# Markers and patterns of organizational resilience for risk analysis

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# Markers and Patterns of Organizational Resiliencefor Risk Analysis

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In recent years, the concept of resilience has been introduced in risk analysis and some approaches have been proposed as an alternative (or a complement) to the conventional safetyassessmentfor sociotechnical systems. In that way, Integrated Risk Analysis (IRA) has been developed at EDF to treat different risk causalities linking human, organizational, technical and environmental factors in a unified framework using performance shaping factors (PSF).However, research is still needed to address the issues relating to the modelling of resilience when considering organizational influences on human activities. Thus, this paper aims contributingat the definition and derivation of resilient markers and, consequently, to consider both resilient and pathogenic organizational patterns in a unifiedrisk model.The riskmodel is initially proposed as a fourth generation method of risk analysis based on probabilisticgraphical modellingofcausal mechanisms. The model is proposed forsafety assessment of technical systems integrating human, environmental and organizational factors.Finally, the feasibility of our proposals is shown on an illustrative case of Integrated Risk Analysis (IRA).

*Keywords:*Resilience, Markers, Organizational factors, Risk analysis, Sociotechnical systems

## 1. INTRODUCTION

Historically, manyapproaches to assess system safety are used to identify pathogenic patterns in order to attribute failures to a component (human or technological). Actually, safety assessment of a sociotechnical system requires a deeper understanding (Back, *et al.*, 2008). In recent studies, as in(Hollnagel & Spezali, 2008), it isfound that, although sociotechnical systems continue to develop and become more tightly coupled and complex, risk and safety assessment methods do not change or develop correspondingly.For example, it is widely recognized that the approaches neither can be adopted norsomehow extended to properly treat human and organizational factors ifstill relying on the same principles that technical safety methods are based on.In particular, it is clear that to address human and organizational factors for risk assessment, methods need to account fornot only pathogenic but alsoresilientpatternsthat canpotentially manifestbefore, during or after accidental/incidental scenarios. In that way, considerableattentionhasbeendevotedtoidentifyingopportunitiesformodelling*resilience*for risk analysis. Although there is nounique accepted definition across all domains, resilience is widely associated to the ability "to reduce the chances of a shock, to absorb a shock if it occurs and to recover quickly after a shock (restore normal performance)"(Bruneau, *et al.*, 2003). So, resilience can be understood as composed by two distinguished mechanisms:

- *Mitigation*,to reduce negative effects caused by perturbations and shocks;
- *Recovery*, tore-establish a nominal (acceptable) condition.

More recently, researchers working in a field known as resilience engineering(Hollnagel, *et al.*, 2006)have introducednew concepts about how to consider resilience for risk assessment.Along with others, resilience engineering has questioned traditional approaches to safety, especially when trying to account for responses to unexpected events and vulnerabilities that fall outside the scope of formal procedure and design. Nevertheless, it still lacks a clear understanding of what manifestations of resilience look like and how to account for both mitigation and recovery mechanisms in a risk model.Indeed, we need approaches for risk analysis toaddress the whole complexity neither of modellingresilience nor to consider in a unified modelthe complex interactions between resilient andpathogenic patterns to assess risks. Thus, it seems still a matter of investigation:

1) Understanding where resilient patterns come fromand so whether*markers*exist totrack such patterns;
2) Identifying a modelling approach to consider both resilient and pathogenic patterns.

Theseissuesareparticularlyworthy of investigationatElectricity of France (EDF)whereIntegrated Risk Analysis (IRA) (Duval, *et al.*, 2012), a global methodology developed by the department of Industrial Risks Management (IRM) and the Nancy Research Center for Automatic Control (CRAN)needs to be reinforced for more reliable safety assessment. In IRA, a human barrier model

(Léger, *etal*., 2009) is used to assess human actionseffectiveness, each action being defined within its specificorganizational context.The causal framework thatthe model is based on relies ona set oforganizational factors (OFs)(Léger, *et al*., 2009). Pathogenic patternsareidentifiedas causal paths linkingorganizational factors to*items*, *i.e.* team and management related human factors. As pathogenic patternsmust bejustifiedwhen used in the model, a set of markershave been identifiedfor each pattern byanalyzingseveral relevant accidents/incidentsoccurredacrossdifferent high-risky domains as nuclear, space and rail transportation. Today, IRA is interested in consolidating the human barrier model by integrating resilience patterns, even if this assimilation is considered onlypartially,*i.e.*with respectto the *mitigation*mechanism. Reasonsbehind this restrictionare that IRAaddressesonly pre-accident situations (*recovery*makes sense only after perturbations has led to the accident). Face to these limitations, this paper aims to focus on the development of contributions related to the concept of mitigation by making some proposals on how (1) to identify markers to trace manifestations of organizational resilience in a sociotechnical system and,consequently,(2)to consider both pathogenic and resilient patterns for risk analysis. Based on these considerations, the paper is organized as follows. Section 2discusseswhat is done today in order toprovide motivation for promoting some contributions. Section 3offers a formalization of such contributions. Section 4 shows the application of these contributionson an illustrative case in the context ofIRA. Finally, conclusions and some perspectives are given inSection 5.

