Resilience Analytics by Separation of Enterprise Schedules: Applications to Infrastructure

Heimir Thorisson[i] and James H. Lambert[i*]

Keywords: Resilience analytics, scheduling, systems engineering, strategic planning, scenario analysis

[*]Corresponding author: lambert@virginia.edu

Introduction

This article identifies literature and other resources for resilience analytics applied to infrastructure, in particular when the emphasis is the disruption of preferences by alternative scenarios. It recognizes that multiple, possibly conflicting, perspectives of politics, economics, demographics, technology, environment, etc., are an inherent part of decision-making and plans and processes need to be resilient to emergent and future conditions that might bring one or more perspectives closer to the front. In a previous volume, the authors provided a review of definitions and quantifications of resilience analytics (Thorisson & Lambert, 2016). Here, the focus is on applications to infrastructure, with a motivating demonstration to building capacity for wireless broadband for public safety agencies (Hassler & Lambert, forthcoming).

Infrastructure risk and disaster management

Agencies are put under considerable strain during disasters. The disruptive effects of disaster can cascade across geographic, political, institutional, and other boundaries. For example, in September 2018, hurricane Florence made landfall on the United States East Coast. Populations in three states, South Carolina, North Carolina, and Virginia, were evacuated from their homes and sought shelter across the Southeast region of the country. Agencies responsible for transportation, public health, education, and others needed to cooperate with local and federal first response and emergency management agencies. In such a scenario, sharing of information and resources across different agencies is critical. To support such data exchanges and facilitate communications, the United States Congress approved in 2012 the creation of a nationwide interoperable public safety broadband network (FirstNet). The enterprise systems planning for the FirstNet accounts for the interests of local, state/territory, tribal and federal public safety agencies across the United States. In particular, FirstNet planners are collaborating with public safety stakeholders and leadership from each state and territory. The coming nationwide broadband network is thus aimed to meet needs of the agency users as they protect communities and lives across the nation. Design and implementation of such a system is subject to a variety of stressors and sources of risk. The objectives of several groups of

[i] Department of Engineering Systems & Environment, University of Virginia

Suggested citation: Thorisson, S., & Lambert, J. H. (2018). Resilience analytics by separation of enterprise schedules: Applications to infrastructure. In Trump, B. D., Florin, M.-V., & Linkov, I. (Eds.). *IRGC resource guide on resilience (vol. 2): Domains of resilience for complex interconnected systems.* Lausanne, CH: EPFL International Risk Governance Center. Available on irgc.epfl.ch and irgc.org.

stakeholders must be balanced. Resilience analytics can be useful to explore the tradeoffs between meeting objectives, accepting risk, and cost.

Risk and resilience

Resilience analytics as described in this article focuses on methods for identifying the perspectives of a system (or particular *risk scenarios* related to the perspectives), that are most in need of investigation, including risk analysis, simulation, experimentation, data collection and analysis, etc. (Karvetski et al., 2009, Teng et al., 2012). It is complementary to traditional risk management by focusing on how differences in priorities between stakeholders can pose risks to the system.

Resilience analytics identifies the perspectives that have the greatest potential to disrupt a prioritization of system milestones/initiatives (Linkov & Trump, forthcoming). The perspectives that are found to have a high disruptive potential are candidates for an in-depth investigation, including an assessment of the consequences and likelihood of risks associated with the particular perspective. Risk analysis often relies on being able to assess likelihood and consequences, while resilience analytics can proceed without that assessment (Thorisson et al., 2017b).

