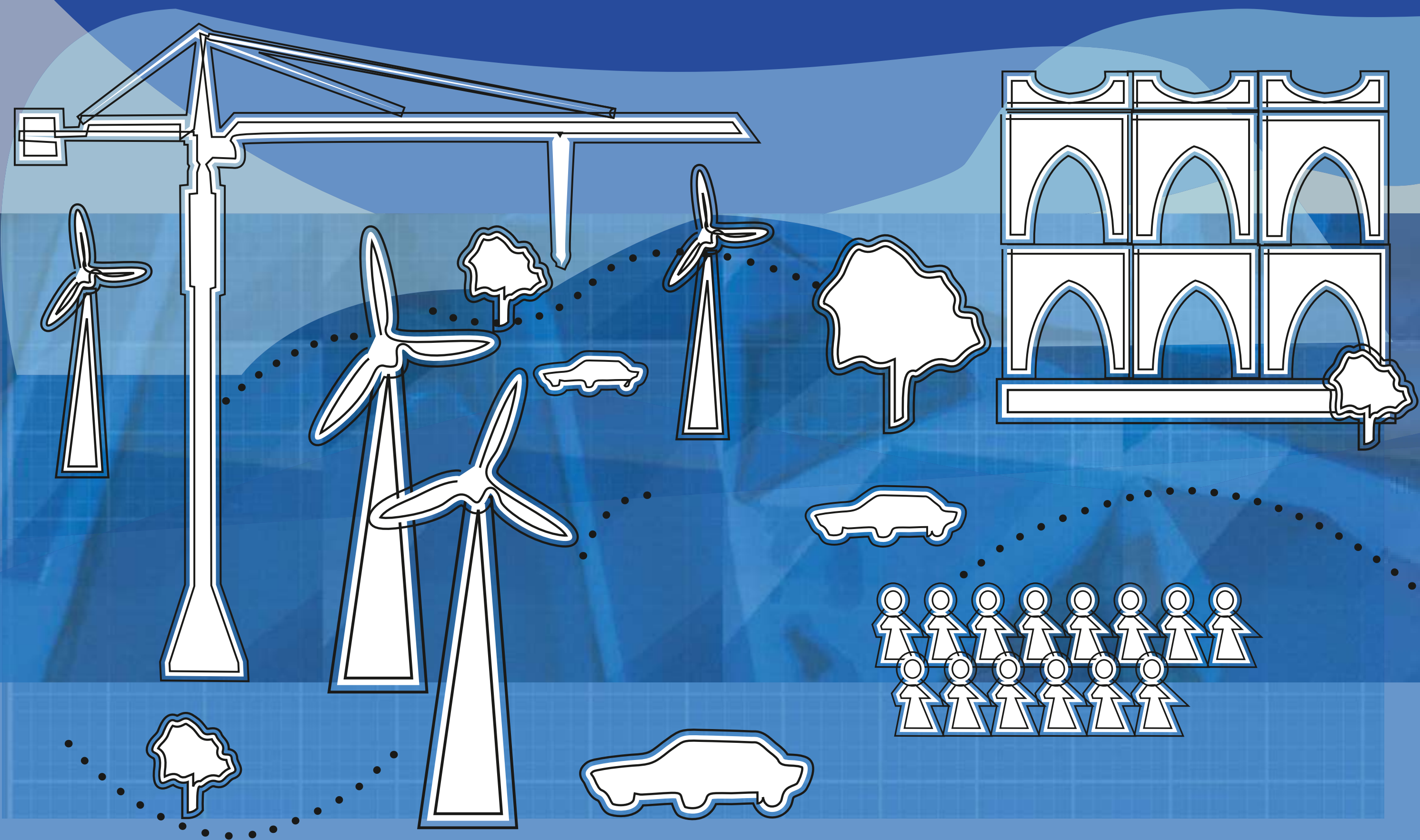
European Commission

RESILIENCE

The 2nd International Workshop on Modelling of Physical, Economic and Social Systems for Resilience Assessment

