Multi-Perspective Scenario-Based Preferences in Enterprise Risk Analysis of Public Safety Wireless Broadband Network

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Abstract

Agencies that have key roles in disaster mitigation in society may be underequipped with communication technology to effectively meet demands during times of crisis. In particular, high-bandwidth software applications that make use of streaming video and transmission of big data are on the horizon. The US national First Responder Network Authority (FirstNet) aims to alleviate this need by providing a public safety broadband network for communications among first responders both during times of crisis and normal operations. Early in the lifecycle of this large-scale system, there are a variety of sources of enterprise risk to be identified and addressed as well as opportunity to improve enterprise resilience at a variety of geographic and temporal scales. This thesis identifies the emergent and future conditions that most and least matter to enterprise risk management, demonstrating a risk analysis model that is grounded in the latest theory of multi-perspective scenario-based preferences analysis. The effort extends theory and practice by iteratively applying a multi-perspective approach, testing the approach in the new circumstances of an advanced communication system. It demonstrates how scenarios relatively influence the prioritization of initiatives for each key stakeholder and how to update the assessment for the monitoring of risk over months and years of the deployment. The steps of the approach are the following (i) literature and practice review, (ii) data collection on emergent/future conditions, initiatives, and success criteria, (iii) initial exercise of the model, (iv) stakeholder feedback and validation with partner efforts, (v) revision and iteration of the model, and (vi) recommendations for tracking of enterprise risks into the future. This effort is coordinated with the efforts of two other teams of investigators who provide (i) technology assessment of broadband wireless networks for public safety, and (ii) the legal and social context. The intellectual merit is enterprise risk analysis addressing emergent and future conditions influencing the success criteria for interrelated distributed investments in wireless broadband. The broader impact is a framework for use by the 56 US states and territories that are concurrently adopting FirstNet over the next decade, expected to protect cost, resources, and time.

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Contents

List of Figures

List of Tables

1 Introduction

1.1 Chapter overview

This chapter describes the motivation for the thesis, the need for exploring uncertainties in emergent and future conditions for a new enterprise system with conflicting objectives and motives. It describes the purpose and scope of the thesis as well as the general organization of chapters and materials to be presented.

1.2 Motivation

The deployment of a new system presents many associated risks as well as opportunities to build resilience and robustness. In order to design resilient and risk tolerant systems, analysis must be done to investigate how to set priorities and what scenarios most and least matter in a developing system. Various stakeholders will have different objectives and motivations for the system. These conflicting aims among stakeholders must be taken into account. The systems engineer can fill the important role of providing research, methods and tools to aid in the development of metrics, models and solutions, methods that

prioritize among candidate solutions, and procedures for monitoring of progress. Additionally, risk analysis can identify emergent and future conditions that can disrupt the system and understand how these risks disrupt priorities. Together, a model can be developed for stakeholders to be able to understand future uncertain conditions with the ability to update with the introduction of new information. There are *deep* uncertainties (Karvetski & Lambert, 2012) in the development of a new system and without reliable knowledge of probability and severity, analysts must engage other methods for assessing and mitigating risk. Hamilton et al. (2015) address these challenges with scenario-based preference model based on stakeholder engagement and an iterative approach. This approach seeks to engage the stakeholders and applies the modeling techniques to update information in the model continually. You et al. (2014) integrate multiple stakeholder perspectives in assessing the model. This approach seeks to integrate the varying opinions of stakeholders rather than aggregating them throughout the entire modeling process. Yet, these approaches are in need of refinement and testing for both multiple perspectives and updating circumstances. This thesis aims to bridge this gap.

During disasters, public safety agencies are put under considerable strain. It quickly becomes clear how inadequate the communication within and between different sectors of public safety is. This became especially apparent during the 9/11 attacks in New York in 2001. When police received the call to evacuate because of the imminent collapse of the towers, this message was not conveyed to fire fighters in the same building. These different agencies could not communicate with one another and as a result lives were lost (Dwyer et al., 2002). This was also not the first-time communications had caused problems at the World Trade Center. Radio breakdown during the 1993 bombing also caused massive delays in the evacuation of the towers (Roberts, 2004). Similar issues arose in the aftermath of Hurricane Katrina when cellular communications were down for many days (weeks in some areas) preventing public safety from being able to effectively respond to emergencies (Banipal, 2006). In the wake of disasters such as these, the U.S. Congress passed the Middle Class Tax Relief and Job Creation Act of 2012 which funded the

creation of the First Responder Network Authority (FirstNet), a nationwide, interoperable public safety broadband network (Middle Class Tax Relief and Job Creation Act of 2012). FirstNet is now in the process of being rolled out to states and territories across the nation. Each state or territory has the option to opt-in or out of the plan. AT&T has been awarded a 25-year contract to supply the service to states that have opted-in. It is yet unclear what the risks and requirements will be for an effective rollout of the FirstNet program in the Commonwealth of Virginia. Arriving at a set of priorities as well as which emergent conditions could greatly disrupt the system for risk mitigation and resilience will be beneficial for all stakeholders involved.

1.3 Purpose and scope

This thesis develops an iterative approach to a multi-perspective scenario-based preferences model and demonstrates the approach in the context of the development of the First Responder Network Authority system in the Commonwealth of Virginia. This method differs from previous efforts by accounting for updating of elements of the approach in an iterative fashion while also addressing the differing perspectives of key stakeholders. The elements that can be updated include (i) perspectives, (ii) criteria, (iii) initiatives, and (iv) emergent conditions and scenarios. In particular, it avoids aggregating stakeholder outlooks and provides tailored results for each key stakeholder and uses iteration to further investigate these differences with the aim of coming to a consensus about what will most disrupt the system as a whole. The work will demonstrate how various emergent conditions will affect the prioritization of initiatives aimed at bolstering the FirstNet program. Stakeholders such as the regulatory body (state governors, state emergency management departments, etc.) first responders (police, fire, medical personnel), vendors (cellular network providers) and others are able to see the outcome of their input without the dilution of other perspectives which allows for comparison across perspectives to find an ideal prioritization and risk management strategy. This strategy can be updated through further iterations to continually benefit the stakeholders involved throughout the lifetime of the system.

1.4 Organization of thesis

This thesis is organized as follows: Chapter 2 discusses literature relevant to the thesis in the risk analysis and multicriteria and scenario analysis fields with an emphasis on complex systems analysis. Chapter 3 provides a detailed look at the technical approach for the thesis and outlines the methodology that will be used. Chapter 4 demonstrates the methods presented to the case study of the First Responder Network Authority. Chapter 5 discusses the implications of the findings and addresses some limitations of the model and considers the contributions of this thesis and discusses the need and direction of future work.

1.5 Chapter summary

This chapter has defined the motivation for the thesis and gave an introduction of the later chapters. It also discussed the purpose of the work to determine the scenarios that most and least matter to the FirstNet system, a public safety wireless broadband network and quantify their disruption.

2 Background

2.1 Chapter overview

This section will review relevant literature that provides a theoretical foundation for this thesis. It presents the papers that support the goals of this thesis and covers the categories of risk filtering and identification, multi-criteria and scenario analysis and multiple perspective and iterative approaches to systems analysis. This chapter covers the challenges of current literature and acknowledges gaps of current work.

2.2 Literature review

Multicriteria analysis enables decision-makers to structure problems and make traceable, justifiable and explainable decisions (Linkov et al., 2006; Belton & Stewart, 2002; Chankong & Haimes, 1983). Montibeller and Franco (2010) integrate scenarios to multicriteria analysis. Multicriteria analysis with scenario-based preferences has moved away from the traditional risk analysis of focusing on probabilities and consequences and is instead shifting the focus on risk as the influence of scenarios on priorities (Almutairi et al., 2018; Collier et al., 2018; Karvetski & Lambert, 2012; Thekdi & Lambert, 2013). The integration of

qualitative methods such as risk identification using HHM (Haimes, 2004; Haimes et al., 2002; Lambert et al., 2001), and scenario planning with multi-criteria analysis promotes and supports robust strategic decision making (Montibeller & Franco, 2010). When exploring uncertainties of complex systems where probabilities are derived from expert opinions and subject to cognitive bias, scenario planning is been useful (Goodwin & Wright, 2001). For situations facing deep uncertainties this is particularly relevant. Emergent and future conditions are elicited from stakeholders, and scenarios are developed as combinations of one or more of these risk conditions identified. The criteria are adjusted to account for uncertainties introduced in particular scenarios. The influence of each scenario on the prioritization has been quantified using rank correlation measures such as Spearman rank correlation coefficient (Thorisson et al., 2017), sum of squares ranking change (Hamilton et al., 2016; Hamilton, Thekdi, et al., 2013) and Kendall Tau-b distance (You et al., 2014).

