Preserving resilience while managing changes, an assessment framework

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***Résumé* – Les changements technologiques ou managériaux visent à améliorer les performances, la productivité générale, la rentabilité ou la qualité des systèmes sociotechniques. Dans certaines circonstances, les changements peuvent affecter, comme effet secondaire, les propriétés de sécurité du système et faciliter la survenue d'accidents ou bien diminuer la capacité du système à prévenir et atténuer les effets d'un accident. L'anticipation des potentielles conséquences de changement sur la résilience des systèmes sociotechniques nécessite des connaissances, des méthodes et des outils prenant en considération leur complexité. Cet article présente un cadre méthodologique fondé sur l'Ingénierie de la Résilience visant à identifier les potentiels impact de changements sur les comportements individuels et collectifs dans une perspective de gestion de sécurité.**

***Abstract* – Technological or managerial changes aim to improve socio-technical systems' performance, general productivity, profitability, or quality. In some circumstances, changes can affect, as a side effect, system safety properties and facilitate the occurrence of crises or by decreasing system ability to mitigate crises. Anticipating potential consequences of change on socio-technical systems' safety properties requires knowledge, method, and tools covering socio-technical' complexity. This paper presents a Resilience Engineering-based methodological framework aiming to support the identification of the impact of a change on individual and collective behaviours within the perspective of safety management.**

***Mots clés* – Changements, Impacts, Sécurité, Résilience, Hommes**
***Keywords* – Change, Impacts, Safety, Resilience, Humans**

1 INTRODUCTION

Movements, adaptations, changes are organizations' new routines (Alter 2003). Evolutions in their cultural, political, social, technological, economic, physical, or legal environment impose organizations to initiate change management projects to preserve their competitive advantage and survive (Porter 2008, Hatch 2012).

Changes in a complex system can lead to different types of consequences (Merton 1936, Morin 1990): positive, unexpected benefits usually referred to as serendipity or a windfall; adverse effects, which occur in addition to the desired effect of the change; Perverse effects, i.e., the unexpected adverse effect is greater than the expected beneficial effect; the futility of innovation, e.g., the more things change, the more they stay the same; threat of achievements, i.e., the consequences are the opposite of the initial intentions.

Consideration of change is one of the prerequisites of a proactive safety management system. The anticipation of opportunities and threats induced by change or innovation is one of the cornerstones of organizational resilience (Hollnagel et al., 2006). ISO 31000 monitoring and review requirements include detecting changes in the external and internal context, requiring revision of risk management processes, and identifying emerging risks (NF ISO 31000).

Managing change is generally associated with efforts to overcome resistance induced by a change by identifying potential sources of resistance and applying the appropriate change management strategy. Such approaches aim to make the change effective. However, several examples of accidents and disasters illustrate that successful changes can contribute to unwanted consequences, and research needs to be conducted that complements change management approaches with safety concerns.

This paper presents a methodological framework aiming to define a strategy of assessment guiding experiments to prevent the failure of change and anticipate the occurrence of unwanted impacts on the resilience of sociotechnical systems. The first section presents a synthesis of the theoretical background integrated within the framework. Then, the second describes the framework, and the last one illustrates its application.

2 THEORETICAL BACKGROUND

Leading a change must overcome various obstacles that can negate the efforts and investments made. Societal, organizational, and technological constraints can be at the origin of the rejection of a seemingly relevant change (Owens 2012). Existing frameworks dedicated to change management in maritime, nuclear, or railway used risk assessment, generally technical risk assessment, and cost benefits. The proposed framework aims to extend the scope of potential impacts considered when conducting change management by considering targets related to the different risk management periods: impacts on the risk of technical failure, human and organizational factors, and system resilience (cf. figure 1).

