators to measure those issues are developed. The three lowest levels in the SmartResilience structure are phases, issues and indicators (Jovanovic et al. 2016b). Further, the issues (and corresponding indicators) are structured according to five dimensions, also presented in Figure 3. The practical values of indicators in the SmartResilience methodology are defined in the case studies in the project.

In addition to the three lower levels of the structure, i.e. phases, issues and indicators, the overall structure consists of three more levels. Starting from the top, is the area level, e.g. a city or smart city, for which the degree of "smartness" will differ, but the assessment methodology applies for all cases. The second level consists of the critical infrastructures (CIs), and the third level deals with the threats. The overall structure of the SmartResilience methodology is illustrated in Figure 3.

The SmartResilience methodology is deliberately kept as simple, transparent and easily understandable as possible. Thus, there is reluctance to add additional levels or crosscutting topics, which would increase the complexity. The six-level structure allows also to address the specific aspects such as:

1. How to deal with the Information & Communication Technology (ICT) infrastructure as an overarching infrastructure,
2. How to deal with cascading effects, interdependencies and interactions, and finally,
3. How to deal with the potential vulnerability and opportunities of smart features being increasingly introduced in critical infrastructures (Jovanovic et al. 2016b).

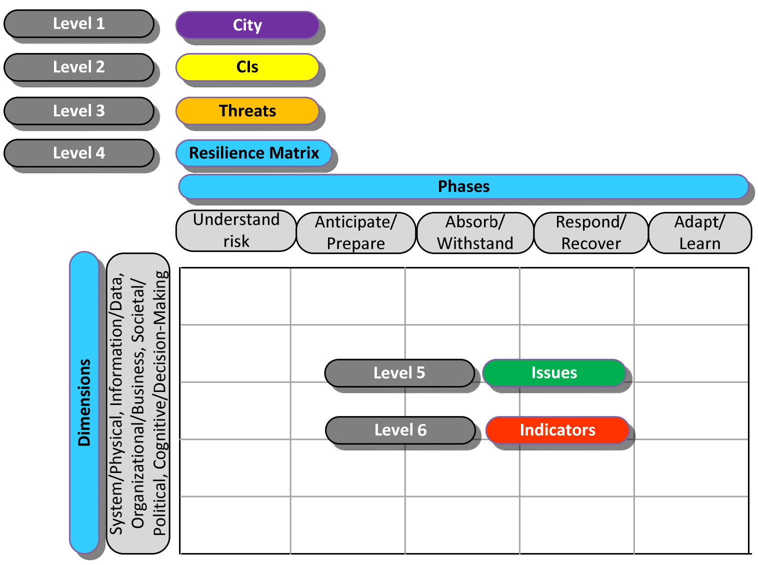

Figure 3. Basic outline of the SmartResilience methodology

Some particular issues such as the ICT ones may affect several infrastructures, and they need to be explicitly addressed. Cascading effects are treated as a specific type of threat. Smart features ("smartness") of critical infrastructures are included explicitly as smartness vulnerability and smartness opportunity on the issue level.

The SmartResilience method steps are:

Step 1. Select the area, e.g. a smart city – *Level 1*

Step 2. Select the relevant critical infrastructures (CIs) for the area – *Level 2*

Step 3. Select relevant threats for each critical infrastructure – *Level 3*

Step 4. Consider each phase for each threat – *Level 4*

Step 5. Define the issues within each phase – *Level 5*

Step 6. Search for the appropriate indicators for each issue – *Level 6*

Step 7. Determine the range of values (best and worst estimate) for each indicator

Step 8. Assign values to the indicators

Step 9. Perform the assessment (e.g. by calculating the score(s))

Step 10. Use results for e.g. comparison, benchmarking and "stress-testing"

The assessment of resilience can be performed for an entire city or some other area, for one or more critical infrastructures, and for one or more threats. The term "scenario" is used here, for a specific selection of critical infrastructures and threats for a given area/city, i.e. the selected area, critical infrastructures and threats.

Steps 1-6 are selections and considerations related to the six levels of the methodology as explained previously. Steps 7-10 are related to the calculations and the use of the results.

The indicators in the SmartResilience methodology, can be of different types such as yes/no questions meaning that they can be yes/no questions, numbers, percentages, portions, etc. Their real values, are collected and transformed to a *score* (or rating) on a scale from 0 to 5.