## 2. RESILIENCEMARKERS AND JOINT CONSIDERATION OF PATHOGENIC ANDRESILIENT PATTERNS

A first step towards resilience consideration consists in providing a more precise definition of resilience and understanding how thisconcept translates when referred to sociotechnical systems.

### 2.1*Resilience and sociotechnical systems*

Resilience is a very complex concept difficult to be defined in a unique way. Indeed, generalization is quite impossible as resilienceisnota system component but shouldbeunderstood rather asan emergent property.For risk analysis, a main definition is issued from the resilience engineering(Hollnagel, *et al*., 2006) in which resilience is considered as“the ability of a system or organization to respond and recover after disturbance, with aminimum effect on the dynamic stability of the system”. This definition was updated always by (Hollnagel, *et al*., 2010)as it follows:“*asystem is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions*.”Whilethere is no universally shared definitions of resilience, experts in risk analysis agree on the meaning of resilience when deployed in the context of sociotechnical systems. In fact, four interrelated dimensions, *i.e.* technical, organizational, social and economic, characterize resiliencefor a sociotechnical system.Understanding whether a technical component rather than the organizational part of a system is resilient, is quite different, as they do not use the same mechanisms to manifest resilience. Therefore, assumptions made by investigating on a particular dimension of resilience cannot be easily generalized as holding for all the other ones.

In that way, thispaper ismainly focusing on resilience manifested at the **organizational**level, *i.e.* resilient patterns implicating organizational factors.

### 2.2*Identifying markersof resilient patterns*

A first issuearisen inconsideringresilient patternsishow to derivecorresponding markers, *i.e.*all information useful to track manifestationsofresilience. With respect to this issue, the resilience engineering (Hollnagel, *et al*., 2010) suggests to analyze all well-ended scenarios to gain information about resilient processes. Unfortunately, this approach hardlyappliestorisky industries as today most of the available feedback collected after analyzing past accidental/incidental scenarios concerns failures. In risk analysis for nuclearindustry, for example, fewinformationis available for unpredictablescenarios. This missingknowledge about potential future scenarios automatically prevent risk assessment methodsfrom investigatingmarkers of resilient patterns by following the approach proposed bythe resilience engineering. (Back, *et al*., 2008) have emphasized the importance of identifying contributors to resilience to assess computer systems safety and reliability. In particular, a general framework is proposed based onresilient markersreferring to different levels of granularity (individual, small team, plant level, etc.). Nevertheless, the focusis placedmainly on the identification of resilient strategies at the individual and teamworking situations levels, while no words is given about the approach usedto derivetheir resilient markers.

Today, it is still unclear where and how markers relating to resilient patterns can be systemically obtained, and how they can be employed in reference to predefined organizational factors for risk analysis.

### 2.3*Accounting for both pathogenic and resilient organizational patternsin risk analysis*

The second issue addressed in accounting for resilience in risk analysis is how to considermanifested resilient patternsin a modelling approach. This consideration requires a clear understanding of how resilient patterns interact with pathogenic ones in producingconsequences in terms of risk. Most conventional methods to assess safety proceed by identifying failure mechanisms related to system components (technical failure rates) as well to human and organizational factors (human error probabilities, etc.).Techniques focusing on human and organizational factors,which are commonly referred to as human reliability analysis (HRA) methods (U.S.N.R.C, 2005),may find difficulties to considerthe great complexityhidden behind causal mechanismsleading to a ‘human error’. Actually, most of HRA methods make use of the so-called performance shaping factors (PSF) to assess a human error probability (HEP). In general, the analyst attributes to PSFs a weighting-value definedbetween -1 and 0 if supposed to implicate negative effects, and between 0 and 1 if effects arepositive. Nevertheless, similar approaches do not really handle the problem of how resilient and pathogenic patterns producing positive and negative influences, respectively,*interact* in leading to HEPs.Others,as (Galan, *et al*., 2007) and (Mohaghegh, *et al*., 2009)have worked to overcome these limitations by taking into account human and organizational factors in more robust models. However, the problem of integrating resilience in their model may need some further work. At the IRM department of EDF, this issue has been addressedin MERMOS(Le Bot & Pesme, 2007), an HRA method based on a systemic approach,by means ofa model based on sociological theoriesand referred to as‘model of resilience in situation’ (MRS) (Le Bot & Pesme, 2014), but this approach does not fit toIRA.In fact, unlike MERMOS, in IRA the purpose is modelling resilience as part of a complex interaction in which more *global*(*i.e.* plant versus team level*)*organizational patternsinteract and their effectsare assed in terms of impact on factors and items downstream at teams and management level.