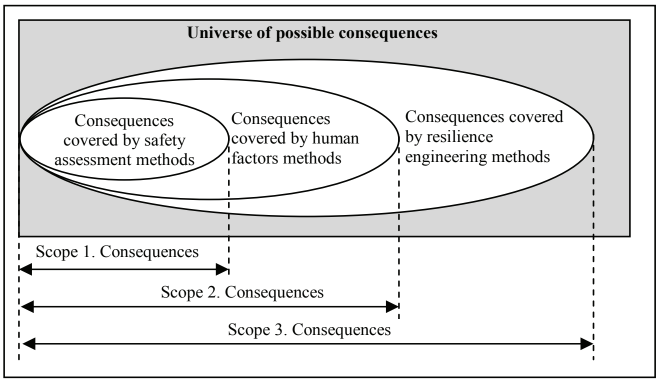

Figure 1. Type of potential impact considered

2.1 Impacts on the risks of technical failures

The need for safe and reliable technologies has led to the development of risk assessment methods to prevent failures and the associated consequences. Based on the practices of the chemical, aeronautics, or nuclear industries, the field of Operational Safety (Villemeur, 1988; Lannoy, 2008) structures a set of fundamental concepts such as reliability (ability of an entity to perform a required function under given conditions and for a given duration), availability (the ability of an entity to perform a required function under given conditions and at a given time) or safety (the ability of an entity to avoid the occurrence, under given conditions, of critical or catastrophic events). Tools like the frequency-severity matrix make it possible to classify risks according to their probability of occurrence and the severity of their potential consequences. The preliminary risk analysis (RPA), the analysis of failure modes, their effects, and their criticality (FMECA), or the Hazard and Operability Analysis (HAZOP) make it possible to qualify, quantify and describe the risk scenarios.

2.2 Impacts on the risks of human errors

Human error was first associated with the deviation from a standard, a procedure, or a frame of reference. Then, it considers different behavior modes and associated errors: inattention in a routine situation, applying an inappropriate rule in a regulated situation, and inability to adopt an acceptable behavior in a situation for which no rule has been formalized (Rasmussen and Jensen, 1974). Reason (1993) proposes a typology of human error by distinguishing between faults, failures, selection, sequence, time, or quality errors. Work is carried out on information processing modes that distinguish different reasoning modes depending on the situation, particularly the SRK model (Rasmussen, 1983), which distinguishes behavior guided by skills, rules, or l experience. The first methods of analyzing human reliability were developed, such as the THERP method, Technique for Human Error Rate Prediction (Swain and Guttman, 1983), which makes it possible to calculate a probability of error in the execution of a task in combining a decomposition of the task using a tree representation and error probability tables.
The occurrence of major technological disasters in the mid-1980s, such as the Bhopal, Chernobyl, or Challenger accidents, questioned the theories, models, and practices of risk management and led to the consideration of the organizational characteristics of the systems.

2.3 Impacts on the risks of organizational failure

The development, in sociology, of theories about industrial accidents, offers new perspectives on accidents and risk management needs by integrating organizational topics (hierarchical system, culture, or technology).
The idea that a period in which visible symptoms are not perceived and not considered by the system preceded accident or disaster is first stated (Turner, 1978). Vaughan enunciates the normalization of deviance theory (1996) and corroborates this idea. Based on the study of the evolution of NASA preceding the shuttle Challenger explosion, this theory shows that the organization accepts disruptions and deviations from the rules and gradually generates a routinization of deviations, creating the conditions for the occurrence of a disaster.
The normal accident (Perrow, 1984), and the High-Reliability Organizations (Laporte and Consolini, 1991) theories are developed following the Three Miles Island nuclear accident. The first theory states that the complexity of organizations (centralization, decentralization, or redundancy.) is such that it is almost impossible to represent them correctly and consequently to identify and prevent failure scenarios. Also, it states that risk management barriers contribute to the complexity of the systems and thus increase the systems' vulnerability. Therefore, the accident is inevitable because it is not the result of failures but of the normal functioning of systems whose complexity is greater than the ability to control risk management systems.
The second theory enunciates that organizational mechanisms (culture and priority of leaders, organizational and technical redundancy, adequate decision-making and communication structure, organizational culture, continuous training of agents, organizational learning) promote prevent failures and disasters. New methods such as CREAM, Cognitive Reliability, and Error Analysis Method (Hollnagel, 1998) or TRIPOD (Groeneweg et al., 1998) are developed. Their ambition is to consider organizational factors when performing risk analysis and accidental investigation tasks.