14-16 December 2017
Ispra



Joint Research Centre

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Luxembourg: Publications Office of the European Union, 2017

Print	ISBN 978-92-79-74443-3	doi:10.2760/379177	KJ-04-17-951-EN-C
PDF	ISBN 978-92-79-74444-0	doi:10.2760/556714	KJ-04-17-951-EN-N
EPUB	ISBN 978-92-79-74445-7	doi:10.2760/761297	KJ-04-17-951-EN-E

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International workshop on Modelling of Physical, Economic and Social Systems for Resilience Assessment

The Joint Research Centre of the European Commission in close collaboration with NIST (National Institute of Standards and Technology, US Department of Commerce) and Colorado State University organised the **2nd International Workshop on Modelling of Physical, Economic and Social Systems for Resilience Assessment on 14–16 of December 2017.**

It followed the 1st International Workshop on Modelling of Physical, Economic and Social Systems for Resilience Assessment which took place in Washington, DC on 19-21 of October 2016, and was organised by NIST and Colorado State University.

Interest in resilience has been rising rapidly during the last twenty years, both among the policy makers and academia, as a response to increasing concern about the potential effect of shocks to individuals, civil infrastructure, regions, countries and social, economic and political institutions. The objective of the workshop was to bring together the scientific community and policy makers towards developing better policies and practices incorporating the element of resilience in various fields.

The JRC therefore is building on previous experience acquired during the JRC and the European Political Strategy Centre (EPSC) annual conference "Building a Resilient Europe in a Globalised World" which took place in September 2015. This workshop was aimed at identifying strategic needs and providing an outlook of future policy making actions.

This 2nd International Workshop in 2017 aimed at building on the experience gained from these previous events focusing both on the high-level strategic needs and on the current scientific advances on modelling of physical, economic and social systems. The primary goal was to explore how these are linked in order to support resilience assessment in various dimensions aiming to:

- Bring together the most up-to-date knowledge in the field of resilience across different disciplines.
- Establish the dialogue between policy and research with a two-fold scope: to provide scientific advice and support for policies that incorporate the element of resilience, and to provide guidance to the scientific community on the knowledge and tools needed to support current and future policies.

- Contribute towards establishing a coherent resilience assessment framework for communities and societies.
- Identify the constituents for measuring the resilience at various scales (local, regional, national, international) towards establishing the necessary indicators.
- Establish a long-standing partnership among the key actors in the area of resilience at global level that will support the continuous development of models that fit into the assessment framework and consequently the respective training curricula.

The following dimensions were covered:

- Resilience of technological systems (e.g. electricity, gas, water, transport) that provide essential services to citizens during normal conditions as well as during crises.
- Resilience of the built environment, thus civil engineering structures that need to guarantee a certain level of functionality both in terms of safety as well as in terms of business continuity and socioeconomic services that are supported by these buildings.
- Resilience of communities and societies to cascading effects that propagate across infrastructures and networks of infrastructures.
- Economic and societal resilience of modern societies and communities during shocks but also to longer term adaptations.
- Resilience of individuals, depending on social and economic contexts, as well as inter-dependency relationships between individuals and the rest of the society (being communities or national institutions) with respect to risk assessment, risk mitigation and post-crisis recovery.
- Resilience to changes brought about by population growth, utilization requirements, and environmental conditions.

The Organizing Committee thanks all contributors for submitted research papers, which feed into future work on resilience modelling.

