Anticipating the consequences of change on safety performance: A proposed methodological framework

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ABSTRACT: Change management generally refers to efforts to overcome resistance induced by a change. Several examples of situations demonstrate that a change can be at the origin of unwanted situations affecting the efficiency and safety performance of a system. Methods and tools must be developed to support change management taking into consideration these side effects. This article presents some theoretical considerations and a framework that aims to support anticipation of the consequences of change on safety performance.

1 INTRODUCTION

Consideration of change is one of the prerequisites of a proactive safety management system. Anticipation of opportunities and threats induced by change or innovation is one of the cornerstones of organisational resilience (Hollnagel et al. 2011). ISO 31000 monitoring and review requirements include the detection of changes in the external and internal context, which can require revision of risk management processes and the identification of emerging risks (NF ISO 31000).

A change occurring within a system or in its environment can affect safety performance in different ways. It can:

- Increase or decrease the degree of risk.
- Affect perception of risk.
- Be at the origin of emerging risks.
- Create new threats.
- Increase or decrease the capacity of the system to respond to threats.
- Etc.

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

This paper presents a framework that complements traditional change management practices in order to support anticipation of the potential consequences of change on system safety performance. The paper is structured into two sections. The first relates to the theoretical background that structures the development of the framework. The second presents the framework

2 THEORETICAL BACKGROUND

This section presents a set of theoretical issues aimed at structuring the development of a framework for the anticipation of the consequences of change. The following sections discuss diversity in the origin of change, the diversity of technological systems, diversity in the consequences of change and the diversity of safety dimensions that can be affected by change.

2.1 *Diversity of sources of change*

Sources of change can be structured using a framework composed of six dimensions. Four of these dimensions relate to the description of the internal parts of an organization (its social structure, technology, physical structure and culture) and the other two to its environment (organizational and general) (Hatch, 1997).

Social structure is related to all the means used to divide work into distinct tasks and to allow coordination of their execution. This complex system is the result of a combination of the formal structure and real interactions between agents of the organization. Formal structure is generally described as exchanges between strategic top levels, hierarchical reporting lines, operational centers, technological structures and logistic supports.

Technology is related to the means used to achieve a result (an objective, a product, a service, etc.). It includes physical objects or artifacts (products, tools, production means, etc.), processes and knowledge necessary for the development and use of equipment, tools and methods.

Organizational culture designates a set of meanings that are publicly accepted and collectively validated by a specific group at a given moment. Organizational culture includes beliefs, hypotheses, values, norms and artifacts that structure decisions and actions in the organization.

Physical structure concerns the relationships between different physical elements of the organization (buildings, technological devices, furniture, etc.). It includes the spatial localization of the different facilities of the organization, the logistic network between them and the internal layout of offices and production means.

The organizational environment designates entities that are in direct interaction with the organization. It can include economic entities (clients, suppliers, subcontractors, competitors, trade unions, banks, etc.), institutional entities (regulatory bodies, economic facilitators, etc.) and entities that are situated in the same spatial area (industrial facilities, residential areas, rivers, forests, etc.).

The general environment is related to general forces that can have an impact on the organization. Different sectors can be distinguished:

- The social sector relates to mechanisms that structure social behavior (demography, mobility model, lifestyle, etc.).
- The cultural sector relates to history, culture, traditions and values which structure the decisions and actions of the business.
- The legal sector is dedicated to the constitution and laws governing territories where the organization acts.
- The political sector relates to the separation and concentration of powers and the nature of the political system in the countries where the organization is active.
- The economic sector relates to the job, financial, goods and services markets.
- The technological sector relates to knowledge and information resulting from scientific progress.
- The physical sector relates to nature and natural resources (coal, oil, pollution levels, climatic conditions, etc.).

All of these systems can be at the origin of a change (new strategy, new procedures, new technology, new organizational identity, new facilities, new regulations, etc.) and be affected by it.