2.4 Impacts on system resilience

Resilience Engineering aims to foster sociotechnical systems with the requisite imagination and the resources to respond and overcome the diversity and the complexity of possible situations (Adamski et Westrum 2003, Woods et Hollnagel 2006). While risk management provides basements to prevent failures identified when analyzing accidents, Resilience Engineering aims to prevent systems from losing the potential of adaptation to their changing environment. Among many definitions, the ones proposed by Woods (2006) and Hollnagel (2011) influence theoretical and practical researches within Resilience Engineering. Woods (2006) defines resilience as the "ability to recognize and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of processes, strategies, and coordination." Hollnagel (2011) suggests that resilience refers to "the intrinsic ability of a system to adjust its functioning before, during or following changes and disturbances so that it can sustain required operations under both expected and unexpected conditions." Hollnagel (2013) considers two approaches for safety management. "Safety I" focus on managing failures and "Safety II" on the management of the system capacity responding and overcoming disturbances.

3 A FRAMEWORK FOR PRESERVING RESILIENCE DURING CHANGES

The framework aims to define a strategy of assessment guiding experiments to prevent the failure of change and anticipate the occurrence of unwanted impacts on sociotechnical systems' resilience. Two processes constitute the framework. The first objective is to create a culture of resilience and formalize a system resilience model. When a change occurs, the second process aims to study it to prevent unexpected consequences. Safety managers can use the framework to enhance their understanding of the system's complexity and structure change management activities to improve their security. They can apply it at a different scale (technological system, process, unit, or plant).

3.1 Roles and responsibilities

A set of essential roles supports the distribution of responsibilities when applying the framework, considering that one person can assume different roles.

The "evaluation owner" is the person who is mainly responsible for the system to be assessed. This critical role encompasses the following responsibilities: defining the goal and scope of the evaluation process, supporting the assessment team in providing access to the agents of the system, and to documents and resources needed by the assessment (room, material, etc.).

The "evaluation coordinator" is the person who is mainly responsible for the evaluation process. The evaluation coordinator should cover the following responsibilities: defining the target, the scope, and the objective of the evaluation process with the "evaluation owner," planning the different steps of the assessment, monitoring the realization of the different steps, managing issues when performing the different steps.

The "stakeholder coordinator" is the person who is mainly responsible for the coordination with the various agents involved in the assessment. The stakeholder coordinator should cover the following responsibilities: identifying the agents, invite the agents to workshops, provide feedbacks of the assessment to the agents.

The "technical coordinator" is the person who is mainly responsible for the realization of the assessment task. The evaluation coordinator should cover the following responsibilities: organizing and animating workshops, writing deliverables.

3.2 Defining resilience performance.

For defining the resilience performance of the studied system, the team firstly organized workshops for describing the system studied, the diversity of events it has to respond to, and its capacity to respond. The team designs an assessment methodology and associated supportive material (diagnostic schedule, interviews and observation guidelines, and assessment grid). The team conducts individual and collective interviews and observations for collecting qualitative and quantitative data about the system structure and dynamic in regular times and when disturbances occur with considering the different actors of the system (operational, managers, and directors).

3.3 Promoting a culture of resilience preservation while conducting changes.

For integrating into the organization's safety culture, the relevance of studying the consequences of resilience performance changes: The team share lessons learned about situations where change contributes to unwanted consequences. They formulate a methodology of managing the impact of changes' consequences on resilience. They develop related expertise within the organization. They control that consequences of change on resilience management are carried out with sufficient time so that change managers can take into consideration potential adverse impacts. Finally, they diffuse lessons learned within the organization.