The Resilient Bow-tie and Decision-Making under Uncertainty

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Abstract

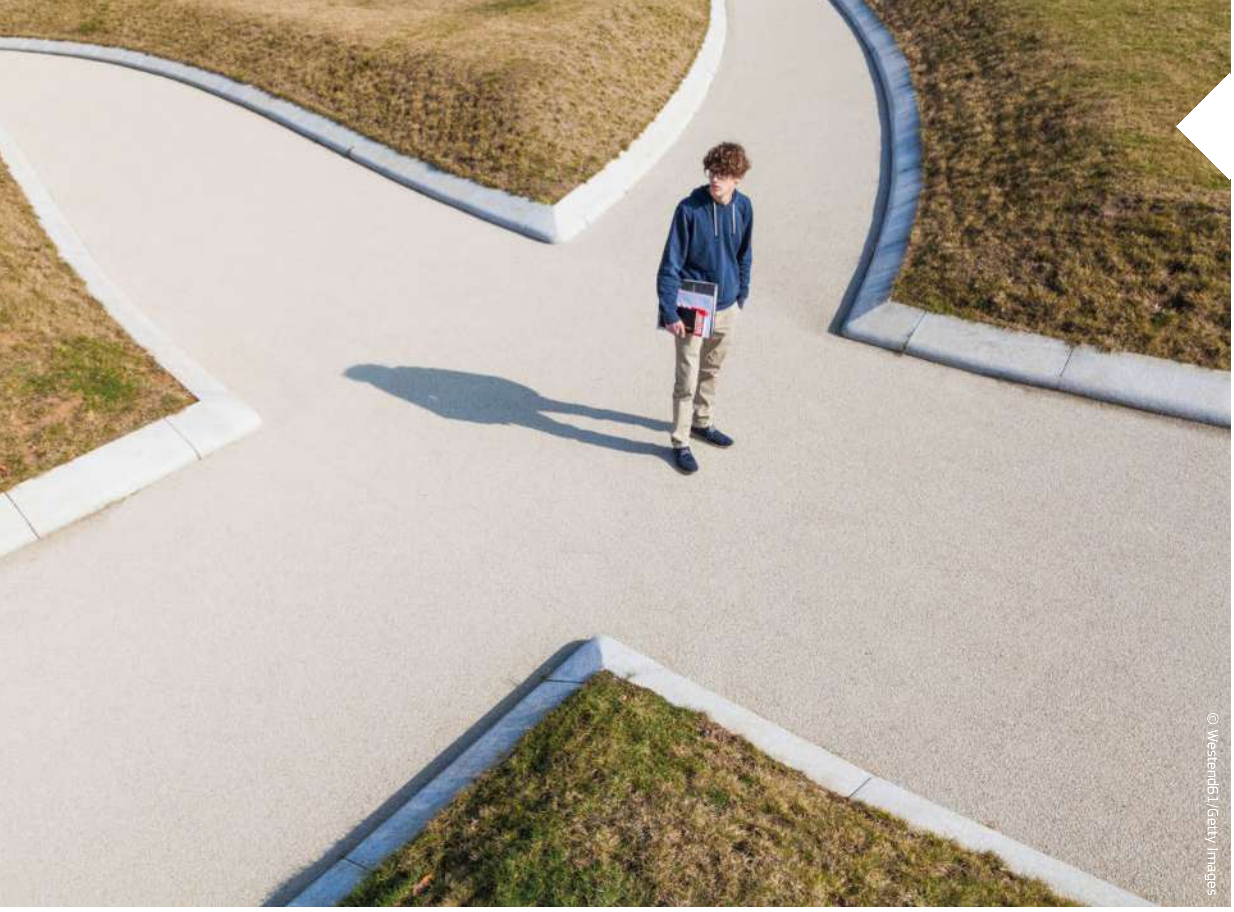
The Dutch National Institute for Public Health and the Environment (RIVM) uses bow-ties for evaluating major hazard and occupational risk. The bow-tie is a well-known model in risk assessment for quantifying risk and prioritising risk reduction. Outcomes are linked to causes and the approach is to identify ways to eliminate or reduce causes that result in the realization of the risk e.g. the release of a hazardous chemical and its subsequent effects on workers, the public and the environment. It has been argued that risk assessment is a reactive approach that fails to address the positive aspects of the human resource. Humans are necessary for supporting the flexibility required in complex changing environments typified by interactions, variability in conditions and weak signals of potentially important events. In a European SAF€RA project "*Success in the face of uncertainty: human resilience and the accident risk bow-tie*" a start was made on developing the success components of the risk bow-tie. This served as a basis for understanding and developing approaches to resilient performance in recovering from situations that could otherwise have been disastrous. Disasters are frequently triggered by a surprise, something unforeseen. In the success bow-tie resilience was incorporated as an aspect of interventions in response to such unexpected events. This aspect reduces the uncertainty associated with achieving a successful outcome, thereby increasing the chance of success. The results of this SAF€RA project were further developed for the purpose of bringing resilience into practice with the use of workshops and tools. One approach that is being developed with the help of safety professionals in the Netherlands is a serious game that can be applied to situations of decision-making under uncertainty and limited time.