Concerning IRA, it is now necessary to investigate, firstly, on the derivation of markers tracking resilient patterns and, secondly, on how the identified resilient patterns can be integrated in the causal ‘*conflicting*’ mechanisms involving pathogenic mechanisms.

## 3. MODELLING MARKERS AND PATTERNS OF ORGANIZATIONAL RESILIENCE

The ability to deal successfully with hazardous events and shocks, *i.e*. resilience, is to a large extent dependent on a specific set of skills, practices and attitudes. For this potential to translate into resilient performance, it is needed to be supported by appropriate resources, system characteristics, and organizational structuresidentifying**resilient** patterns.Markers of pathogenic patternsspecify which conditions potentially lead to a degradation that affects items and consequently the effectiveness of human actions(Dien , *et al*., 2004). In the case of resilience patterns(focused on *mitigation*), corresponding markersshould specify conditions that need to hold for a system or organization to perform resiliently and reduce the negative effects produced by pathogenic patterns.As previously mentioned, feedback knowledge is available for incidental and accidental events. Thus, a way to derive resilient markers should be to look at the pathogenic ones.

### 3.1*Deducting resilient organizational markers*

For technical safety methods, knowledge collectedthrough the analysisof past relevant accidental/incidental events occurred in risky domains lead to underline failure mechanisms.Consideringhuman and organizational factorsinvolved in risk assessment, accidents analysis hasequally provided to experts qualitative information to identifyfailing behaviours or organizational strategies and in general all theinformation allowed for outliningpathogenic patterns. Then, it would be reasonable to refer to markers associated to such patterns as **pathogenic**. Now, pathogenic markers may contain other information about what couldhave been done ‘*right*’ to perform resiliently in similarhazardous conditionsin order tomitigate effects produced by pathogenic paths. An example is the ‘Paddington train crash’, whenanalyzing the main contributor factors led to establish safety and health measures with respect to recognized regulatory shortcomings. In that way, itshould be possible to go further and gathering information about resilienceby referring to pathogenic markers.

In order to proceed to the identification of the resilience markers by such an approach, the following assumptions have been made:

**Assumption 1.**

*For**expected** situations, there is a relation between resilientand pathogenic markers.*

In Fig.1 all possible situations are identified depending on the combination of the system resilience level and the likelihood of perturbations and hazards.

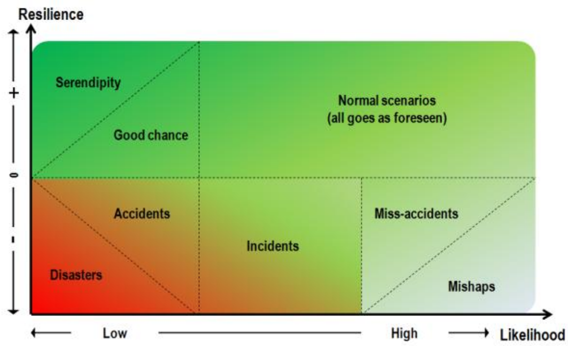


Fig.1. Resilience versus adverse event likelihood diagram and corresponding scenarios (Pariès, 2006)**.**

Regions denoted by “serendipity”, “good chance” and “normal scenarios” (*i.e*. situations defined by high system resilience and either low or high likelihood of hazards)and “miss-accidents” and “mishaps” (*i.e*. situations defined by low resilience but high likelihood), are those that resilience engineering aims to investigate as they represent what ‘*we do not know*’. However, at the moment the only source of information available for deriving resilience markers is achievable in situations denoted in Fig. 1 by “disasters”, “accidents” and “incidents” (*i.e*. situations characterized by low resilience and very low likelihood of hazards). As both pathogenic and resilient markers at least refer to perturbations that the system already experimented, a relationship can be established between them.Let us consider two generic sets of markers referred to an organizational factor $X$:

- $M^r$, composed by resilientmarkers denoted by$m_i^{r\to X}$, and
- $M^p$, composed by pathogenicmarkersdenoted by$m_j^{p\to X}$.