Robustness of initiatives is assessed by measuring how the rank of initiatives deviates from the baseline under different scenarios. This has been applied to many fields such as container port operations (Collier et al., 2018), bidirectional electric vehicles (Almutairi et al., 2018), energy security (Thorisson et al., 2017; Hamilton, Lambert, et al., 2013; Karvetski et al., 2011), development of a biofuel industry (Collier et al., 2017; Connelly & Lambert, 2016; Connelly et al., 2015), disaster management (Lambert et al., 2013; Parlak et al., 2012), and impacts of climate change to infrastructure investment (Hamilton et al., 2015; Karvetski et al., 2011; You et al., 2014).

In the domain of risk analysis of complex systems, various formal methods have been developed to aid analysts in risk identification and filtering. Hierarchical holographic modeling (HHM) is one such method for risk identification and filtering as described by Haimes (2015, 1981). HHM describes that systems cannot be sufficiently modeled from a single perspective and offers a method to deconstruct system into multiple, complementary hierarchical structures. Qualitative or semi-quantitative methods have also been proposed by Morgan et al. (2000) and Baccarini & Archer (2001). The risk filtering, ranking and

management framework (RFRM) filters scenarios by likelihood and consequences, as well as their ability to defeat three defensive properties of the system (redundancy, resilience and robustness) (Haimes et al., 2002). Lambert et al. (2001) outlines five ways to identify sources of risk or stressors:

- Interviews with stakeholders
- Review of requirements documents and other planning materials
- Review of relevant third-party program analyses
- Review of lists of risks prepared by program managers
- Consult third-party consultants familiar with the program

The addition of separating out multiple perspectives to was added to the scenario-based preference modeling by You et al. (2014). This addition aims to highlight the various needs and goals of multiple stakeholders and thereby strengthening the results of the analysis. Hamilton et al. (Hamilton et al., 2016) discuss the need for multiple iterations over various time steps strengthen and refine results. There is a need to utilize both multiple perspectives and multiple time steps in a scenario-based preference model for complex systems.

2.3 Chapter summary

This chapter reviewed relevant literature on risk identification and filtering as well as on multi-criteria analysis for complex systems. It identified the need for expanding scenario-based preference modeling for multiple perspectives and multiple time frames. The methods used to achieve this expansion are outlined in the following chapter.

3 Technical approach

3.1 Chapter overview

This chapter describes a multiple perspective scenario-based preference model as a way to: identify competing initiatives in a system, assess the influence of scenarios to prioritization of initiatives, and apply an iterative approach to reconcile stakeholder perspectives and obtain the most effective risk management strategies. Figure 1 summarizes the steps in the methodology. This chapter is organized as follows first an overview of the methodology will be presented. Next the single perspective scenario analysis will be explained followed by the introduction of multiple perspectives and finally the iterative approach will be described.

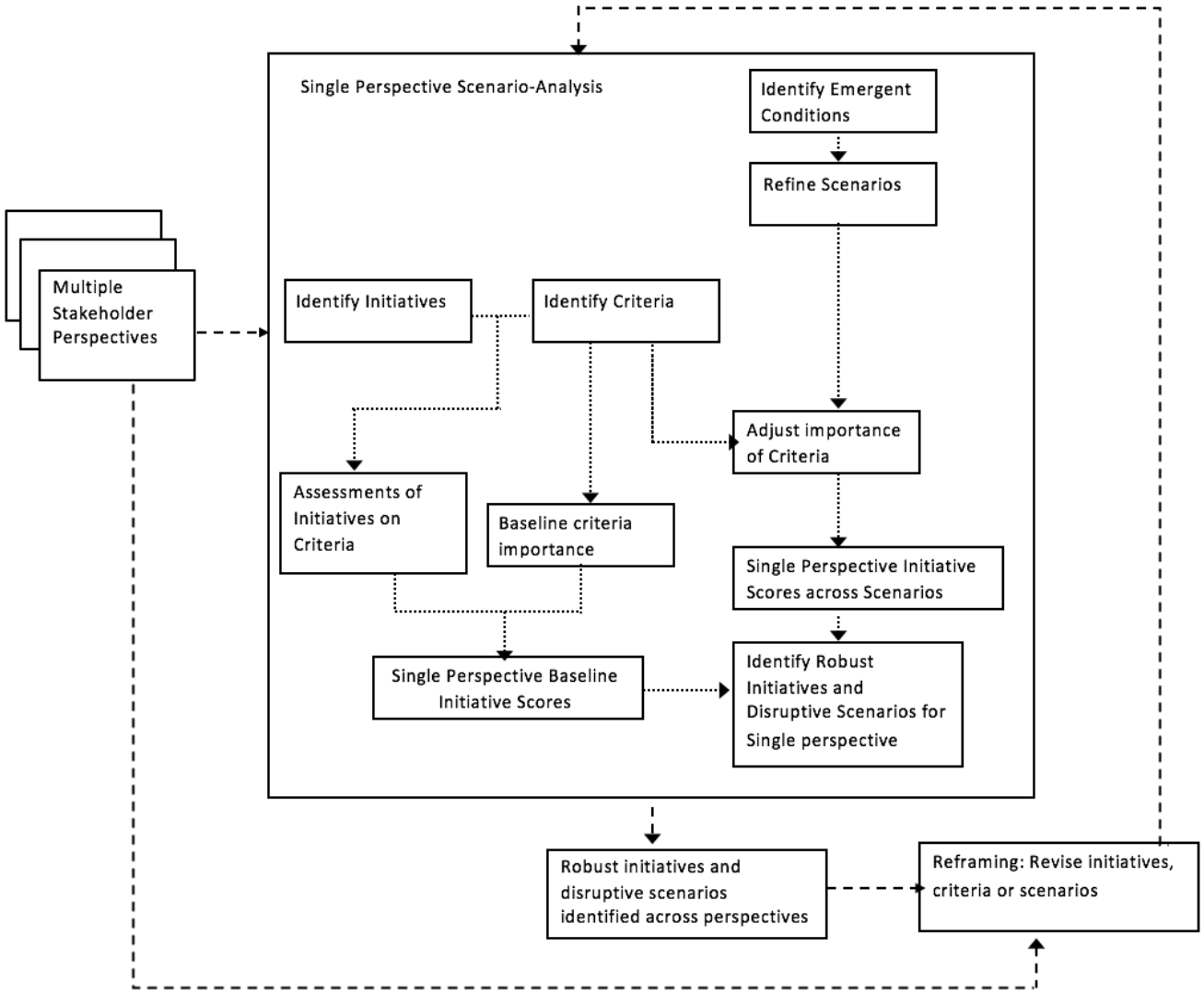

Figure 1 Summary of methodology to identify scenarios that most and least matter in enterprise risk analysis

3.2 Single perspective scenario analysis

This methodology aims to identify the scenarios that most and least matter to stakeholders as well as identifying the most and least resilient initiatives for the system. Intermediate outputs are several prioritizations, different for each scenario.

Initiatives represent a set of decision making objectives that could be in the form of technologies, policies, assets, projects, or other such investments. The set of initiatives, $X = \{x_1, \dots, x_n\}$, is developed through elicitation of stakeholder and expert opinions as well as from review of third party analyses. This list is not exhaustive and can be expanded and adapted according stakeholder input. Success criteria are then developed to measure the potential success of investment initiatives. These are based on goals set by stakeholders for the system. The set of criteria, $C = \{c_1, \dots, c_k\}$ are derived from a review of relevant third-party program analyses and literature review.