Keywords
Bow-tie, safety, resilience, uncertainty, serious game

1. Introduction

1.1. Risk assessment and failure

For industrial hazards which threaten workers, the public and the environment a certain level of protection is expected to be in place. There are regulatory requirements for prevention and for dealing with events that could arise if prevention fails. Risk assessment is one way in which failure scenarios can be understood and managed. In the Netherlands a prescribed method for quantitative risk assessment (QRA) of chemical plants is used for land use planning. The method groups possible scenarios into a limited number of categories covering the foreseen risks (Uijt de Haag et al, 2013). There is also an occupational risk assessment tool, WebORCA (RIVM, 2008) and a set of bow-ties (36 occupational hazards & 1 major hazard loss of containment bow-tie). Together these databases currently contain around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30,000 accident scenarios (event sequences) developed from detailed reportable accident investigations by the Dutch Labour Inspectorate. The bow-tie models are constructed from safety barriers in a tool called Storybuilder™ (Bellamy et al, 2008, 2013). The data enable detailed qualitative and quantitative analyses to be made of barrier failures, failures in human tasks that directly relate to the barriers and underlying management factors which deliver resources to these tasks. Identification of hazards and risks are needed in order to be able to prioritise risk reduction and manage the remaining risks. As the European Agency for Safety & Health at Work state – "Risk assessment is the cornerstone of the European approach to prevent occupational accidents and ill health".[33]

1.2. Resilience, uncertainty and success

Recently risk assessment and the approach to addressing safety through analysis and avoidance of failure has been criticised by technical and human engineers working in the safety field for focussing solely on failure avoidance and not also addressing successful responding in the normal functioning of socio-technical systems (Hollnagel et al, 2011). Resilience Engineering (RE) defines (safety) success as "the ability to succeed under varying conditions" and concentrates on how adjustments to changes and disturbances sustain operations. RE is particularly popular in areas like transportation (aviation and railways) and healthcare (patient safety) sectors. Systems, like Air Traffic Control, are considered to be too complex and dynamic to be sufficiently addressed by classical risk assessment (Hollnagel ***et al,*** 2013).

Risk assessment uses historical (and in its absence also expert judgement) data, which do not exist with new and emerging risks and with increasing uncertainties like those in these dynamic and complex systems. Leveson (2017) explains that systems can fail without component failures due to emergent phenomena of complex interactions. With unpredictable futures, and ones that could even be made worse by risk-based actions, Ramírez and Ravetz (2011) suggest that "scenario planning" (Wack, 1985a, 1985b) is needed to address the hitherto unthinkable. Scenario thinking, simulation to support decision-making and signal watching for early detection are approaches to uncertain futures suggested by a number of authors (Brooker, 2010; Dinh et al, 2012; Paltrinieri et al, 2012). When considering safety strategies, the heart of resilience from the perspective of the human component

[33] https://oiraproject.eu/en/what-risk-assessment

of the system is to understand as much as possible the complexities and uncertainties and to be prepared for what that may deliver in order to maximise the chance of success. Mountaineers, for example, might be considered to be very reliant on resilience. This can be contrasted with normative management systems like the major hazard (petro)chemical processing industry where the human component largely follows procedures in a standardised technical environment with automated supervisory systems. However, even when replaced by automation humans still have a role in adjustment and recovery, except that it can get even more complex. This is the irony discussed in the timeless paper by Bainbridge (1983) – the more advanced the control system the more crucial the contribution of the human operator.