The symbol→ denote that markers relating to an $X$. So, as a first attempt to describe such a relationship, it should be written that:

$$m_i^{r \to X} = 1 - m_j^{p \to X} \quad (1)$$

Nevertheless, the concept of complementarity as expressed in(1) can be included within a generic function as below:

$$m_i^{r \to X} = f(1 - m_j^{p \to X})(2)$$

*i.e*. a resilient marker maynot be exactly the complementary part of the corresponding pathogenic marker, but more generally a *function*of it.

A further generalization should lead to consideran external term representing unknown (or not considered) information which can help to better characterize the resilient marker. This term, denoted by $\varepsilon$, has been included in (2) to give the following expression:

$$m_i^{r \to X} = f(1 - m_j^{p \to X}, \varepsilon) \qquad (3)$$

Equation (3)represents in a quite general and symbolic fashion a relationship that allowsfor deriving a resilient marker from its corresponding pathogenic one.

Now, it has been assumed earlier that resilient markers are derived– in principle – for expected situations.

Nevertheless, given the intrinsic uncertainty on a resilient response,it is compulsory to investigate the validity of the same markers in (3) for *unpredictable* situations. In order to better understand the concept behind thisextension of **Assumption 1**to unpredictable situations, the following analogy with the medical and health care domain is proposed(Dien , *et al*., 2004).

Let us consider a patient who suffers from a known and well identified disease. According to a set of symptoms (leading in turns to specific pathogenic markers) the doctor prescribescurative measures. He can eventually provide to the patient some recommendations on how to act in the future for similar situations. These recommendations allow the patient to be, in this sense, resilient if he would find himself involved in the same '*expected*' conditions. Nevertheless, nothing prevents that the same recommendations could help the patient toperform resilientlyin '*unexpected*' circumstances that the doctor was not aware of. This hypothesis will be extended to the following developments.

Following the approach described by (3) and illustrated in the analogy above, resilient markers have been identified from the pathogenic ones for a set of organizational factors. For example, pathogenic and resilient markers have been identified for the factor *Organizational Complexity Treatment* (*OCT*), as shown inTable 1.

**Table 1. Pathogenic and resilient markers referred to the organizational factor OCT.**

| **Organizational Complexity Treatment** | |
|---|---|
| **Examples of Pathogenic markers** | **Examples of Resilient markers** |
| Geographical remoteness of decisional centers.Difficulties in reaching decision-making bodies | Good communication between decisional and operational centers |
| Management fails to consider system complexity and opacity, excessive confidence in management, attitude to ideological positions | Management is capable to question themselves |
| Bottom-up circuits absent or biased(insufficient or biased internal communication) | Management allows operational feedback for ascending to decisional centers |
| Inter- and intra-organizational conflicts | Ability of leaders to converge towards a shared and accepted vision |
| Interference between facilities and tasks affecting security ('co-activity') | Ability to take into account the coactivity |

To go further in the consideration of resilience, it should be studied how resilient patterns –meant as mitigationpatterns– interact with pathogenic patterns in contributing to the risk.

3.2*Interactionmechanismbetween pathogenic and resilient patterns*

Let us consider now a set of $n$generic organizational factors (OFs). Nevertheless, it is assumed that $k$ out the $n$OFs are denoted by $X^{i \to l}$($i \in \{1, \dots, k\}$as they affectthe items$Y_l$ ($l \in \{1, \dots, m\}$)(the symbol→ denote aninfluence on$Y_l$) by means of a *pathogenic pattern*, and $n - k$ are denoted by $X^{j \neq i \to l}$($j \in \{k+1, \dots, n\}$)astheymayaffect item$Y_l$by means of a *resilient pattern*.OFs have two possible states (*present*, *absent*). Then, some assumptions have beenmade for combining OFs statesand their influence on items:

**Assumption 2**.

*If a set* $M^p$ *of pathogenic markers* $m_i^p$ *are identified attesting that an OF* $X^{i \to l}$ *has a* **pathogenic** *influence on item*$Y_l$, *then this fact is represented by the* **'absence'***of*$X^{i \to l}$.