Emergent conditions could be a stakeholder belief or value, future event, or trend that could impact how initiatives are evaluated. These emergent and future conditions could potentially disrupt the prioritization of initiatives by posing danger to the system or exploiting vulnerabilities. This set of conditions is in no way a complete set of all potential conditions as it would be nearly impossible to list all circumstances that could arise. The emergent conditions are drawn from stakeholder interviews and similar conditions that have impacted public safety in the past. These emergent conditions are used to develop scenarios. Scenarios are made up of one or more emergent conditions and represent the most crucial challenges or risks that face the system. Each of these building blocks are discussed in further detail in Chapter 4.3.

After criteria, initiatives, and scenarios have been established, an assessment of each criterion j is performed. This assessment is performed through stakeholder interviews and expert elicitation. Three relevance options are offered: *high*, *medium*, and *low* as demonstrated in Chapter 4.3.5. These relevance options correspond to weights decided upon by experts and stakeholders. The normalized assessments form the entries w_{jB} in the $m_B \times n$ baseline impact matrices W_B.

After baseline weights are created the criterion are again assessed for each scenario s_k. Through stakeholder input each criterion is given one of five relevance measures based on how the relevance changes under a given scenario. These measures are *decreases, decreases somewhat, no change, increases somewhat,* and *increases.* Each measure is assigned a ratio for change. This reweighting is done for each scenario. The scores form the entries w_{jk} in the $m_k \times n$ impact matrices W_k for scenario s_k.

Following the establishment of baseline criteria weights and the reweighting of criteria for each scenario and each stakeholder perspective, each criterion is then assessed on whether it is addressed by a given initiative. This is also performed through stakeholder interviews and expert elicitation. The available levels of impact for initiative assessment are *strongly agree, agree,* and *somewhat agree*. Criterion can also not be addressed by the given initiative (i.e. no impact). *Strongly agree* is represented by a filled circle (●), *agree* is represented by a half-filled circle in the matrix (◐), *somewhat agree* is represented by an unfilled circle (○), and neutral entries are left blank. These assessments correspond to weights decided upon by stakeholders and experts. Thus, entries x_{ij}, the score initiative x_i receives for criterion c_j, in an impact matrix X_i is created for each initiative.

A score for each initiative is then created under each scenario through linear additive value function shown in Equation (1).

$$V(x_i)_k = W_k X_i \tag{1}$$

Given a score for each initiative, the initiatives can now be ranked and prioritized such that if the score for a given initiative under a given scenario is higher than that for another initiative under a given scenario then the first initiative should be prioritized higher. This is represented symbolically in Equation (2).

$$\text{IF } V(x_i)_k > V\left(x_j\right)_k \text{ THEN } x_i \succ x_j \tag{2}$$

Where $\succ$ means “has higher priority than”.

This assessment can be adjusted in many ways depending on stakeholder input and for further iteration. Weights for the criteria can be adjusted as well as weights and ratios on the reweighting of criteria.

Another key takeaway from this assessment is the ability for stakeholders to see how initiatives perform across a variety of scenarios. Resilient initiatives would consistently have higher scores or rankings.

Once arriving at a score for each initiative under each scenario the initiatives can be ranked where $R(x_i)_k$ represents the rank of initiative x_i under scenario s_k. Thus, a disruptiveness measure for each scenario, $D(s_k)$ can be obtained by using sum of square ranking illustrated in Equation (3) where n is the number of initiatives and b represents the baseline scenario.

$$D(s_k) = \Sigma_{i=1}^{n}[R(x_i)_b - R(x_i)_k]^2 \quad (3)$$

These scores can then be normalized on a 0-100 scale for the purpose of comparison. It can thus be illustrated to stakeholders which scenarios are most and least disruptive to the system.

3.3 Multiple perspective identification

Rather than aggregate stakeholder opinions and input it is valuable to separate the major stakeholder opinions to run the assessment. It is also valuable to see how different initiatives perform for different stakeholder perspectives. Initiatives that perform well across all stakeholders can be given higher priority as all stakeholders can gain value from them. The stakeholders included in the assessment must first be identified. This can occur through a review of the system and speaking to participants already involved about which stakeholders have the most investment in the system. Once the stakeholders have been identified their perspective can be included in the scenario analysis. The criteria established must be assessed for each perspective p. A *low, medium,* or *high,* is given to each criterion for each perspective. The normalized assessments form the entries w_{jB}^{p} in the $m_B \times n$ baseline impact matrices W_B^p for each perspective p. The criteria are then assessed again under each scenario s_k for each perspective. These assessments form the scores for the entries w_{jk}^{p} in the $m_k \times n$ impact matrices W_k^p for scenario s_k and perspective p. The initiatives do not need to be reassessed for each criterion as these are the same across all stakeholders. Each perspective is taken into account through the weighting and reweighting of criteria. Thus, in the same manner illustrated before we have scores for each initiative and perspective. Priority

amongst initiatives is also assessed the same as illustrated before. The same can be done to measure the disruptiveness of each of the scenarios under each perspective as well.

3.4 Agreement between stakeholder perspectives and iteration

At this point in the assessment it is now valuable to compare the results across stakeholder perspectives. If there is a consensus that arises for initiatives that are most resilient and most highly prioritized and scenarios that are most disruptive then there is a clear recommendation for future actions and planning, if there is not a consensus or more information is desired the assessment can then be iterated. Iteration includes revising initiatives, revising criteria and reframing scenarios. Initiatives are revised by adding initiatives that address highly disruptive scenarios and add resilience to the system, combining or redesigning initiatives that are redundant, or eliminating initiatives that do not perform well. Criteria are revised by assessing whether all desired goals are being met with the given initiatives and eliminating criteria that are redundant. Scenarios are reframed by reexamining emergent and future conditions and considering whether all relevant scenarios are covered or whether new scenarios arise from development of new initiatives. Once all of these reframing questions are answered the assessment can begin again and new results and recommendations developed. This can be repeated until a model is developed that appears appropriate to all stakeholders. This methodology is illustrated in Chapter 4.3.7.

3.5 Chapter summary

This chapter has described the methods for an iterative approach to a multiple perspective scenario analysis model that will be used in Chapter 4 to understand the First Responder Network Authority system. This chapter also described the building blocks and their relationships necessary to the implementation of the model. The quantification of disruption with respect to the prioritizations of initiatives under different scenarios was then described and the reframing questions for an iterative approach discussed.

4 Demonstration

4.1 Chapter overview

Communications plays a crucial role in the regular functioning of public safety agencies. The development of the new First Responder Network Authority aims to fully develop a modern communications system for these agencies and provide broadband to a community that has relied on older technologies for far longer than general public. This chapter demonstrates the application of the methods presented in Chapter 3 to FirstNet. It includes historical background and discussion about the context of the FirstNet system that the method will be applied to. The scope of the demonstration is the deployment of the FirstNet system in the state of Virginia involving various stakeholders, with multiple perspectives, goals and objectives. The demonstration will cover all necessary steps in the methodology, identifying success criteria, investment initiatives, emergent and future conditions, and relevant stakeholders, developing prioritizations and quantifying the disruption of scenarios. The results of which will be compared and iterated for further investigation. This demonstration includes two iterations: Iteration 1 and Iteration 2.

4.2 Background

The everyday functioning of public safety agencies requires extensive communication. Dispatchers receive emergency calls from citizens and that information must be conveyed to the correct agencies in a timely fashion with all necessary details. There is also the need for communication between branches of public safety. For example, during a fire the fire department must be contacted by emergency medical services to meet the needs of any injured persons. Interoperability between these branches is lacking with the current system. In addition, there is the need to communicate amongst the different jurisdictions in an area such as county and city departments. There is a dire need to update the current state of public safety communications. Whereas millions of everyday citizens use a smart phone to communicate, public safety agencies have not updated to this technology and instead rely upon radios or occasionally personal devices to communicate. Radios present numerous interoperability issues as well as lack of resources to communicate audio or video files necessary in the digital age and personal devices places an undue burden on the men and women who dedicate their time to this public service. The First Responder Network Authority aims to help solve this problem by bringing public safety communications into the twenty first century, but with the rollout of a new system it is crucial to understand the risks that face the system and to explore how those risks can be mitigated and how resilience can be built in the system.