At every level, there is a possibility to give *weights*. However, it is recommended to be restrictive with the use of different weights as this will lead to less transparent calculations and results.

When performing the resilience assessment, the indicators real values are entered into the calculation (Step 8), and the issue scores are obtained as average weighted scores of the indicator scores. Thus, also issues (level 5) are measured using scores on a scale from 1 to 5, similar as the indicators (level 6). It is also possible to let a specific indicator overrule the effect of the other indicators, i.e. having "knock out indicators" where, in the case of a low value, the effect is not "averaged away" through an average weighted score of all the indicators.

On the next higher level (level 4 – phases), the scores are transformed to a scale from 0 to 10, providing *resilience levels*. This scale is kept from phases and upwards, i.e. for threats (level 3), critical infrastructures (level 2) and areas (level 1).

The reasoning behind the selected scales is that a scale from 0 to 5 for indicators (and issues) are sufficiently broad, especially if there are needs to perform expert judgments to provide scores for the indicators (or directly for the issues) in case of lack of data (Øien, 2001). This is similar to the use of safety integrity levels (SIL) for safety instrumented systems (IEC 61508, 2010), only using integer values from 0 to 4.

The calculation is performed in a database and the assessment for the given case/scenario is saved (Step 9). In step 10, the results can be used for comparison, benchmarking and “stress-testing”.

5 APPLICATION CASE: ASSESSING RESILIENCE OF AN INDUSTRIAL ZONE

The case study is developed for the City of Pančevo with its Southern Industrial Zone. The industrial zone encompasses a nitrogen fertilizer factory (HIP Azotara Pančevo a.d.), a petrochemical plant (HIP-Petrohemija a.d. Pančevo) and the NIS Oil Refinery Pančevo. The oil refinery is located in the immediate vicinity to the city of Pančevo (about 120,000 inhabitants) and near the eastern banks of the River Danube. The refinery is considered as a (smart) production/supply critical infrastructure.

The main goal of the case study is to test the Smart Resilience methodology in deriving indicators which measure the level of resilience of a city containing SCIs (Industrial production plants). In order to understand the influence of the individual industrial sites to the overall city resilience, it is necessary to evaluate the resilience of the single infrastructures and then apply appropriate methods for analyzing dependencies and interdependencies.

The safety indicators currently used in the NIS Oil Refinery Pančevo have been explored. The indicators used currently follows mainly the OGP approach (OGP, 2011). The OGP is used for benchmarking towards other industries.

Resilience indicators derived on the basis of the OGP approach are managed and maintained in the company by the security and safety department.

6 PRELIMINARY APPLICATION RESULTS

In the project, the methodology has been preliminary applied to the industrial zone in Serbia in order to calculate the Resilience Index according to the principle setup shown in Figure 4.

The *Level 1* of the methodology corresponds to the Pančevo city, the *Level 2* relates the critical infrastructures present in the city: NIS Oil refinery, fertilizer factory (HIP Azotara), petrochemical plant (HIP Petro-Hemija). The relevant threats considered for the *Level 3* are then the terrorist attack, cyber-attack and extreme weather conditions. Under each of these threats, the resilience phases are analyzed. Under each phase, the sample issues and indicators are identified for the *Level 4 and 5* of the methodology respectively:

Phase 1: Understand Risk
- *Issue:* Hazard Identification and Risk Analysis
  - *Indicator:* Incidents with risk assessment as a route cause (CCPS, 2009)
  - *Indicator:* Number of updates and revisions of the Risk Register (oil refinery)
- *Issue:* Integrity of Assets
  - *Indicator:* Remaining life time of the assets (oil refinery)
  - *Indicator:* Inspection, testing and maintenance activities completed on schedule (CCPS, 2009)

Phase 2: Anticipate /Prepare
- *Issue:* Emergency response
  - *Indicator:* Number of drills conducted with local emergency responders (CCPS, 2009), (oil refinery)
  - *Indicator*: Cooperation with state authority (oil refinery)
- *Issue:* Training
  - *Indicator*: Percentage of employees trained in emergency plans (IAEA, 2000)
  - *Indicator*: Percentage of errors due to deficiency in training (IAEA, 2000)

Phase 3: Absorb/withstand
- *Issue:* Safety/security by design
  - *Indicator*: Alternates and back-ups for electric power (Petit et al. 2013)
- *Issue:* Operation of safety equipment
  - *Indicator*: Number of times safety alarms activates (oil refinery)
  - *Indicator*: Number of times emergency shutdown system activates (oil refinery)