**Assumption 3**.

*If a set* $M^r$ *ofresilient markers* $m_{j \neq i}^r$*are identified attesting that an OF* $X^{j \neq i \to l}$*has a* **resilient***influence on an item*$Y_l$, *then this fact is represented by the* **'presence'** *of*$X^{j \neq i \to l}$.

It means thatOFs leading to a resilient pattern have an impact in the sense that they are '*present'*, while OFs leading to pathogenic patterns have an impact in the sense that they are*'absent'*.If assumptions 1 and 2 hold, the following step is tospecify which mechanismbetter represents the interaction between resilientand pathogenic patterns affecting items.

This relationship can be expressed by a general function specifically referred to the affected item$Y_l$, as follows:

$$Y_l = f(X^{1 \to l}, \dots X^{i \to l}, \dots X^{k \to l}; X^{k+1 \to l}, \dots\ X^{j \to l}, \dots X^{n \to l};\ \varepsilon)(4)$$

However, resilience is considered here only in reference to the mitigation mechanism. Thus, the generic function in (4) can betranslated – for example, in a probabilistic risk model (De Galizia, *et al*., 2015) – torepresenta*mitigation mechanism***.**To continue towards a further formalization, let us consider a set of OFs$X^{i \to l}$. These latter act by means ofresilient patterns (in the state '*present*')and mitigatethe effects produced by a set of OFs$X^{j \to l}$ that act by means ofpathogenic patterns(in the state '*absent*').

In this sense, another assumption is made about this mechanism:

**Assumption 4.**

*The result of* ***amitigation mechanism****ofresilientpatternson the pathogenic ones isa decreaseofpotential adverse effects*$E_i$*due to the pathogenic patterns*$X^{i\to l}$.

Interaction between $k$ resilient and $n-k$ *pathogenic* patterns on item $Y_l$is represented in Fig. 2.

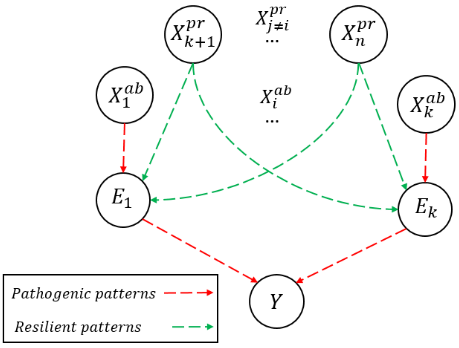


Fig.2.Mitigationmechanism of pathogenic effects$\boldsymbol{E_i}$affecting item$\boldsymbol{Y^l}$.

OFshaving a *pathogenic* effect$E_i$ are denoted by$X_i^{ab}$ ('*absent*') and red arrows, while OFs mitigating these effects are denoted by $X_j^{pr}$ ('*present*')and green arrows.So, the impact onitem$Y_l$ is assessed by following the mitigation mechanism between pathogenic and resilient influences produced by the OFs $X^{i\to l}$ and$X^{j\to l}$, respectively. For the sake of simplicity, let us consider two generic organizational factors$X^{i\to l}$ and $X^{j\to l}$affecting item$Y_l$. For this simplifiedcase, Table 2resumesall possible scenarios resultingfrom the interaction between resilient and pathogenic patterns and the mitigation mechanism.

**Table 2. Interaction mechanisms matrix between resilient and pathogenic organizational patterns**.

| Mechanisms affecting $\boldsymbol{Y_l}$ | $\boldsymbol{X^{i\to l}}$ | |
|---|---|---|
| $\boldsymbol{X^{j\to l}}$ | *Present* | *Absent* |
| *Present* | Mitigation of residual effects | Mitigation of pathogenic effects |
| *Absent* | Residual effects | pathogenic effects |

From all the formulations discussed before, it is now shown their applicability on an illustrative case declined in the framework of IRA.

## 4. ILLUSTRATIVE CASE– APPLICATION TO THE HUMAN BARRIER MODELOFIRA

Let us consider the problem of defining resilience markers and then the interaction of pathogenic and resilient patternsin the framework of IRA. In particular, let us refer to the IRA human barrier model (HBM) represented in Fig. 3. A set of organizational factors (OF) can affect one or more items, *i.e.* management and team related factors.In the HBM, human actionseffectivenessis factorized inthree *phases*: preparation (*P*), execution (*E*) and closure (*C*). Each phase is a function of a set of items (delegation '*De*', training '*Tr*', aides '*Ai*', work design, tasking and direction '*Wdtd*', experience '*Ex*', collective management and team dynamics '*Cmtd*', contextual factors '*Cf*', real time control '*Rtc*', implementing of local feedback experience '*Ilfe*'). Finally, a set ofOFs (safety culture '*SC*', production culture '*PC*', organizational complexity treatment '*OCT*', implementing of feedback experience loop '*IFEL*', re-examining of design hypothesis '*RDH*', control bodies '*CB*',daily safety management '*DSM*') canhave an impact items. As an illustrative case, the influences of3 OFs on '*De*' is considered, as shown in Fig.3.