Resilience and uncertainty from a human perspective was addressed in a SAF€RA (European ERA-NET) project which continues its aims to provide a research coordinating network in the area of industrial safety[34]. "**S**uccess **I**n **T**he **F**ace **O**f **U**ncertainty: Human Resilience and the Accident risk Bow-tie" (Resilience Success Consortium, 2015), or "SITFOU", was one of the first coordinated projects to be undertaken, starting in 2014, and had a multidisciplinary research team[35] with expertise in risk assessment, human factors, crisis management, and in the areas of modelling occupational and major hazard risk.

Using the "four cornerstones of resilience" as a basis (Hollnagel, 2009) - anticipating, monitoring, learning and responding - common human and organisational Factors (HOFs) were identified from 350 pages of transcribed interviews from top professionals working in major hazards, dangerous maintenance, and mountaineering and coming from the Netherlands, Belgium, France, UK, and Denmark (Van Galen & Bellamy, 2015). Amongst these were production and process managers, HSE professionals, and process safety specialists from installations falling under the Seveso Directive (EC Council 2012). They provided their perspectives on handling uncertainties in relation to unforeseen and uncertain circumstances, in their case concerning the possible release of major hazard (petro)chemical substances. In the different circumstances of mountaineering and dangerous maintenance (using rope access in difficult locations) similar HOFs could be identified from the case studies as the positive shapers of uncertainty-reducing interventions for unforeseen changes and deviations.

In SITFOU, resilience was considered as *the ability to increase the chance of a successful recovery or adjustment to deviations through uncertainty reduction*. The SITFOU project pioneered a success bow-tie which could be used to evaluate successes under different levels of uncertainty and where the centre event of the bow-tie is successful intervention. Like the failure bow-tie, this can be used to collect scenarios but with the purpose to improve the monitoring of success and the understanding of recovery under uncertainty. The difference between a failure and a success bow-tie is explained in section 2 of this paper.

Section 3 then describes the implementation in practice of the results of SITFOU by involving users from Dutch industry. Implementation was facilitated through the development of simple practical tools as well as networking events, initiated and managed by the Centre for Safety of the Dutch National Institute for Public Health and Environment (RIVM). The key aim was to bring the exploratory results into practice in response to the interest in resilience shown by Dutch safety professionals and the perceived lack of tools. The tool of interest in this paper is a serious game which can be used to help train people to understand uncertainty and analyse situations to support decision-making and to better understand the nature of near miss type successes.

[34] http://www.safera.industrialsafety-tp.org/

[35] White Queen Safety Strategies, NL (coordinator); NCSR Demokritos, GR; Technical University of Denmark, DK; Anne van Galen Consultancy, FR

2. The bow-tie as a model for both normative and resilient safety

The understanding and representation of risk has many different models of which the bow-tie is one (see Figure 1). This is a graphical model which is not only important for understanding and improving the control of risk but also for communicating about risk. The bow-tie has been used since the 1970s to represent causes and effects of critical failure events in risk analysis, particularly in high hazard industry such as at Shell's Pernis refinery (Zuiderduijn, 1999). Bow-tie models may specifically incorporate the failure of safety barriers as a way of modelling accidents (Duijm, 2009; Papazoglou et al, 2017) and for analysing near misses (Ansaldi et al, 2016). The centre event of a bow-tie might be quite specific or quite general. That event is the release of some kind of hazard-agent with various possible consequences.