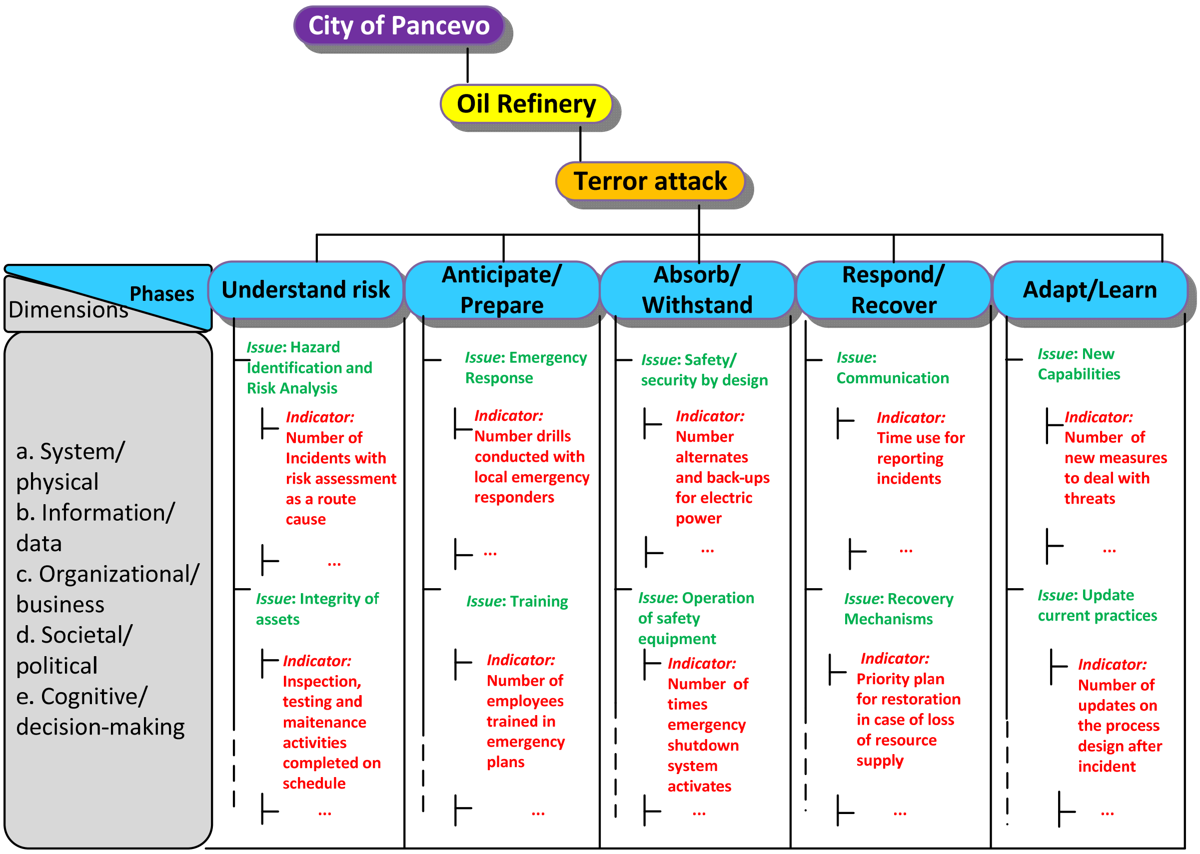

Figure 4. Preliminary results

- *Indicator*: Number of times safety valves activates (oil refinery)

Phase 4: Respond/recover

- *Issue:* Communication
  - *Indicator*: Time used for reporting incidents (oil refinery)
- *Issue:* Recovery mechanisms
  - *Indicator*: Time to re-start operations after a shutdown (oil refinery)
  - *Indicator*: Priority plan for restoration in case of loss of resource supply (Petit et al. 2013)
  - *Indicator*: Entities to support facility restoration (Petit et al. 2013)

Phase 5: Adapt Learn

- *Issue:* New capabilities
  - *Indicator*: Number of new measures to deal with threats (Petit et al. 2013)
  - *Indicator*: Training based on lessons learnt (oil refinery)
- *Issue:* Update current practices
  - *Indicator*: Number of updates on the process design after incident
  - *Indicator*: Number of updates in procedures based on incidents

Currently around 70 indicators have been selected to be used in the SmartResilience methodology. An excerpt from the complete list is shown in the Table 1. An example of how some of the process safety indicators are used further in the methodology is shown in Table 2. For each of the indicators selected from safety sources and other sources, an adaptation towards resilience is made and, consequently, the range of values (best and worst) are determined. Values are assigned to the indicators which are finally quantitatively aggregated to calculate the resilience index.