4.3 Demonstration of methods

This section will identify and quantify the disruption potential of several scenarios for the deployment of the FirstNet system. The process will include the identification of perspectives and a prioritization of initiatives for each of these perspectives. Reframing questions will be posed and the entire model will be iterated to demonstrate the importance of continuing evaluation as the system develops throughout its lifetime.

4.3.1 Identification of perspectives

Three diverse perspectives emerge from the FirstNet analysis. These perspectives include *Vendor*, *Regulatory*, and *Public Safety Agencies* and are shown in Table 1. A short description of each of these perspectives is also provided in the table. These are the three key perspectives selected because they incorporate the largest three stakeholders in the system. The *Vendor* has an interest in how the system invests its time and energy as they will be the ones running the physical aspects of the system. Especially during the deployment stage, the *Regulatory* perspective has unique interest in how the FirstNet system will affect the state as a whole. The *Public Safety Agencies* have a vested interest as well in how the system functions as they are the primary users of it. There are other perspectives that could be considered but for this analysis only these three were explored. Any other stakeholders could be added or updated in a later iteration.

Table 1 Description of stakeholder perspectives that will influence the relevance among success criteria and, ultimately, the identification of scenarios that most and least matter in enterprise risk analysis

Index	Perspective	Description
p_1	Vendor	Cellular service provider: AT&T (awarded a 25-year contract)
p_2	Regulatory	State level officials: governor, lieutenant governor, Virginia Department of Emergency Management, etc.
p_3	Public Safety Agencies	Police, fire and emergency medical service providers
p_j	Others	To be defined in later iterations

4.3.2 Identification of Criteria

To measure the appeal of the various initiatives, a list of criteria is developed from various sources. Several places around the world are developing plans to implement wireless broadband both for first responders and for community consumers in general. Sources ranging from local municipalities to nation states implementing similar programs are reviewed, and these criteria are selected based on commonly identified key objectives and goals of a broadband system. These sources include a Broadband Feasibility Study for the City of Boulder, a Government Accountability Office report as well as a report from the state of Oregon on FirstNet among others (Columbia Telecommunications Corporation, 2016; Science Applications International Corporation, 2015; U.S. Government Accountability Office, 2015). The set of criteria, $C = \{c_1, \dots, c_{10}\}$, identified in this review are listed in Table 2. These criteria represent the goals and objectives of the system during the rollout phase. Criterion c_1 *Availability* refers whether the network is working when it needs to be. Criterion c_2 *Privacy* refers to the level of privacy and security the network will have. Criterion c_3 *Interoperability* refers to the level at which the network will be usable for various parties. Criterion c_4 *Usability* refers to how easy to use and network will be, especially in comparison to existing technology. Criterion c_5 *Quality of Service* refers to many things, among which include the quality of customer service and the quality of the network. Criterion c_6 *Affordability* refers to the cost induced by various projects. Criterion c_7 *Standards based* refers to how well the network meets different standards set by regulating agencies. Criterion c_8 *Flexibility* refers to the ability of the network to meet the specific needs of public safety. Criterion c_9 *Coverage/Ubiquity* refers to if the network brings service to all areas of the expected region. Criterion c_{10} *Risk Aversion* refers to whether the network is minimizing exposure to risks. Criteria can be adjusted and updated in later iterations of the model if deemed necessary.

Table 2 Success criteria used to identify scenarios that most and least matter in enterprise risk analysis

Index	Criteria	Source
c_1	Availability	(Martinez, 2013)
c_2	Privacy	(Martinez, 2013; Science Applications International Corporation, 2015)
c_3	Interoperability	(Martinez, 2013)
c_4	Usability	(Martinez, 2013; Science Applications International Corporation, 2015)
c_5	Quality of Service	(Martinez, 2013)
c_6	Affordability	(Columbia Telecommunications Corporation, 2016)
c_7	Standards Based	(Martinez, 2013)
c_8	Flexibility	(Martinez, 2013)
c_9	Coverage/Ubiquity	(Columbia Telecommunications Corporation, 2016; U.S. Government Accountability Office, 2015)
c_{10}	Risk Aversion	(Columbia Telecommunications Corporation, 2016)
c_m	Others	To be defined in later iterations

4.3.3 Iteration 1: Identification of initiatives

The set $X = \{x_1, \dots, x_{12}\}$ represents the 12 initiatives developed for Iteration 1 of the demonstration. This set is developed from third-party program analyses and is shown in Table 3. The initiatives are gathered from several sources interested in promoting a national public safety broadband network (Benson & Feldman, 2017; Felts et al., 2016). These initiatives represent sources of interest for many of the stakeholders involved. The given set is not exhaustive and could be updated to include the varying opinions of more stakeholders or viewpoints as the system develops as well as new programs or projects that have been suggested. The initiatives include strategies for laying out the system as well as physical programs to develop the broadband network.

Table 3 Iteration 1 initiatives for the FirstNet model assessed to identify the scenarios that most and least matter in enterprise risk analysis

Index	Initiative	Source
x_1	Promote data integration	(Benson & Feldman, 2017)
x_2	Promote better network resilience	(Benson & Feldman, 2017)
x_3	Promote better data processing	(Benson & Feldman, 2017)
x_4	Improve data source access	(Benson & Feldman, 2017)
x_5	Develop automated alerts	(Benson & Feldman, 2017)
x_6	Software development	(Felts et al., 2016)
x_7	Develop information sharing and analysis center	(Felts et al., 2016)
x_8	Gap analysis of disparate databases	(Felts et al., 2016)
x_9	Initiate pilot programs	(Felts et al., 2016)
x_{10}	Develop software analytics framework	(Felts et al., 2016)
x_{11}	Define device requirements	(Felts et al., 2016)
x_{12}	Develop data standards	(Felts et al., 2016)
x_n	Others	To be defined in later iterations

4.3.4 Iteration 1: Identification of emergent and future conditions and scenarios

The set $E = \{e_1, \dots, e_{13}\}$ represents the 13 identified emergent conditions, listed in Table 4. These emergent conditions represent stressors that could disrupt the prioritization of initiatives. Emergent conditions can be internal, such as failure of public safety agencies to adopt new technology, or external such as environmental events disrupting the system. These emergent conditions were sourced from a variety of third-party analyses, including Ernst & Young, 2014 and Magellan Advisors, 2017. It should be noted that this is not a complete or exhaustive list of conditions, but only an initial summary for Iteration 1 of relevant conditions that could occur and affect the system.

From these emergent conditions a set, $S = \{s_1, \dots, s_5\}$, is formed by combining one or more emergent conditions, listed in Table 5. Thus, we have a set of scenarios such that many combinations of conditions can be assembled to represent a variety of future scenarios. They are inspired by the different perspectives considered and are assessed as some of the most crucial future conditions that were considered. The emergent conditions included in each scenario is displayed in Table 6.