2.2 *Diversity of technological change*

Technological system diversity can be captured by two typologies (Parasuraman et al. 2000). The first is related to the type of functions potentially performed by a technological system. They can be divided into four types:

- Information acquisition. Automation is applied to the sensing and registration of input data.
- Information analysis. Automation is applied to inferential processes for data extrapolation over time or prediction.
- Decision and selection of actions. Automation is applied to the definition of alternatives and selection of the one that is most suitable.
- Action implementation. Automation is used to execute a set of actions

The second typology is related to the balance between automation and operator functions for the execution of a task. There are ten levels that range from high- to low-level automation, namely: the computer decides everything and acts autonomously, ignoring any human intervention (10); it informs the human only if it – the computer – decides to (9); it informs the human only if asked (8); it acts automatically, then must inform the human (7); it allows the human a limited amount of time to veto the action before automatic execution (6); it executes actions only if the human approves (5); it suggests an alternative action (4); it narrows the selection of actions down to a few (3); it offers a comprehensive set of decision/ action alternatives (2); it offers no assistance – the human must make all decisions and take all actions (1).

These two typologies capture the diversity of the nature of technological systems and they can be used to support a definition of the nature of the changes occurring in an organization. Nevertheless, other factors are necessary in order to capture the diversity of technological change:

- *Purpose*. The qualitative and quantitative reasons that motivated the change (enhancement or reduction of performance criteria, technological innovation, etc.).
- *Justification*. Elements that support the change and its impact.
- *Position*. Changes that take place in the context of the system: endogenous change (which occurs within the system studied) or exogenous (which occurs outside the system being studied).
- *Magnitude*. The scope of the change within the system being studied: changing one dimension of the system or changing the overall structure of the system.
- *Timings*. Steps, times and transitions constituting the process of change.
- *Direction*. The overall strategic context in which change takes place (linked to purpose).

- *Stability*. The change may be permanent or transient (i.e. depending on a given state of the environment).
- *Delay*. The time that elapses before the effects of the change can be seen.

These factors make it possible to consider the variety of technological change. The next section is related to diversity in the consequences of change.

2.3 *Diversity in the consequences of change*

Technological systems and human performance in a complex system can lead to different types of consequences that are related to initial goals, specifications (for technological systems), intention (for humans) and interactions and feedback with the environment in which they take place (Merton 1936, Morin 1990).

Change can lead to:

- Positive, unexpected benefits usually referred to as serendipity or a windfall.
- Negative 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
- Futility of innovation, e.g. the more things change, the more they stay the same
- Threat of achievements (we wanted to improve society, but only succeeded in removing freedoms and safety).

Several factors can explain these unexpected consequences:

- Ignorance: It is impossible to anticipate everything, thereby leading to an incomplete analysis.
- Error: An incorrect analysis of the problem or following habits that have worked in the past but may not apply to the current situation.
- Immediate interest: This may override long-term interests.
- Basic values: These may require or prohibit certain actions even if the long-term result might be unfavorable.
- Self-defeating prophecy or fear of consequences: These drive people to find solutions before a problem occurs, thus the non-occurrence of the problem is unanticipated.

Those concepts help to describe the diversity of potential consequences of a change. The next section describes the different dimensions to be taken into account when considering the consequences of change on safety performance.

2.4 *Diversity of safety dimensions affected by change*

This section describes different safety-based dimensions in order to capture the diversity of the consequences of a technological change on safety performance. Four dimensions are considered: risk, human factors, organizational resilience and inter-organizational.

Risk is related to the potential failure of a technological system, its probability and the gravity of the consequences.

Human factors are related to human non-technical skills that can be affected by the technological system: situational awareness, communication, stress, fatigue, decision-making, etc. (Flin et al. 2008).

Organisational resilience is related to the set of capacities that contribute to the organisation's ability to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Hollnagel et al. 2011).

The inter-organisational dimension is related to the set of systems that interact with the organisation and that can be at the origin of unexpected consequences. Such systems can be the legal system, population, clients, suppliers and competitors, entities situated in the same geographical area, etc. (Rinaldi et al. 2001).

The diversity of technological system change, the consequences of change and safety dimensions have to be taken in account in a technological assessment process.

Existing approaches do not focus on managing successful change taking in account the safety dimension, nor are they based on traditional risk assessment methods such as Failure Mode Effects and Criticality Analysis (FMECA), the Technique for Human Error Rate Prediction (THERP) or fault tree analysis. Such approaches make it possible to consider a set of consequences but present limitations regarding, among others things, the complexity of human behaviours and large-scale socio-technical systems.