The indicators developed in the project are stored in the database and will be used in the methodology as shown in Figure 5.

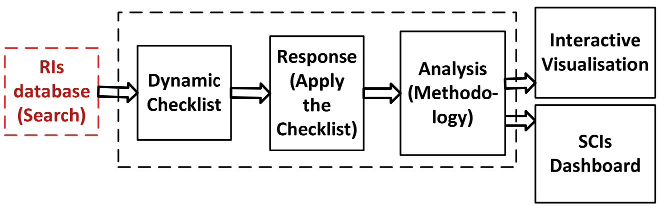

Figure 5. Specifying the resilience indicators database

Table 1 Preliminary list of indicators

#	Reference	Resilience Indicator
1.	CCPS	Number of incidents with risk assessment as a route cause
2.	CCPS	Inspection, testing and maintenance activities completed on schedule
3.	CCPS	Number of errors during simulation training
4.	CCPS	Number of drills conducted with local emergency responders
5.	Internal Indicators	Number of updates and revisions of the Risk Register
6.		Remaining life time of the assets
7.		Cooperation with state authority
8.		Number of times safety alarms activates
9.		Number of times emergency shutdown system activates
10.		Number of times safety valves activates
11.		Time used for reporting incidents
12.		Training based on lessons learnt
13.		Number of updates on the process design after incident
14.		Number of updates in procedures based on incidents
15.	API 581	Resilience policy documented and applied?
16.	API 581	Resilience-related responsibility are clearly defined?
17.	API 581	Training for resilience management in place?
18.	API 581	General & specific resilience training procedures exist?
19.	API 581 /ANL	Emergency control center designated & operational?
20.	API 581 & ANL	Personnel assigned to contact for emergency plan?
21.	API 581 /ANL	Incident investigation procedures include?
22.	IAEA	Percentage of employees trained in emergency plan?
23.	IAEA	Percentage of events due to deficiency in procedures?
24.	ANL	Business continuity training conducted for personnel?

Table 2 An example of the use of safety indicators in SmartResilience

Source	Safety indicator	Resilience indicator	Details of the indicator	Phase
CCPS	Number of incidents with risk analysis/assessment as a root cause of the incident	Number of Incidents with risk assessment as a route cause	Are there incidents with risk assessment as a root caused recorded? What is the percentage of events with risk assessment as a root cause *High:* less than equal to 39% of the events *Medium*: between 40-69% of the events *Low:* between 70- 100% of the events *No record*	Understand risk
CCPS	Percentage of sites that conducted a drill with local emergency responders during the year	Number drills conducted with local emergency responders	Are the regular drills conducted with local emergency responders? How often the regular drills are conducted to evaluate and reinforce the emergency plan? *High:* once/ month *Medium:* once/ 6 months *Low:* once/ 1 year *Never*	Anticipate/Prepare
CCPS	Number of errors during simulation training	Percentage of errors due to deficiency in simulation training?	Are the errors due to deficiency in training recorded? What are the percentage of errors recording in simulator? *High:* less than 5% *Medium:* between 5-10% *Low:* more than 20% *No record*	Anticipate/Prepare

CONCLUSIONS

For quite some time it seemed that the areas of risk/safety, on one side, and resilience on the other side would stay apart and independent – the risk/safety analysis considering the probability of the event and the resilience analysis issuing that the event takes place, no matter the probability. In other words, to improve safety "one should try to reduce the probability of an adverse event first", in order to improve resilience "one should improve the absorb/recover capacity first".

But, on the level of practical actions, especially for the industrial plants such as chemical plants or refineries, it becomes evident that similar activities lead to both reduction of the probability and improvement of resilience. This is clearly reflected on the level of the indicators: both the safety related indicators and the resilience ones are based on the similar activities and can be used in both safety and resilience assessment. The most prominent examples are the improvement of organizational measures and/or training. In addition, the work performed here was confirmed that the main "open issues" is not that much the "choice of right indicators", but rather "ensuring that the selected indicators are providing complete and realistic picture of the resilience of the infrastructure.

7 ACKNOWLEDGMENTS

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