3.4 Studying changes for preventing unwanted consequences

For conducting investigations on the potential consequences of a change on the system's resilience, the team achieves the following tasks. Firstly, the team provided a model of the change. This model is used to define the assessment strategy and design the different data collection and analysis modules. Then, the different modules are conducted, and a list of consequences is deduced. The team deduces from the consequences a list of risks and opportunities associated with the change. This list is used to provide recommendations.

4 LESSONS FROM THE APPLICATION OF THE FRAMEWORK

The framework's ongoing development progresses with the application of instances of the framework within different industrial contexts.

4.1 Application within the gas transportation system

The first instance of the framework was applied on a case of change within the gas transportation system (Zarea et al. 2010, 2013a, 2013b).

The change was an innovative workflow aiming to detect, identify and localize threats susceptible to affect pipeline integrity: 1) Acquisition of image data with geographic reference via a lightweight autonomously operating UAV; 2) Automatic image pre-processing: image mosaicking and geo-referencing; 3) Automatic change detection: automatic detection of changes (threat candidates) using object-based image analysis techniques; 4) Visual threat candidate validation: Software guided validation of threat candidates.

The team designs a strategy aiming at assessing: 1) the relevance of using an automated aerial surveillance system to monitor a pipeline section; 2) the legality to use an automated aerial surveillance system within an area; 3) the feasibility to use an automated aerial surveillance system within an area; 4) the pipeline stakeholders' acceptability to use automated aerial surveillance.

The experiment's campaign firstly consisted in the realization of experimental flight in France, Spain, and Germany. Secondly, surveys, interviews, and role games to identify issues related to acceptance of civil aviation, acceptance of safety regulators, general public acceptance, and acceptance of traditional service providers doing pipeline surveillance.

The studies' results were promising; nevertheless, due to the various constraints, a set of requirements were proposed to support change management with minimizing risks of failure, efficiency, and reliability of the workflow, conformity with changing regulation, and acceptability by both operators and society.

4.2 Application within the maritime context

A refined instance of the framework was applied to study the potential impact of using the 3D technologies by ship pilot (Rigaud et al. 2012a).

The team designs a strategy aiming at assessing: 1) the relevance of using a 3D chart when piloting ship 2) maritime stakeholders acceptability constraints.

The experiment's campaign firstly consisted of the simulation of search and rescue operations using bridge simulators. The team compares pilot behaviors with situations where they used a traditional radar and used a 3D chart. Secondly, focus groups on identifying maritime stakeholders' perception of the 3D chart and potential obstacles to overcome to be used on bridges.

The studies' results demonstrate the ship bridges simulator's relevance to operationalize human factors risk assessment methods such as situation awareness, stress, or communication risks assessment. They demonstrate the potential of the change but the existence of regulatory obstacles.

A dedicated team used lessons from this first case study to study the potential added value and constraints of using a visual analytic environment when monitoring maritime areas' safety and security (Rigaud et al. 2014, Vatin et al. 2014). A focus on the impact of data quality and its potential consequences on monitoring performance was analyzed.

4.3 Application within the air traffic control context

The framework was also applied to study the potential impact of a technological change within the air traffic control network (Rigaud et al. 2012b, Martinie et al. 2012).

The team provides a model of the air traffic control system's resilience and develops an integrated model to support technological failure propagation and escalation within a complex network.

The model was used to study the potential consequences of using a fully automated decision support system in tower control under various conditions and the potential of systemic failure.

4.4 Application within the railway context

An extended version of the framework was provided following its application within the railway context (Rigaud et al. 2013, Cote et al., 2014a, 2014b, Rigaud 2017, Rigaud et al., 2017, 2018).

A dedicated module aimed at supporting the definition and assessing the resilience of a sociotechnical system was elaborated. More particularly, a set of indicators related to the system's capacity to respond to the regular, irregular, and unexampled threats was developed so as a dedicated data collection and analysis method.

An extended version of the framework was provided following its application within the railway context (Rigaud et al. 2013, Cote et al., 2014a, 2014b, Rigaud 2017, Rigaud et al., 2017, 2018).

