CONSIDERING TRADE-OFFS WHEN ASSESSING RESILIENCE

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Abstract. This article describes the development of a prototype Resilience Analysis Grid for rail traffic management. The findings from testing of the initial model led to the identification of a set of potential vectors for improvement, in particular the need to integrate trade-offs. Based on Resilience Engineering trade-off theory this paper discusses how to integrate trade-offs into the system description and the impact of trade-offs on the four main resilience capacities.

1 INTRODUCTION

Resilience is an integrative concept that appeared in 21st century scientific thinking and encompasses two main ideas: recovery and the sustainability of systems in coping with stressful events (Reich et al., 2010). In Safety Science, resilience-based research aims to provide responses to the emergence of new and unanticipated threats that cannot be controlled by traditional prevention and protection practices. These threats are the consequence of changes in society and the emergence of vectors such as globalisation, increasing interdependence and complexity, the spread of potentially dangerous technology, etc. (Comfort et al., 2010).

The Resilience Engineering community aims to improve the control function of complex adaptive systems so that they are able to adjust their functioning prior to, during, or following changes and disturbances and can sustain the required operations under both expected and unexpected conditions (Hollnagel et al., 2011). Resilient processes aim to support the measurement of resilience factors, to monitor short-term developments and their consequences, to anticipate the emergence of long-term opportunities and threats and to provide adequate feedback loops from past events (Hollnagel et al., 2011).

A framework dedicated to the assessment and control of system resilience is currently under development (Rigaud et al., 2013). The framework is based on the Resilience Analysis Grid (Hollnagel et al., 2011) and aims to be able to define the resilience of a system, including: the definition and assessment of resilience factors and associated margins, the definition of a control scorecard and the definition of a list of improvement actions. Initial experiments established the need to be able to integrate trade-offs that may be the origin of performance variability.

This article discusses the issues raised by the integration of trade-offs into a resilience assessment and control process. The first part provides the foundation for the discussion that follows. It presents the initial Resilience Assessment framework developed for rail traffic management and the improvement vectors that emerged from initial testing. The second section offers some preliminary findings concerning the integration of trade-offs into the observation and description of a system and the causalities between trades-offs and resilience abilities.

2 THE RESILIENCE ASSESMENT FRAMEWORK

The first phase of the project was to formalise a generic Resilience Analysis Grid (RAG) in order to develop the capacity of systems to monitor their resilience performance. The grid was composed of a set of indicators that were related to the four capacities of a resilient organisation: the capacity to respond in an effective and flexible manner to normal, unusual and unanticipated situations; the capacity to monitor short-term developments and threats; the capacity to anticipate long-term threats and opportunities; and the capacity to learn from past events to correctly understand what happened and why (Hollnagel et al. 2001).

On the basis of this grid, focus groups were organised in order to develop a framework for the assessment of the resilience of rail management processes (Rigaud et al., 2013). The framework initially consisted of thirty-eight indicators related to the four resilience capacities (cf. Table 1), together with some introductory material about resilience performance and assessment guidelines and forms.

The resilience framework aims to monitor performance that is not captured by current assessment tools. Initial experiments identified both positive and negative outcomes and potential areas for improvement. Some indicators were difficult to understand and others were more or less relevant to the functions performed by an agent. The data collected was difficult to compare and aggregate and consequently it was difficult to use it as a basis for extracting relevant lessons and recommendations. Three areas for improvement were identified. The first concerns the refinement of indicators. The second is the integration of trade-offs into the framework, and the third relates to improvements to data collection and analysis processes.

Table 1. Example of an indicator

Indicator 2	**The time required to provide resources needed to respond is appropriate to the situation**	**Capacity to respond**
Indicator description		
Human and material resources required to respond have to be available and operational to provide an efficient response.		
Evaluation		
Insufficient. The availability and efficiency of resources does not receive particular attention.		
Average. Regular checks are made of the suitability of major resources.		
Acceptable. Regular checks are made of the suitability and availability of major resources.		
Satisfactory. Major and minor resources are exclusively dedicated to the response plan and their suitability and availability are regularly checked.		

2.1 Refinement of indicators

The aim of refining the four main capacities of organisational resilience was to make it easier to assess and control nuances. Starting with the four initial capacities, eleven key indicators were defined (cf. Table 2).