Figure 1. Failure bow-tie

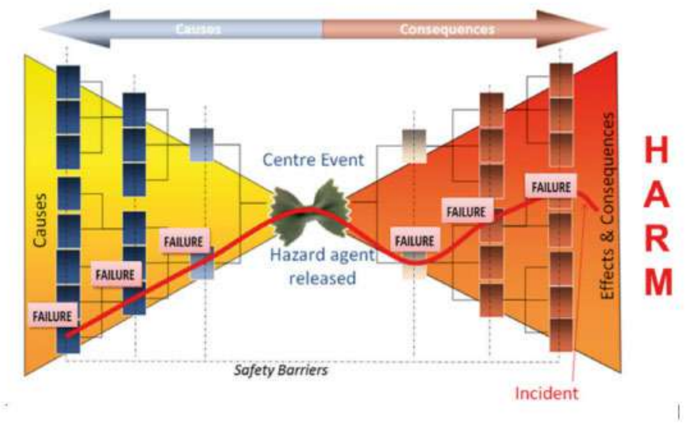
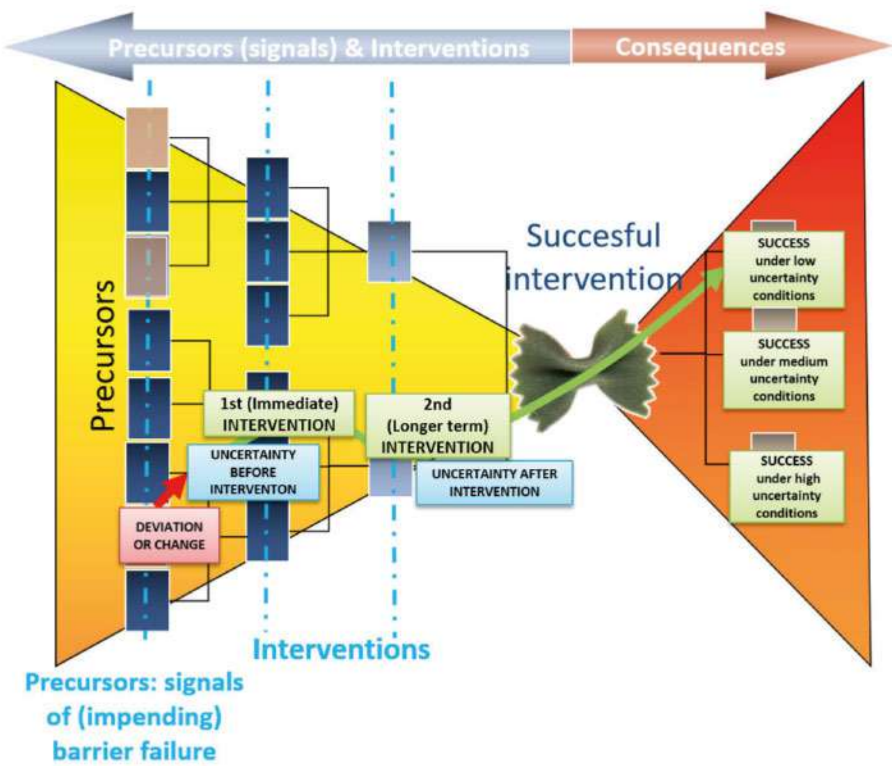


Figure 2. Success bow-tie



The underlying model for successful intervention is also a bow-tie, initially developed in the SITFOU project, where it was used to analyse a near miss database (Resilience Success Consortium, 2015). The broad framework of the success bow-tie is shown in Figure 2. The centre event is not a failure but a successful intervention leading to success under different levels of uncertainty conditions. It is intended to capture reported sequences of events that occur in so-called near miss or recovery scenarios triggered by a deviation or failure event (precursor) that ends in success (no harm and continued functioning of the system). In the success bow-tie pure luck would be represented by an outcome of success under a very high level of uncertainty. A success outcome is considered more likely the more the uncertainty is actively reduced in the process of intervention. The bow-tie structure captures the nature of the detection of the deviation or change, the evaluation of options and the selected response, including identification of any resilient components in the process which contribute to uncertainty reduction. A successful outcome under conditions where uncertainty has been reduced to low or medium is distinct from a success where there were large uncertainties but no attempt or possibility to reduce them. In practice the different types of success may be indistinguishable, which renders success particularly dangerous because it gives the message to go on doing the same.