A dedicated module aimed at supporting the definition and assessing the resilience of a sociotechnical system was elaborated. More particularly, a set of indicators related to the system's capacity 1) to respond and overcome the diversity of situations that may arise; 2) to monitor that which changes or may change in the near term that it will require a response; 3) to learn from both positive and negative experience of the past; 4) to anticipate development, threats, and opportunities further into the future.

The team formalize seven situations of resilience to be considered when collecting data and assessing the resilience capacity:

1. The situation is normal, considered by procedure or good practices, and the context (time, knowledge, competencies, and information) necessary to respond is available. Agents can recognize the situation, define their future behaviour by using their experience or with adapting a known and regularly applied procedure, and apply it in conformity with all the dimensions of performance of the activity.
2. The situation is normal, considered by procedure or good practices. However, the context (time, knowledge, competencies, information) necessary to respond is not available. Agents can recognize the situation, define their future behaviour by using their experience or adapting a known and regularly applied procedure and apply it with creativity to conform with all dimensions of the activity's performance despite the lack of one kind of resource.
3. The situation is normal and not considered by procedure or good practices. Agents can recognize the situation and that neither procedure nor good practices support them to define the behaviour to adopt, they are creative to define their future behaviour and apply it in conformity with all dimensions of the activity's performance.
4. The situation is abnormal (perturbation, crisis, etc.), considered by procedure or good practices, and the context (time, knowledge, competencies, and information) necessary to respond is available. Agents can recognize the situation and the necessity to adopt a non-routine behaviour, they define their future behaviour with using their experience or with adapting a known procedure or find one in a guideline, they apply it in conformity with all dimensions of the activity's performance in contributing to the continuity of the activity of the system.
5. The situation is abnormal, considered by procedure or good practices, but the context (time, knowledge, competencies, information) necessary to respond is not available. Agents can recognize the situation and the necessity to adopt a non-routine behaviour; they define their future behaviour by using their experience or with adapting a known procedure or find one in a guideline, and apply it with creativity in order to conform with all dimensions of the activity's performance despite the lack of one kind of resources.
6. The situation is abnormal and not considered by procedure or good practices. Agents can recognize the situation and the necessity to adopt a non-routine behaviour. Neither procedure nor good practices support them to define the behaviour to adopt. They are creative in defining their future behaviour and applying it in conformity with all the activity's performance dimensions.
7. The situation is unexampled. Agents are creative to respond and to contribute to the continuity of activity of the system.

These situations structure the change management module where a guidelines to organize interviews and focus groups on identifying how a change can positively or negatively affect one or several situations is targeted.

4.5 Lessons from applications

The application and the refinement of the framework within different context allow the identification of a set of lessons:

1. The definition of resilience performance is time-consuming and requires the operator to understand and consider specific concepts and contextualize them to their context.
2. Modeling changes and their potential impacts on the system requires integrating several models and a specific simulation framework.
3. Agents are willing to discuss how they adapt when disturbances happen. Nevertheless, talking about actions at the limit or outside the procedural context is difficult with the hierarchy's presence.
4. Budget optimization policies make it difficult to realize changes aiming to consider the analysis results.
5. Considering the impact of change on the risk of failure is complicated, even within the organization where

anticipating unwanted consequences of changes is present. Succeed in applying the change is generally considered as the priority.
6. Technological simulator provides insights for identifying unimagined impacts.

5 Conclusion

This article presented a framework whose purpose is to identify the potential impact of changes on systems' security. Based on the theoretical framework of Resilience Engineering, it aims to extend the potential for preventing the unintended consequences of a change in individual and collective behaviour, allowing control of the diversity of situations that may arise. Applying the method requires time and resources to collect and organize the knowledge necessary to model and assess resilience. Although the results provide recognized added value, taking them into account in operational and strategic decisions requires an evolution of organizations' safety culture.

The framework's perspective is to adapt it in order to be able to apply it for studying the impact of trends, changes, and crises on urban resilience.

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