The next section describes elements related to a technological assessment and the identification of consequences.

2.5 *Technological assessment*

The technological assessment (Westrum, 1991) relates to practices which aim to systematically consider the potential consequences of a change.

The technological assessment process can be structured in two steps.

- **Step 1**. *Broad Outline*. This broad outline characterizes the nature of the change being studied; it identifies some of the consequences of

change and thus the potential targets and stakeholders who would be affected by the change.
- **Step 2**. *Consequences Assessment*. The representative group constituted as a result of Step 1 then undertakes a set of exercises designed to help them identify and imagine future consequences.

Among the potential techniques that can be used to identify the consequences of change, some commonly used methods are:
- Mathematical modeling, simulation and trend analysis. These techniques attempt to provide formal computer models that are sufficiently specific to enable quantitative predictions.
- Technological forecasting. Here the emphasis is on predicting the development of technology and assessing the potential for it to be adopted, including a market analysis.
- Cross-impact analysis. Because technologies have interactive effects, realistic forward planning must consider the multiple potential impacts of technologies on society. The state of society in which the technology in question will be used must be considered.
- Scenario building. Definition of plausible action sequences used to facilitate consideration of unforeseen possibilities.
- Gaming. Gaming forces planners to take account of the actions of others who, as in real life, are likely to do surprising things.
- Delphi methods. A Delphi procedure provides a method of pooling expert opinion, and in its more sophisticated forms it forces experts to re-examine their own opinion in the light of possibilities raised or assessments made by others. The key is not simply to create an "average" assessment, but rather to provide a spectrum of opinions and their rationales.

A set of basic questions form the foundation for the technology assessment.
- How will the technology evolve? An assessment must determine what will happen to the technology itself. How much is it likely to change? Will it become cheaper? More efficient? Will competitive technologies spin off from it?
- What will the technology be used for? Often the answer to this question is not clear at the outset, but it has a great deal to with overall impacts.
- Who are the users? The primary impact of a new technology is felt by its users. Determining who they are likely to be allows us to answer many other questions.
- Who will decide how the technology will be used? Knowing who will sponsor a technology is valuable in anticipating its development; knowing who will resist it is equally important.

Requisite Imagination theory (Adamski & Westrum 2003), which is defined as the "art of anticipating what might go wrong" offers a framework dedicated to the support of change assessment. This framework is structured into eleven cognitive tasks:
- *Clarify the task*. Knowledge of the context of task design (purpose, technical demands, operators, etc.) has to be taken into account in the assessment process.
- *Consider the organization*. The organization and its management can negatively influence, delay or lead to the cancellation of planned changes. Organizational issues (customers and users, required and available resources, evaluation, people who have and don't have the authority to modify the project, the ultimate decision maker, etc.) have to be taken into consideration.
- *Align Designer/User Worlds*. Designers and users rarely shared the same representation of the task. User issues such as the typical perception of the task, its purpose and outcome; knowledge and skills required to complete the task; differences between novice, intermediate and expert users; user's perceptions of constraints and limitations; and feedback etc., have to be taken into consideration.
- *Consider the operational domain*. The specificity of the environment and the context of the system where actions takes place are different from one domain to another and have to be taken into account in the assessment.
- *Survey past failures*. Lessons can be learned from the past. Integrating historical reviews and failure analyses can prevent failures involving equipment, procedures, human and organizational factors or training.
- *Minimize "switchology*". The inappropriate use of controls (switches, buttons, levers, etc.) is a source of performance errors. Controls may not work the way they were intended, working conditions (light, time of day, etc.) may lead to difficulty in using controls.
- *Account for human error*. The different typologies of human error can be used as foundation for unexpected scenario design.
- *Consider information needs*. The nature and the quality of information required by actors in order to achieve their task must be identified and assessed.
- *Examine procedures*. Procedures related to task design must be studied in order to prevent side effects related to wrong interpretations by users.
- *Consider convention.* Conventions used in the system context must be identified in order to prevent failures related to their use.
- *Review constraints*. All internal and external constraints that can influence the task design process have to be identified and taken into account in the

process of identifying what can go wrong in the new system.