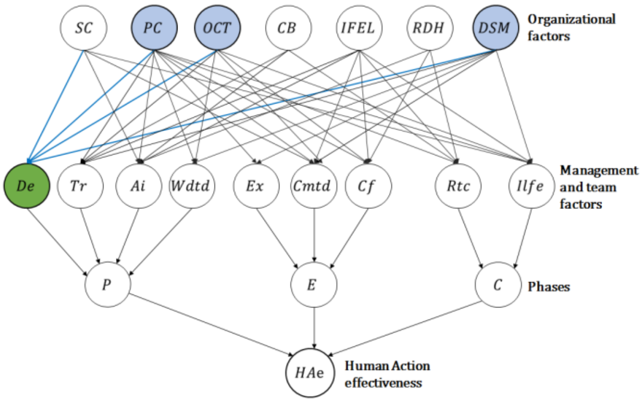


Fig.3. The human safety barrier model used in IRA to evaluate a human action effectiveness.

The following OFsare considered:

- *Production Culture* (*PC*):injunctions to bypass or deliberately ignore certain dimensions of safety in order to promote short-term profitability criteria;
- *Organizational complexity treatment* (*OCT*):measures to facilitate working relationships and decision-making, as well as communication about risks and safety;
- *Daily safety management*(*DSM*): practical implementation of safety requirements within the organization.

Experts' elicitation based on (3) has provided the following results in terms of markers and, consequently,corresponding patterns have beenassigned to each OF, as shown in Table 3.

**Table 3. Markers justifying resilient and negative patterns ofPC, OCT, DSM.**

| OF | Markers | Pattern |
|---|---|---|
| **PC** | - Strategic management objectives focusing on production and productive performance<br>- Too limited delays affecting safety | *Pathogenic* |
| **OCT** | - Good definition of the strategic plan, overall priorities (safety, security, quality, reliability, production)<br>- Benefits and disadvantages analysis of managerial decisions | *Resilient* |

| | | |
|---|---|---|
| **DSM** | - Good and safe maintenance practices (coactivity risk)<br>- Team meeting frequent and well organized | *Resilient* |

So, based on principles expressed in **Assumption 4** and represented inFig. 2, it is found that effects produced by pathogenicpatterns(*PC*) on *De* are mitigated byresilient patterns (*OCT* and*DSM*).

Table 4 shows in detailshowthe mitigation mechanism reducespathogenic effects produced on *De*.

**Table 4. Effects on delegation produced by the interaction of pathogenic and resilient patterns.**

| Combination of OFs states | | | Effects on 'Delegation' |
|---|---|---|---|
| ***PC*** | ***OCT*** | ***DSM*** | |
| *Absent* | *Present* | *Present* | Pathogenic effects mitigated by both OCT and DSM |
| | | *Absent* | Pathogenic effects mitigated by OCT |
| | *Absent* | *Present* | Pathogenic effects mitigated by DSM |
| | | *Absent* | Pathogenic effects induced by PC |
| *Present* | *Present* | *Present* | Residual effects mitigated by both OCT and DSM |
| | | *Absent* | Residual effects mitigated by OCT |
| | *Absent* | *Present* | Residual effects mitigated by DSM |
| | | *Absent* | Residual (not modelled) effects |

This illustrative case shows that this modelling approach may provide benefits to IRA in considering resilience for the assessment of human activities effectiveness.

## 5. CONCLUSIONS AND PERSPECTIVES

The consideration of resilience inassessing risks in sociotechnical systems is gaining a great interest. The aim of this paper is contributing to this issue by focusing on resilient organizational patterns in the form of mitigation mechanisms. Some contributions have been proposed for firstly deriving markers and then modelling patterns of organizational resilience in the frame of probabilistic graphical modelling. Finally, the feasibility of such contributions has been shown on an illustrative case of the human barrier model in IRA. In the future,concepts here formalized will be applied to a large-scale model integrating human, technical, organizational and environmental factors to testto test the representativeness of the organisational factor of the barrier model and how resilient patterns propagatein terms of the total risk, possibly consolidating the organisational model.

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