In application, milestones of a system are prioritized such as to most effectively meet system goals and objectives. This prioritization can vary between different system perspectives. In the development of a public safety broadband network, at least three perspectives must be considered, each representing a distinct group of key stakeholders:

- The *government/regulatory perspective* represents the owners of the system (and the constituents they represent)
- The *vendor perspective* represents the technical developers and operators of the system
- The *public safety perspectives* represent the system users, public safety agencies

If there are large discrepancies between the perspectives about the prioritization of system milestones, the system is less resilient as stakeholders do not agree on how to mitigate losses or recover from disruptions. Multiple success criteria, measuring the goals and objectives of the system, need to be considered. Table 1 describes ten identified criteria along with their relevance in each perspective. Using multicriteria analysis (e.g., Karvetski et al., 2009), the coverage of criteria by the system milestones (Hassler & Lambert, forthcoming), can be used to prioritize the milestones. An aspect of resilience analytics is to identify milestones with large differences in priority between perspectives to help guide further risk management. The different relevance of criteria to the various stakeholder groups results in a different prioritization in each perspective.

Table 1: Success criteria to prioritize schedule milestones in public safety broadband networks, and their relative relevance for three stakeholder perspectives.

Index	Criteria	Government/regulatory relevance	Vendor relevance	Public safety relevance
c_1	Availability	*high*	*high*	*high*
c_2	Privacy	*low*	*low*	*medium*
c_3	Interoperability	*high*	*medium*	*high*
c_4	Usability	*medium*	*high*	*high*
c_5	Quality of Service	*low*	*high*	*low*
c_6	Affordability	*high*	*medium*	*medium*
c_7	Standards Based	*low*	*low*	*low*
c_8	Flexibility	*medium*	*low*	*medium*
c_9	Coverage/Ubiquity	*high*	*high*	*high*
c_{10}	Risk Aversion	*medium*	*low*	*medium*
c_m	Others			

Figure 1 illustrates the prioritization of milestones in the development of a public safety broadband network. The figure shows 22 milestones, ranging from promoting cyber security, to investing in customer service, to developing data standards. The milestones are prioritized from the three perspectives, allowing for comparison of prioritization across the perspectives. Some milestones, such as *x20: Invest in satellite services*, have a wide range in priority among the three perspectives (described above), suggesting these are vulnerable in case the schedule is disrupted. Others, such as *x04: Improve data source access*, are consistently prioritized similarly. The variation of a milestone in priority between perspectives can help guide risk management as a milestone with a large difference could be a point of contention when negotiating recovery strategies following a disruption.