Managing the change process has to consider the complexity of the consequences of change on an organization in order to facilitate positive results and prevent unwanted consequences.

3 THE IMPACT METHOD

The IMPACT method provides a set of recommendations for a change process management. It is based on an analysis of the potential consequences and opportunities or risk. Consequences are identified through the application of an assessment strategy that is defined alongside an examination of the change considered.

Application of the method is based on methodological guidelines describing the different steps to be achieved and a toolbox describing data acquisition processes and performance indicator assessment guidelines.

3.1 *Methodological guidelines*

The IMPACT method is based on four phases.

- **Phase 1**: General Outline. This phase describes the knowledge necessary to understand the technological change studied and defines a strategy dedicated to the identification of its potential consequences. The strategy is based on the selection of a set of relevant assessment targets.
- **Phase 2**: Consequence identification. The purpose of this phase is to identify potential consequences of the change in question by applying the assessment strategy defined in the first phase. The result of this phase will be a list of potential consequences.
- **Phase 3**: Risks and opportunities analysis. This phase evaluates the risks and the opportunities associated with the change in question. The set of consequences identified in the previous step is looked at and a list of potential risks and opportunities is defined.
- **Phase 4**: Recommendations for decision-making. The purpose of the last phase is to define a set of recommendations for change design and management processes based on the analysis of the set of risks and opportunities identified in the previous step.

In order to support the application of the method, a set of methodological guidelines related to the information acquisition process and the performance dimension assessment is suggested.

3.2 *Toolbox*

The IMPACT toolbox consists of two methodological guidelines: data collection processes and performance indicator assessment processes. These processes provide assessment modules to be applied during the consequences assessment phase of the method.

In the operational version, there are three types of data collection processes:

- *Risk assessment*. Traditional risk assessment processes based on different methods (FMECA, HAZOP, THERP, CREAM, etc.).
- *Focus groups*. Focus groups is an approach that consists of asking a group of people about their feelings, opinions, and beliefs concerning an idea, a concept, a product, etc.
- *Simulation*. Simulation can be an efficient way to identify the consequences of a change on a system. Simple role-playing games or more elaborate simulations using technological facilities such as bridge, flight or crisis management simulators can be used in order to acquire information about the consequence of a change by, for example, comparing the execution of a given scenario with and without the application of the change.

Four levels of performance indicators are suggested:

- *Risk based consequences*. Consequences related to technical, human or organisational failure modes.
- *Human- and organisational-based consequences.* The consequences related to human and organizational factors approaches include: non-technical skills definition and assessment; research and development activities, e.g. situation awareness, decision-making, communication, teamwork, leadership, stress, fatigue (Flin et al. 2008); control performance assessment (Hollnagel & Woods 2005); and risk governance e.g. pre-assessment, management, appraisal, characterization, evaluation and communication (Renn & Walker 2008).
- *High Reliability Organisations (HRO) and Resilience Engineering-based consequences*. Consequences identified by safety science research include: organizational resilience capabilities, e.g. Respond, Learn, Monitor and Anticipate (Hollnagel et al. 2011); HRO abilities for the management of unexpected situations, e.g. Preoccupation with failure, Reluctance to simplify interpretations, Sensitivity to operations, Commitment to resilience, Deference to expertise (Weick & Sutcliffe 2001); and the Efficiency Thoroughness Tradeoff model i.e. Work ETTO, Psychological ETTO, and Organizational ETTO (Hollnagel 2009).

4 CONCLUSION

The objective of the IMPACT framework is to integrate safety dimensions into change management and technological assessment processes.

Some initial methodological guidelines were developed using a modular approach that integrates different data collection processes and performance indicators.

This framework was tested in the context of an assessment of the potential consequences of the use of a 3D Chart for navigation functions. A focus group was organized with representatives from maritime systems and a set of bridge simulations based on a search and rescue mission was carried out using the use of Stress, Control and Situation Awareness assessment modules.

It is currently being tested in the assessment of potential consequences associated with the use of UAS and automated threat recognition software for pipeline monitoring. A focus group was organized with representatives of pipeline monitoring systems and a set of role-playing games attempted to identify stakeholders.

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