Table 4 Iteration 1 emergent conditions used to create sets of scenarios for enterprise risk analysis

Index	Emergent Condition
e_1	Insufficient coverage/bandwidth for public safety emergency
e_2	System outage during public safety emergency
e_3	Funding revoked
e_4	Too few public safety agencies enrolled
e_5	Poor interoperability between public safety agencies
e_6	Network unable to meet unique public safety requirements
e_7	Change of vendors during rollout
e_8	Equipment becomes obsolete
e_9	Environmental events disrupt service
e_{10}	Cyber security measures become outdated
e_{11}	Too much congestion on network
e_{12}	Government policy continues to support FirstNet
e_{13}	Government policy does not support FirstNet
e_i	Others

Table 5 Iteration 1 scenarios developed from emergent conditions for enterprise risk analysis

Index	Scenario
s_1	Funding Decreases
s_2	Change of Vendor
s_3	Environmental event disrupts service
s_4	Low number of public safety agencies enroll
s_5	Change in government policy
s_k	Others

Table 6 Iteration 1 emergent conditions comprising scenarios for enterprise risk analysis

	Scenarios					
Emergent		s_1	s_2	s_3	s_4	s_5
Conditions	e_1			x		
	e_2					
	e_3	x	x			
	e_4	x			x	
	e_5		x		x	
	e_6			x		
	e_7	x	x			
	e_8					
	e_9			x		
	e_{10}					
	e_{11}					
	e_{12}		x			x
	e_{13}					x

4.3.5 Iteration 1: Prioritization of initiatives

The prioritization of initiatives is assessed in three steps. The first of these is assessing the baseline relevance of each criterion for each perspective. Table 7 shows this assessment for perspective p_1 *Vendor*. Perspective p_1 *Vendor* has four high relevance criteria, two medium relevance criteria and four low weight criteria. Table 8 shows this assessment for perspective p_2 *Regulatory*. Perspective p_2 *Regulatory* has four high relevance criteria, three medium relevance criteria and three low relevance criteria. Table 9 shows this assessment for perspective p_3 *Public Safety Agencies*. Perspective p_3 *Public Safety Agencies* has four high relevance criteria, four medium relevance criteria and two low relevance criteria. The next step is to assess whether each criterion is addressed by the given initiative. This assessment is the same across all perspectives and is shown in Table 10. As discussed in Chapter 3.2, the filled circles represent *strongly agree*, the half-filled circles represent *agree*, the empty circles represent *somewhat agree*, and a blank entry means the criteria is not addressed by the initiative. The scenarios described in Chapter 4.3.4 may disrupt or upset the prioritization of initiatives and the degree to which the scenarios affect the prioritization is modeled through the effect they have on the criteria. For each perspective and each scenario, it must be determined whether the relevance *decreases, decreases somewhat, increases somewhat, increases* or there is no change. Table 11-Table 13 show the reweighting for each respective perspective. The tables are read as follows: *The criterion c_j (row) changes (decreases, decreases somewhat, increases somewhat, increases, or no change) under scenario s_k (column) relative to the baseline scenario relevance.* The baseline relevance for each criterion is included as the final column in each table for reference. It should be noted that the scenario s_2: $Change\ of\ Vendor$ is not included in the reweighting and analysis of perspective p_1 *Vendor* as this scenario invalidates the perspective of the current vendor.

Table 7 Baseline relevance of criteria for perspective p_1 Vendor for enterprise risk analysis

p_1 Vendor		
The criterion C.01 Availability has	*high*	*relevance among the other criteria.*
The criterion C.02 Privacy has	*low*	*relevance among the other criteria.*
The criterion C.03 Interoperability has	*medium*	*relevance among the other criteria.*
The criterion C.04 Usability has	*high*	*relevance among the other criteria.*
The criterion C.05 Quality of Service has	*high*	*relevance among the other criteria.*
The criterion C.06 Affordability has	*medium*	*relevance among the other criteria.*
The criterion C.07 Standards Based has	*low*	*relevance among the other criteria.*
The criterion C.08 Flexibility has	*low*	*relevance among the other criteria.*
The criterion C.09 Coverage/Ubiquity has	*high*	*relevance among the other criteria.*
The criterion C.10 Risk Aversion has	*low*	*relevance among the other criteria.*

Table 8 Baseline relevance of criteria for perspective p_2 Regulatory for enterprise risk analysis

p_2 Regulatory		
The criterion C.01 Availability has	*high*	*relevance among the other criteria.*
The criterion C.02 Privacy has	*low*	*relevance among the other criteria.*
The criterion C.03 Interoperability has	*high*	*relevance among the other criteria.*
The criterion C.04 Usability has	*medium*	*relevance among the other criteria.*
The criterion C.05 Quality of Service has	*low*	*relevance among the other criteria.*
The criterion C.06 Affordability has	*high*	*relevance among the other criteria.*
The criterion C.07 Standards Based has	*low*	*relevance among the other criteria.*
The criterion C.08 Flexibility has	*medium*	*relevance among the other criteria.*
The criterion C.09 Coverage/Ubiquity has	*high*	*relevance among the other criteria.*
The criterion C.10 Risk Aversion has	*medium*	*relevance among the other criteria.*

Table 9 Baseline relevance of criteria for perspective p_3 Public Safety Agencies for enterprise risk analysis

p_3 Public Safety Agencies		
The criterion C.01 Availability has	*high*	*relevance among the other criteria.*
The criterion C.02 Privacy has	*medium*	*relevance among the other criteria.*
The criterion C.03 Interoperability has	*high*	*relevance among the other criteria.*
The criterion C.04 Usability has	*high*	*relevance among the other criteria.*
The criterion C.05 Quality of Service has	*low*	*relevance among the other criteria.*
The criterion C.06 Affordability has	*medium*	*relevance among the other criteria.*
The criterion C.07 Standards Based has	*low*	*relevance among the other criteria.*
The criterion C.08 Flexibility has	*medium*	*relevance among the other criteria.*
The criterion C.09 Coverage/Ubiquity has	*high*	*relevance among the other criteria.*
The criterion C.10 Risk Aversion has	*medium*	*relevance among the other criteria.*

Table 10 Iteration 1 assessment of initiatives against criteria used for the prioritization of initiatives for enterprise risk analysis

	x01. Promote data integration	*x02. Promote better network resilience*	*x03. Promote better data processing*	*x04. Improve data source access*	*x05. Develop automated alerts*	*x06. Software development*	*x07. Develop information sharing and analysis center*	*x08. Gap analysis of disparate databases*	*x09. Initiate pilot programs*	*x10. Develop software analytics framework*	*x11. Define device requirements*	*x12. Develop data standards*
C.01 Availability is addressed by this initiative.	●	○	○	●		◐	◐	◐	◐			
C.02 Privacy is addressed by this initiative.	○	●	◐	◐		○	○		○		◐	◐
C.03 Interoperability is addressed by this initiative.	●		●	●	○	◐	●	●			◐	◐
C.04 Usability is addressed by this initiative.	◐	◐	●	◐	●	●	◐	◐	●	◐	◐	◐
C.05 Quality of Service is addressed by this initiative.	◐	◐	●	●	◐	○		○	●	○	○	○
C.06 Affordability is addressed by this initiative.				●		◐	○		◐		○	○
C.07 Standards Based is addressed by this initiative.	○	◐	◐			○	◐	◐		●	●	●
C.08 Flexibility is addressed by this initiative.	◐	●	◐	◐	◐		◐	○	○			
C.09 Coverage/Ubiquity is addressed by this initiative.				○		◐	◐	◐	◐	◐	○	○
C.10 Risk Aversion is addressed by this initiative.	○	●	◐	◐			○	○	◐	●	●	●

Table 11 Iteration 1 reweighting of criteria under each scenario for perspective p_1 Vendor in comparison to the baseline relevance for enterprise risk analysis

p_1 Vendor	***S1. Funding Decreases***	***S2. Change of Vendor***	***S3. Environmental event disrupts service***	***S4. Low number of PS agencies enroll***	***S5. Change in government policy***	***S0. Baseline***
C.01 Availability	Decreases Somewhat	-	Increases	Decreases Somewhat	Decreases	*high*
C.02 Privacy	Decreases	-	Decreases Somewhat	-	Decreases Somewhat	*low*
C.03 Interoperability	Decreases Somewhat	-	-	Decreases Somewhat	-	*medium*
C.04 Usability	-	-	Increases Somewhat	Increases Somewhat	Increases Somewhat	*high*
C.05 Quality of Service	Decreases Somewhat	-	-	Increases Somewhat	-	*high*
C.06 Affordability	Increases	-	Decreases	-	Increases	*medium*
C.07 Standards Based	Decreases	-	Decreases	-	Decreases	*low*
C.08 Flexibility	Increases Somewhat	-	Increases Somewhat	Increases Somewhat	Increases Somewhat	*low*
C.09 Coverage/Ubiquity	Decreases Somewhat	-	Decreases Somewhat	Decreases Somewhat	-	*high*
C.10 Risk Aversion	Decreases Somewhat	-	Increases Somewhat	-	-	*low*