The difficulty of distinguishing resilience from luck is well illustrated in the report of the ditching of a plane on the Hudson River where "the investigation revealed that the success of this ditching mostly resulted from a series of fortuitous circumstances" (NTSB, 2010 p.79) whereas the pilot acquired hero status for his miraculous recovery after the loss of both engines.

3. Resilience implementation project

3.1. Cards and strategy

The identified HOFs from the SITFOU study were developed as a set of cards containing pictures and short text descriptions for use in a serious game (see Figure 3). The game simulates a decision dilemma with a group of people who play different roles in the team. The aim is to reduce the uncertainty in the process of deciding on a response and how that will be monitored during its implementation. The players talk about intervention scenarios in uncertain situations (case studies) and use the cards as descriptors for properties of the decision process as subtitles to the steps taken to decrease time pressure and reduce the uncertainty. Time and uncertainty cards are numbered 1-6, which are coupled to the model described in the next section and shown in Figure 5. Decision dilemma cases are provided by the safety professionals, taken from their own experience, but could also be developed from bow-tie data. The *Resilience Card Game* contains 57 cards and is used together with a storyboard which takes the players through the five steps shown in Figure 4 and provides a structure for laying out the cards.

Figure 3. Examples of cards in the Resilience Card Game (by permission RIVM)

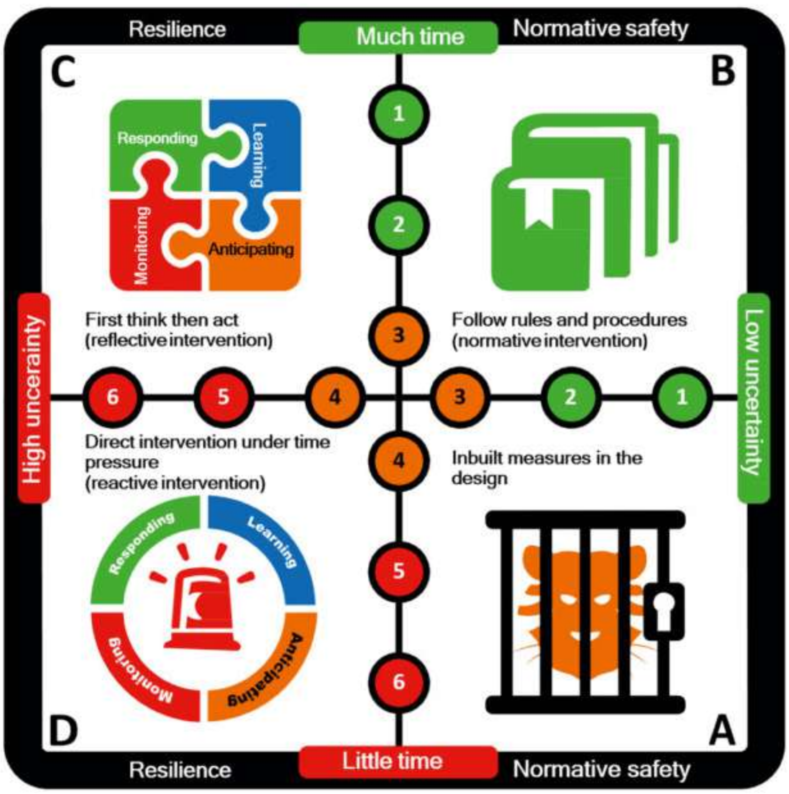
Figure 4. The five steps (by permission RIVM)