Table 2. Eleven abilities of organisational resilience

Capacity	Key indicators
Capacity to Respond	Ability to respond to normal system and environmental variability
	Ability to respond to routine abnormal situations
	Ability to respond to unusual abnormal situations
	Ability to respond to unanticipated situations
Capacity to Learn	Ability to learn from unwanted situations
	Ability to learn from daily situations
Capacity to Monitor	Ability to monitor past safety performance
	Ability to monitor actual safety performance
	Ability to monitor potential future safety performance
Capacity to Anticipate	Ability to anticipate consequences of change
	Ability to anticipate consequences of innovation

2.2 Considering Trade-offs

Hoffman, Woods and Hollnagel have described how trade-offs are fundamental to human adaptive systems (Hoffman and Woods, 2011; Hollnagel, 2009). Their work aims to provide new concepts for modelling individual, collective and organisational behaviours and their impacts on system resilience. They identify five trade-offs: 1) optimality–fragility, 2) efficiency–thoroughness, 3) acute–chronic, 4) specialist–generalist, and 5) distributed–concentrated. These relate to different dimensions of a socio-technical system and can affect different aspects of resilience performance.

Taking trade-offs into account implies that:

- Agents perceive their environment relative to their own experience. An agent's perspective depends on factors such as culture, experience, aims or their unit's perspective.
- Strategy and plans designed to support an agent's performance may fail because of resource limitations (time, knowledge, information, human, technological, etc.).
- The system is divided into units. Each unit has its own goals, performance indicators and risks and responsibilities, which constitute the unit's perspective.
- Activities can depend on the joint performance of several units that can belong to independent systems.
- All the events that can occur in the system environment cannot be identified. Therefore resilience implies the implementation of relevant strategies for responding to known events and sufficient capacity and margin to respond to unanticipated events.

The integration of trade-offs into the resilience assessment and control processes leads to three issues, namely:

- **System description**. This concerns the identification of trade-offs that can influence resilience performance, specific data collection requirements and organisational approaches. What information is necessary to identify and define trade-offs? How is this information acquired? How is the quality of the information defined? How is this information structured?
- **Causality between trade-offs and resilience variability**. For each resilience factor: how to identify the trade-offs that influence variability? How to define and model variability that is due to trade-offs and variability that is due to resilience factors?
- **Trade-off control**. The definition of an improvement action plan and key resilience performance indicators must take into account trade-offs. How to control trade-offs? How to prevent trade-offs negatively influencing resilience

factors? What new trade-offs emerge as the result of controlling trade-offs? Do these emergent trades-offs influence resilience?

The following section discusses the identification of trade-offs during system observation and description and causalities between trade-offs and resilience abilities.

3 INTEGRATING TRADE-OFFS INTO RESILIENCE ASSESSMENT

The integration of trade-offs into resilience assessment means that: i) it must be possible to characterise them through observation and description of the system; and ii) the causalities between them and resilience abilities must be understood.

3.1 Identifying and describing trade-offs

The information collected about the system with the objective of modelling trade-offs relates to the individual, collective and organisational level. Here we propose a framework to describe a system that takes trade-offs into account. This framework looks at the system from four perspectives: the system, the network, the unit and the agent.

System perspective

The optimality–fragility trade-off is linked to the description of threats and safety management. The set of threats that can affect the system are identified and structured in terms of: known threats where specific barriers exist; known threats where there are no specific barriers; and unanticipated situations (if any). The information to be collected relates to the safety management system, safety barriers, accident investigation reports, agent's experience of unanticipated situations and the adaptive capacity required to respond to them.

The evolution of the system and the removal or modifications to safety barriers has an impact on the optimality–fragility trade-off and consequently how agents see such situations (such as confidence in ineffective barriers or an improvised response to a situation where a procedure exists).

Network perspective

The system can be seen as networked units that interact. A first network consists of the organisation's social structure, which is composed of strategic decision-making units, hierarchical units and operational units. A second network is the activity network that consists of all the units (from different social structures) participating in the execution of an activity (production, control, etc.).

The specialist–generalist and distributed–concentrated trade-offs are linked to the description of the system's organisational networks. The system's formal and informal units are identified in terms of their interrelations and perspectives. In order to map the organisational network of a system, data must be collected about the organisation's formal social structure, its activity networks and agent's perceptions of informal units.

Changes in the organisational structure of the system and its economic environment will affect the model of its network structure.