Table 12 Iteration 1 reweighting of criteria under each scenario for perspective p_2 Regulatory in comparison to the baseline relevance relevance for enterprise risk analysis

p_2 Regulatory	***S1. Funding Decreases***	***S2. Change of Vendor***	***S3. Environmental event disrupts service***	***S4. Low number of PS agencies enroll***	***S5. Change in government policy***	***S0. Baseline***
C.01 Availability	-	Increases Somewhat	Increases	Decreases Somewhat	-	*high*
C.02 Privacy	Decreases Somewhat	-	Decreases	-	-	*low*
C.03 Interoperability	-	Increases	Increases Somewhat	Increases	Increases Somewhat	*high*
C.04 Usability	Increases Somewhat	-	Increases Somewhat	Decreases Somewhat	Decreases Somewhat	*medium*
C.05 Quality of Service	Decreases	Increases Somewhat	Increases Somewhat	-	-	*low*
C.06 Affordability	Increases	-	Decreases	Increases	Increases	*high*
C.07 Standards Based	Decreases	Increases Somewhat	Decreases	Decreases Somewhat	-	*low*
C.08 Flexibility	Increases Somewhat	Increases Somewhat	-	-	Increases	*medium*
C.09 Coverage/Ubiquity	Decreases Somewhat	Decreases Somewhat	Decreases	Decreases Somewhat	Increases Somewhat	*high*
C.10 Risk Aversion	Increases Somewhat	-	-	-	Increases Somewhat	*medium*

Table 13 Iteration 1 reweighting of criteria under each scenario for perspective p_3 Public Safety Agencies in comparison to the baseline relevance relevance for enterprise risk analysis

p_3 Public Safety Agencies	***S1. Funding Decreases***	***S2. Change of Vendor***	***S3. Environmental event disrupts service***	***S4. Low number of PS agencies enroll***	***S5. Change in government policy***	***S0. Baseline***
C.01 Availability	-	Increases Somewhat	Increases	Increases Somewhat	-	*high*
C.02 Privacy	Decreases Somewhat	-	Decreases Somewhat	-	-	*medium*
C.03 Interoperability	Increases Somewhat	Increases	Increases	Increases	Increases	*high*
C.04 Usability	-	-	-	-	Increases Somewhat	*high*
C.05 Quality of Service	Decreases Somewhat	Increases Somewhat	Increases Somewhat	Decreases Somewhat	Increases Somewhat	*low*
C.06 Affordability	Increases	Increases Somewhat	Decreases Somewhat	Increases Somewhat	Increases	*medium*
C.07 Standards Based	-	Decreases Somewhat	Decreases Somewhat	Decreases	Decreases	*low*
C.08 Flexibility	Increases Somewhat	Increases Somewhat	Increases Somewhat	-	Increases Somewhat	*medium*
C.09 Coverage/Ubiquity	Decreases Somewhat	Increases Somewhat	Decreases	Decreases Somewhat	-	*high*
C.10 Risk Aversion	Increases Somewhat	Decreases Somewhat	-	-	Decreases Somewhat	*high*

Table 14 shows the rankings and value scores for each initiative under perspective p_1 *Vendor*. Under this perspective initiative x_4*: Improve data source access* ranks number 1 in all scenarios except scenario s_4*: Low number of public safety agencies enroll* where initiative x_3*: Promote data source access* is the top ranked initiative. Table 15 shows the rankings and value scores for each initiative under perspective p_2 *Regulatory*. Under this perspective initiative x_4*: Improve data source access* ranks number 1 in all scenarios. Table 16 shows the rankings and value scores for each initiative under perspective p_3 *Public Safety Agencies*. Under this perspective as well initiative x_4*: Improve data source access* ranks number 1 in all scenarios. Additionally, the median rank for each initiative is also shown in each of these tables. Figure 2-Figure 4 show a visualization of the rankings for each of the respective perspectives. The highest rank an initiative receives under a scenario is illustrated by the blue bars, the baseline rank is illustrated by the black bar and the lowest rank an initiative receives is illustrated by a red bar. The blue and red bars are not included if the baseline rank is the highest or lowest rank received, respectively. Initiative x_4: $Improve\ data\ source\ access$ consistently scores well across all perspectives. It's baseline rank is always 1 and it only varies under perspective p_1 *Vendor* with a lowest rank of 3. Initiative x_9: $Initiate\ pilot\ programs$ is the next highest ranked initiative for perspective p_1 *Vendor* with a baseline rank of 2 and a lowest rank of 4, but this initiative is not resilient across perspectives. For both perspective p_2 *Regulatory* and p_3 *Public Safety Agencies* perspectives it is highly sensitive to different scenarios with a range of 7 and 4 for the two perspectives respectively. Initiative x_5: $Develop\ automated\ alerts$ has a consistently low rank across all perspectives, though it is more sensitive under perspective p_1 *Vendor* with a high rank of 4. Initiative x_6: $Software\ development$ has a baseline rank in the top four for all perspectives but is highly sensitive across the different perspectives. x_{10}: $Develop\ software\ analytics\ framework$ ranked in the bottom two for every perspective and every initiative indicating it is not a highly prioritized initiative in any situation. Initiatives x_2, x_{11}, x_{12} all consistently rank towards the bottom; none ever ranking higher than 5 across all scenarios and

perspectives. Initiative x_7: $Develop\ information\ sharing\ and\ analysis\ center$ is fairly resilient and ranks highly for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies* but is highly sensitive and ranked much lower for perspective p_1 *Vendor*. The remaining initiatives, x_1, x_3, x_8 do not have any consistent rank across perspectives and they are all fairly sensitive. The prioritization in this assessment is not meant to be prescriptive, but rather its primary role is to be used to investigate the disruptiveness of scenarios as described in the following section and is also used to reframe and revise the model in further iterations.

Table 14 Iteration 1 ranking and value scores for each initiative under each scenario for perspective p_1 Vendor for enterprise risk analysis

	x01: Promote data integration	*x02: Promote better network resilience*	*x03: Promote better data processing*	*x04: Improve data source access*	*x05: Develop automated alerts*	*x06: Software development*	*x07: Develop information sharing and analysis center*	*x08: Gap analysis of disparate databases*	*x09: Initiate pilot programs*	*x10: Develop software analytics framework*	*x11: Define device requirements*	*x12: Develop data standards*
Ranking of Initiatives												
S0. Baseline	5	8	3	1	12	3	6	6	2	11	9	9
S1. Funding Decreases	10	5	6	1	9	3	4	11	2	12	7	7
S2. Change of Vendor	-	-	-	-	-	-	-	-	-	-	-	-
S3. Environmental event disrupts service	2	8	4	1	9	5	6	7	3	12	10	10
S4. Low number of PS agencies enroll	6	5	1	3	4	7	12	8	2	11	9	9
S5. Change in government policy	10	9	4	1	5	3	6	11	2	12	7	7
Median Ranking	6	8	4	1	9	3	6	8	2	12	9	9
Value Score of Initiatives												
S0. Baseline	54	43	58	75	33	58	53	53	67	36	42	42
S1. Funding Decreases	29	34	33	86	30	56	47	22	64	13	31	31
S2. Change of Vendor	-	-	-	-	-	-	-	-	-	-	-	-
S3. Environmental event disrupts service	78	55	65	83	42	65	61	60	74	32	34	34
S4. Low number of PS agencies enroll	63	67	90	80	73	58	38	47	88	44	46	46
S5. Change in government policy	44	45	61	77	54	70	53	43	77	37	46	46