3.2. Resilience versus normative strategy

For the serious game, the model in Figure 5 was elaborated from SITFOU. The traditional approach to safety is to learn from failure and then to implement that learning through rules and regulation, technical and management standards and inspections, and the updating of models with new data and understanding. This normative approach is about controlling foreseen risks. Here signals indicate to a person what rule applies (IF-THEN). New signals (change) or surprise outcomes can suggest that a different form of responding is needed. Decision-making dilemmas may arise or signals may be ignored. Phenomena may be encountered that have never been seen before or not predicted by models. The decision-making process in the serious game is intended to focus on these kinds of uncertain situations where the normative approach does not apply. For example, when a petrol storage tank overflowed at the Buncefield oil storage depot in the UK in 2005, a massive explosion generating unexpectedly high overpressures resulted (Health & Safety Executive, 2008). The accident illustrated how humans are very good at ignoring signals of change and not resolving uncertainties. Operators treated the multiple persistent failures of the level gauge in the tank in a normative way. In a low uncertainty (foreseen) situation responses can be specified by procedures. However, under high uncertainty (in this case the unknowns of the repeated level failure) resilience may be required to find the best intervention option. These two situations, low uncertainty and high uncertainty, require different strategies.

Figure 5 distinguishes between resilience and normative safety. The figure shows two dimensions, uncertainty and available time, providing four quadrants for the ways in which safety is handled in these different combinations. When uncertainty is low and risks are foreseen then Quadrant A and B interventions apply. In Quadrant A, inbuilt interventions (like early warnings, shut off systems and back-up power) buy time before more serious consequences ensue. Quadrant B reflects normal day to day operations that can be handled by standard approaches in response to known signals. Ideally in cases of uncertainty when signals of change are detected it is possible to move to Quadrant C, with time available to think out scenarios and options. In rapidly developing scenarios Quadrant D applies.

Figure 5. Resilience-Normative Quadrants (by permission RIVM)



The quadrant model can be used to characterise different safety strategies, organisations and scenarios depending on the uncertainties and the response times available. For example crisis responders could be considered to be predominantly Quadrant A & D types. Major hazard companies are strong on A and B but still face uncertainties where they need to be in C and on rare occasions end up in D.

The uncertainty line does not specifically refer to a range of variability uncertainties and can include scenario uncertainties and recognised ignorance which cannot be assigned probabilities, as in the spectrum provided by Walker et al (2003) that goes from complete determinism (impossible ideal) where everything could be foreseen to total ignorance where foresight is impossible. The numbers on the axes in the quadrants are simply to enable players to express their feelings of uncertainty about a situation and are not anchored in anything specific. The same goes for time pressure. The quadrants are used in the serious game to track the progress of decision-making against the uncertainty-time axes. Being faced with a decision dilemma under uncertainty, the idea of the game is to gain time and then reduce uncertainty in making the final selection of an option. Because the game has to be played as a team, with players taking different roles and having different individual perspectives, the players also experience challenges to their established views and experience, including confronting the dangers of cognitive bias (Kahneman, 2011) such as anchoring on a first piece of evidence arising in a scenario or accepting the first suggested plausible solution (Tversky & Kahneman, 1974).

4. Summary

A serious game has been described that trains people to understand the properties of a successful intervention through a multi-perspective collaborative approach to uncertainty reduction in a decision dilemma. That dilemma has to be a case where the normative management strategy no longer applies because of the uncertainties and so the intervention needs to be resilient. The issues involved in the game are also set in a more formal modelling perspective, the bow-tie, which can be used for data collection and analysis of real life successes in support of learning more about the success phenomenon.

5. Acknowledgements

The SAF€RA research project was funded by the Dutch National Institute for Public Health and Environment (RIVM) and the French Foundation for an Industrial Safety Culture (FonCSI). The National Centre of Scientific Research “Demokritos”, Greece, provided the time and resources of Dr Olga Aneziris and Dr Ioannis Papazoglou, who developed for the SAF€RA project the concept of resilience as uncertainty reduction. The contribution of safety practitioners to the serious game was facilitated by the Dutch Association of Safety Professionals (NVVK).

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