Unit perspective

Units are the nodes of the system's organisational network. The specialist–generalist and distributed–concentrated trade-offs are linked to the unit perspective and the efficiency–thoroughness trade-off influences a unit's performance. Data concerning aims, responsibilities, procedures, performance indicators and the profile of agents belonging to units defines this perspective. Data related to minimal condition profiles (time, information, knowledge, resources, etc.) required to perform activities under normal and abnormal conditions defines unit performance variability.

Variability in both a unit's internal structure and any units connected to it affect the unit's performance.

Agent perspective

Units are composed of agents who work to meet the goals of the unit. The acute–chronic trade-off is linked to the agent perspective and the efficiency–thoroughness trade-off influences their performance. This perspective is defined by data related to the training of agents, their culture and perceptions of activities and risks.

Changes in the unit perspective, unit organisation, agent training or the occurrence of an event can cause variability in the agent perspective. An agent's performance in the unit and the performance of other units can affect the agent's capacity to perform tasks.

3.2 Linking trade-offs and resilience performance models

The following sections describe the potential impact of trade-off variability on each of the four resilience capacities (respond, monitor, anticipate, learn).

Capacity to respond

Organisational and inter-organisational trade-offs influence the capacity of a system to respond in the following ways: the ability to detect that something has gone wrong, to recognise the situation and its criticality, the ability to define a response plan and to actually respond (cf. Table 3)

Table 3. Influence of trade-offs on the capacity to respond

Trade-off	Dimensions affected
Acute–chronic	Agent's perceptions of: - Normal and abnormal functioning of the system; - Criticality of situations; - Response plan; - Adaptation to unanticipated situations.
Efficiency–thoroughness	Availability of time, knowledge, information and resources to: - Detect an abnormal situation; - Recognise the situation; - Consider the criticality of the situation and decide to respond; - Respond.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of the criticality of situations.
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

Capacity to monitor

Organisational and inter-organisational trade-offs influence the capacity of the system to monitor in the following ways: the ability to define and revise indicators, the ability to collect information, the ability to analyse indicators, the ability to respond to variability in indicators (cf. Table 4).

Table 4. Influence of trade-offs on the capacity to monitor

Trade-off	**Dimensions affected**
Acute–chronic	Agent's perceptions of: - Nature of indicators; - Measurement frequency; - Criticality of variability in indicators.
Efficiency–thoroughness	Availability of time, knowledge, information and resources to: - Collect data; - Evaluate indicators; - Analyse indicators.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of the criticality of situations.
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

Capacity to anticipate

Organisational and inter-organisational trade-offs influence the capacity of the system to anticipate in the following ways: the ability to detect changes and innovations and to analyse them in order to identify threats and opportunities (cf. Table 5).

Table 5. Influence of trade-offs on the capacity to anticipate

Trade-off	Dimensions affected
Acute–chronic	Agent's perceptions of: - The potential consequences of change and innovation for risk and the ability to respond; - Ability to identify new threats; - Ability to identify opportunities.
Efficiency–thoroughness	Availability of time, knowledge, information and resources for: - Change and innovation identification; - Change management; - Risks and opportunities analysis.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of the criticality of change and the potential consequences of innovation.
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

Capacity to learn

Organisational and inter-organisational trade-offs influence the capacity of the system to learn in the following ways: the ability to select relevant situations for learning, the ability to identify relevant lessons from situations, the ability to learn from lessons (cf. Table 6).

Table 6. Influence of trade-offs on the capacity to learn

Trade-off	**Dimensions affected**
Acute–chronic	Agent's perceptions of: - The choice of relevant situations for learning; - The ability to identify a diversity of lessons from situations; - Ability to learn lessons.
Efficiency–thoroughness	Availability of time, knowledge, information and resources to: - Study situations; - Learn from the results of investigations.
Specialist–generalist	Communication capacity between units. Variability in unit's perspective of lessons to be learned from past events.
Distributed–concentrated	Communication capacity between units.
Optimality–fragility	Safety culture. Safety barriers.

4 CONCLUSION

The initial test of a resilience assessment framework dedicated to railway management processes highlighted three areas for improvements: the need to refine the description of resilience abilities, the integration of trade-offs and improved data collection processes. This article presented the preliminary results of the refinement process with the aim of producing a new prototype framework. In particular we discussed the issues related to the integration of trade-offs into system observation and description and understanding the causalities between trade-offs and resilience abilities.

These results will be used to define a new structural model of resilience abilities, to improve the data collection processes related to the model and develop an improvement plan.

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