Table 15 Iteration 1 ranking and value scores for each initiative under each scenario for perspective p_2 Regulatory for enterprise risk analysis

	x01: Promote data integration	*x02: Promote better network resilience*	*x03: Promote better data processing*	*x04: Improve data source access*	*x05: Develop automated alerts*	*x06: Software development*	*x07: Develop information sharing and analysis center*	*x08: Gap analysis of disparate databases*	*x09: Initiate pilot programs*	*x10: Develop software analytics framework*	*x11: Define device requirements*	*x12: Develop data standards*
Ranking of Initiatives												
S0. Baseline	6	10	7	1	12	3	2	5	4	11	8	8
S1. Funding Decreases	9	7	8	1	11	3	4	10	2	12	5	5
S2. Change of Vendor	2	10	4	1	11	6	3	5	9	12	7	7
S3. Environmental event disrupts service	2	10	4	1	11	6	3	5	9	12	7	7
S4. Low number of PS agencies enroll	5	11	4	1	10	3	2	8	9	12	6	6
S5. Change in government policy	9	10	8	1	12	3	2	5	4	11	6	6
Median Ranking	9	10	8	1	12	3	2	5	4	11	6	6
Value Score of Initiatives												
S0. Baseline	51	36	49	76	21	55	60	52	53	29	43	43
S1. Funding Decreases	37	44	44	84	28	51	49	30	63	27	44	44
S2. Change of Vendor	81	36	69	86	28	52	71	67	37	13	39	39
S3. Environmental event disrupts service	81	36	69	86	28	52	71	67	37	13	39	39
S4. Low number of PS agencies enroll	50	9	52	97	18	62	64	49	36	4	50	50
S5. Change in government policy	38	28	40	77	17	50	60	46	48	26	42	42

Table 16 Iteration 1 ranking and value scores for each initiative under each scenario for perspective p_3 Public Safety Agencies for enterprise risk analysis

	x01: Promote data integration	*x02: Promote better network resilience*	*x03: Promote better data processing*	*x04: Improve data source access*	*x05: Develop automated alerts*	*x06: Software development*	*x07: Develop information sharing and analysis center*	*x08: Gap analysis of disparate databases*	*x09: Initiate pilot programs*	*x10: Develop software analytics framework*	*x11: Define device requirements*	*x12: Develop data standards*
Ranking of Initiatives												
S0. Baseline	5	10	3	1	12	4	2	5	5	11	8	8
S1. Funding Decreases	4	10	3	1	11	8	2	5	9	12	6	6
S2. Change of Vendor	4	10	6	1	11	5	2	3	7	12	8	8
S3. Environmental event disrupts service	4	10	6	1	11	5	2	3	7	12	8	8
S4. Low number of PS agencies enroll	2	10	6	1	11	5	3	4	9	12	7	7
S5. Change in government policy	4	11	2	1	10	5	3	6	7	12	8	8
Median Ranking	4	10	5	1	11	5	2	5	7	12	8	8
Value Score of Initiatives												
S0. Baseline	55	44	58	73	28	56	62	55	55	33	46	46
S1. Funding Decreases	58	39	63	85	27	46	65	52	41	22	51	51
S2. Change of Vendor	61	25	51	81	23	58	68	63	47	18	34	34
S3. Environmental event disrupts service	61	25	51	81	23	58	68	63	47	18	34	34
S4. Low number of PS agencies enroll	78	21	61	95	20	64	73	67	40	7	40	40
S5. Change in government policy	65	36	73	85	46	64	67	59	51	21	48	48

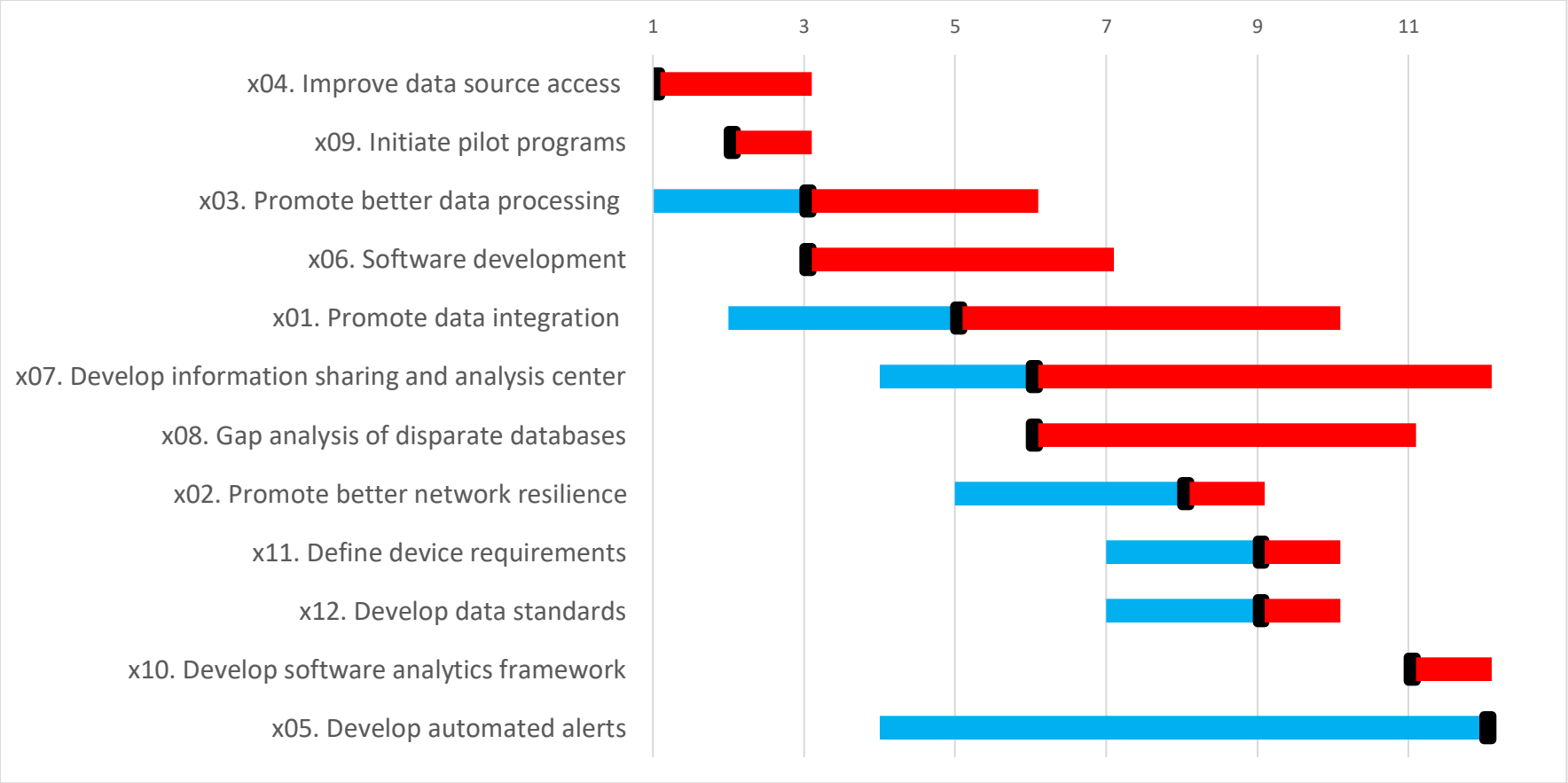

Figure 2 Iteration 1 prioritization of initiatives for perspective p_1 Vendor showing the baseline rank and the high and low ranks for enterprise risk analysis