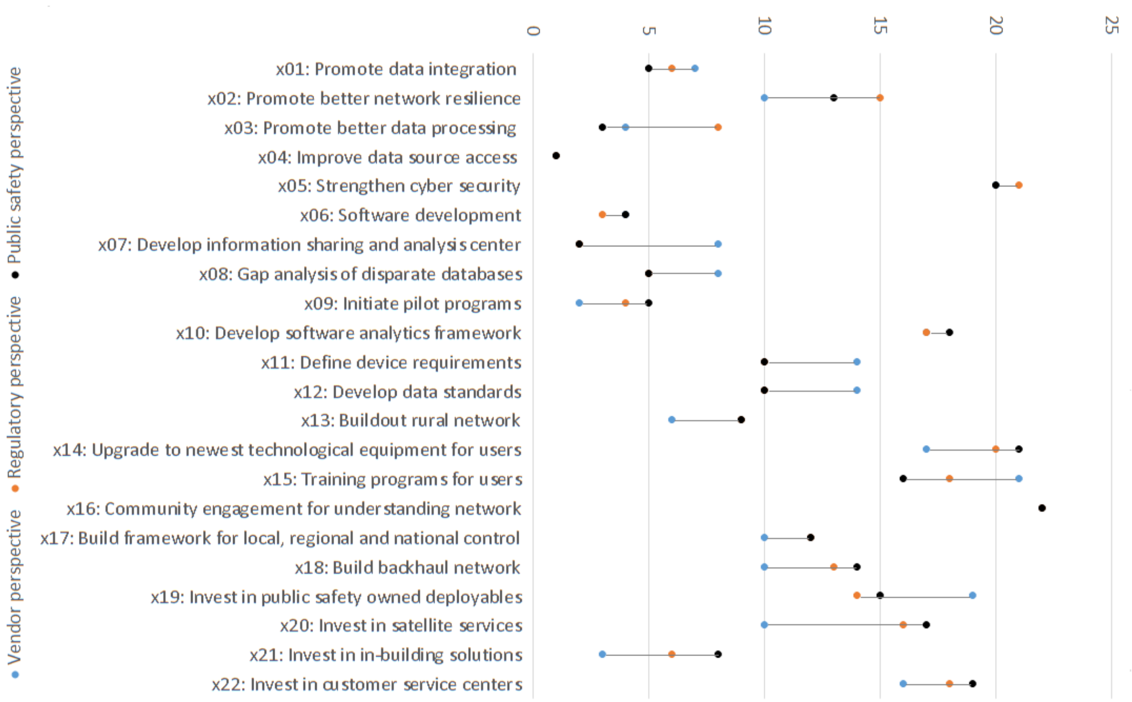

Figure 1: Prioritization of schedule milestones towards a public safety broadband network from three perspectives: owner (regulatory), operator (vendor), user (public safety community).

System transitions and negotiations

The *resilience* (as a separation of priorities between system perspectives) has been quantified as the absolute value of change in prioritization (Connelly et al., 2015, Parlak et al., 2012), the sum of squares of ordering change (Hamilton et al., 2012), Spearman rank correlation coefficient (Thorisson et al., 2017b, Kendall tau rank correlation (Hamilton et al., 2016, You et al., 2014a; You et al., 2014b). Table 2 demonstrates the quantification of resilience from one perspective to another, measured by the Kendall Tau correlation coefficient. The coefficient takes value 1 when all combinations of pairs of milestones have the same order in two perspectives and value 0 when all pairs have the opposite order. Thus, the agreement between the prioritizations in the vendor and public safety perspectives is the lowest among the three perspectives, followed by the agreement between the vendor and the regulatory perspective. Conversely, the regulatory and public safety perspectives have higher agreement. This means that stakeholders in the vendor community have the most distinct priorities among the three stakeholder groups, including priorities during adaptation or recovery from a disruption.

Table 2: Quantification of resilience from one perspective to another (Kendall Tau correlation coefficient)

	Regulatory perspective	Vendor perspective	Public safety perspective
Regulatory perspective	1	0.71	0.90
Vendor perspective	0.71	1	0.68
Public safety perspective	0.90	0.68	1

Assessing how separate priorities of different perspectives are can be helpful when negotiating a schedule, or a recovery plan following a disruption. Acknowledging the differences allows for studying and addressing their root causes or building flexibility.

The methods described have been applied in various other sectors of infrastructure and transportation, including power grid development (Hamilton et al., 2016; Thorisson et al., 2017), disaster recovery (Collier & Lambert, 2018; Connelly et al., 2015; Lambert et al., 2013; Parlak et al., 2012), development of electric vehicle bidirectional charging (Almutairi et al., 2018; Thorisson et al., 2017a), aviation biofuels industry development (Connelly et al., 2015), and others.

Conclusion

Resilience analytics should be considered in the context of negotiations (Thekdi & Lambert, 2015) or development of terms for design and operations of systems (Lambert et al., 2012). *Resilience analytics* as described in this article does not replace traditional approaches of consequence and likelihood-based procedures that analyze the effects of particular events or risk scenarios. However, it adds a layer of preliminary analysis that considers the connections and interactions of stakeholders on an enterprise level. Resilience analytics studies systems based on their schedules and milestones, and disruption, recovery, and adaptation are considered in this light. Quantifying how schedule priorities differ across stakeholder perspectives, and what milestones have the largest discrepancies, provides a starting point for negotiating terms and furthermore identifies urgencies for risk management. Thus, resilience is achieved by anticipating and accounting for the perspectives and other factors that are identified to have the greatest potential to have cascading effects on the overall schedule of implementation.

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