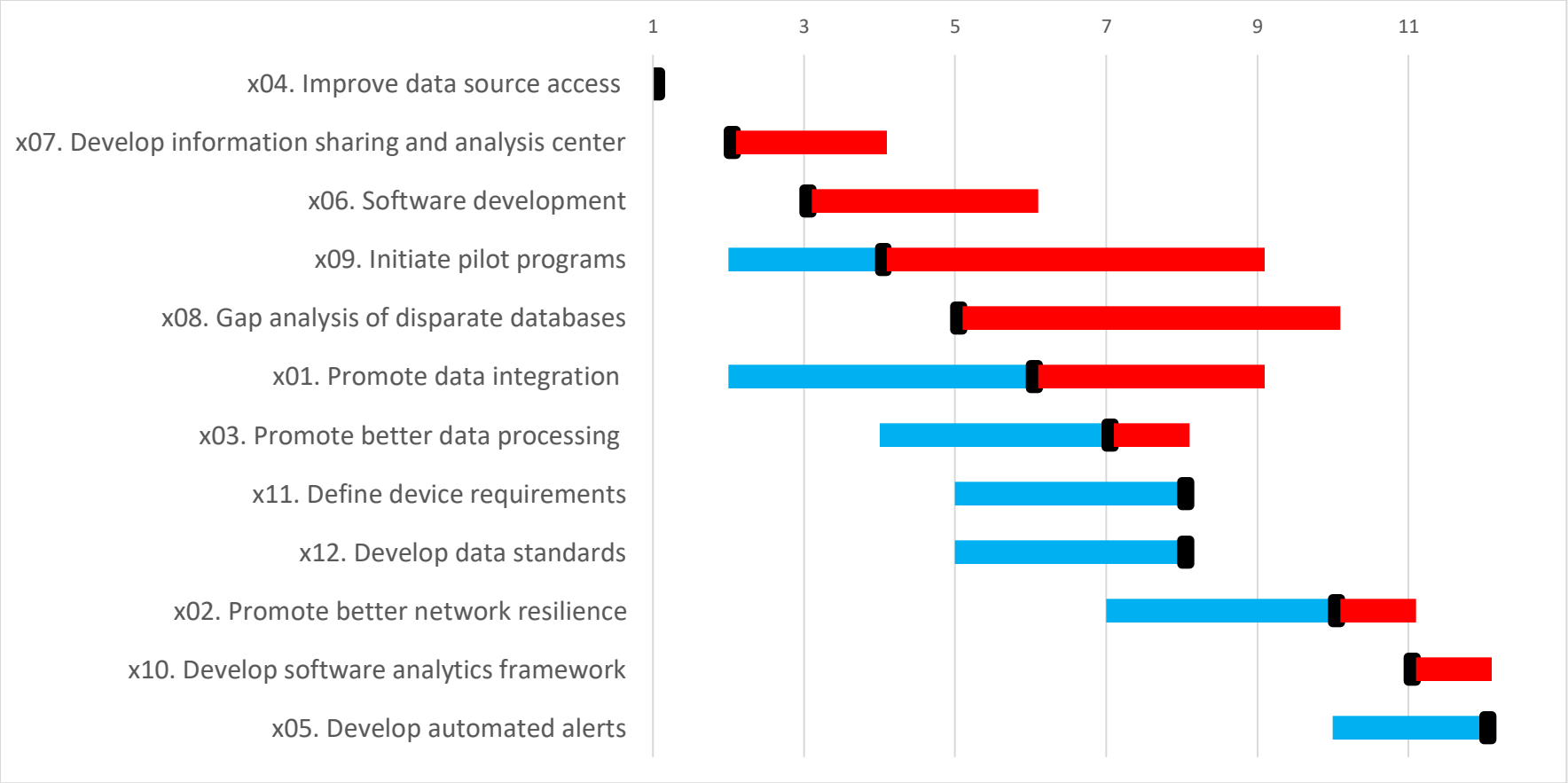

Figure 3 Iteration 1 prioritization of initiatives for perspective p_2 Regulatory showing the baseline rank and the high and low ranks for enterprise risk analysis

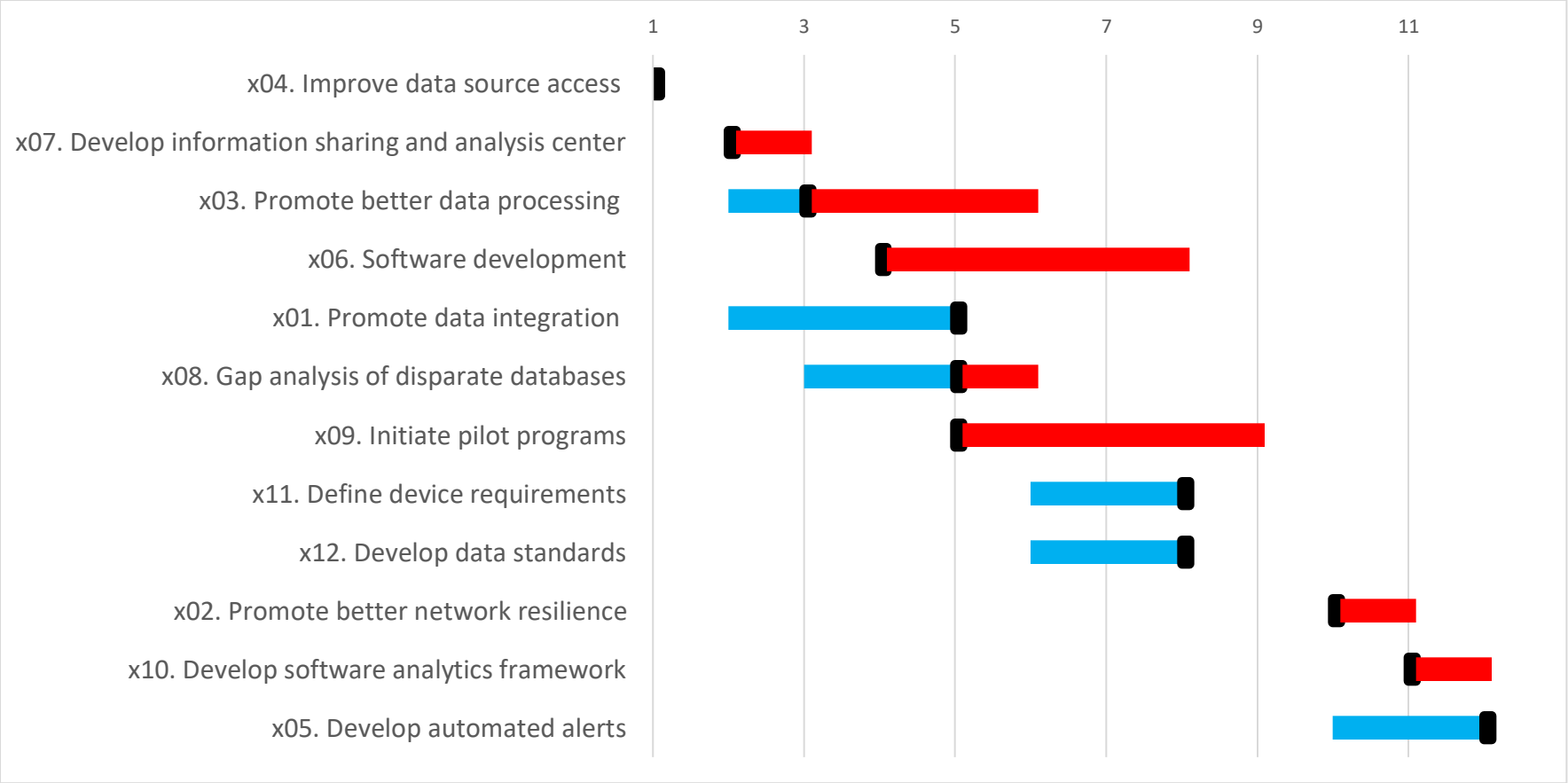

Figure 4 Iteration 1 prioritization of initiatives for perspective p_3 Public Safety Agencies showing the baseline rank and the high and low ranks for enterprise risk analysis

4.3.6 Iteration 1: Disruption of scenarios to the prioritization of initiatives

After the results shown in Chapter 4.3.5 are complete, we are able to use the methods outlined in Chapter 3.2 to calculate a disruptive measure for each scenario under each perspective. These measures can be used to illustrate to stakeholders which scenarios are most and least disruptive. Scenarios with a higher score are considered more disruptive than those with lower scores as they caused more change in the ranking of initiatives than other scenarios. The normalized disruptive scores are calculated for each perspective. Figure 5 shows the disruptive scores for perspective p_1 *Vendor*. Figure 6 shows the disruptive scores for perspective p_2 *Regulatory*. Figure 7 shows the disruptive scores for perspective p_3 *Public Safety Agencies*. The scores for each scenario are out of 100. For perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies*, scenario s_1: $Funding\ Decreases$ is the most disruptive and scenario s_5: $Change\ in\ government\ policy$ is the least disruptive. This is not the case for perspective p_1 *Vendor* where scenario s_4: $Low\ number\ of\ public\ safety\ agencies\ enroll$ is the most disruptive and scenario s_3: $Environmental\ event\ disrupts\ service$ is the least disruptive. This suggests that there is interest in investigating these scenarios further in future iterations.

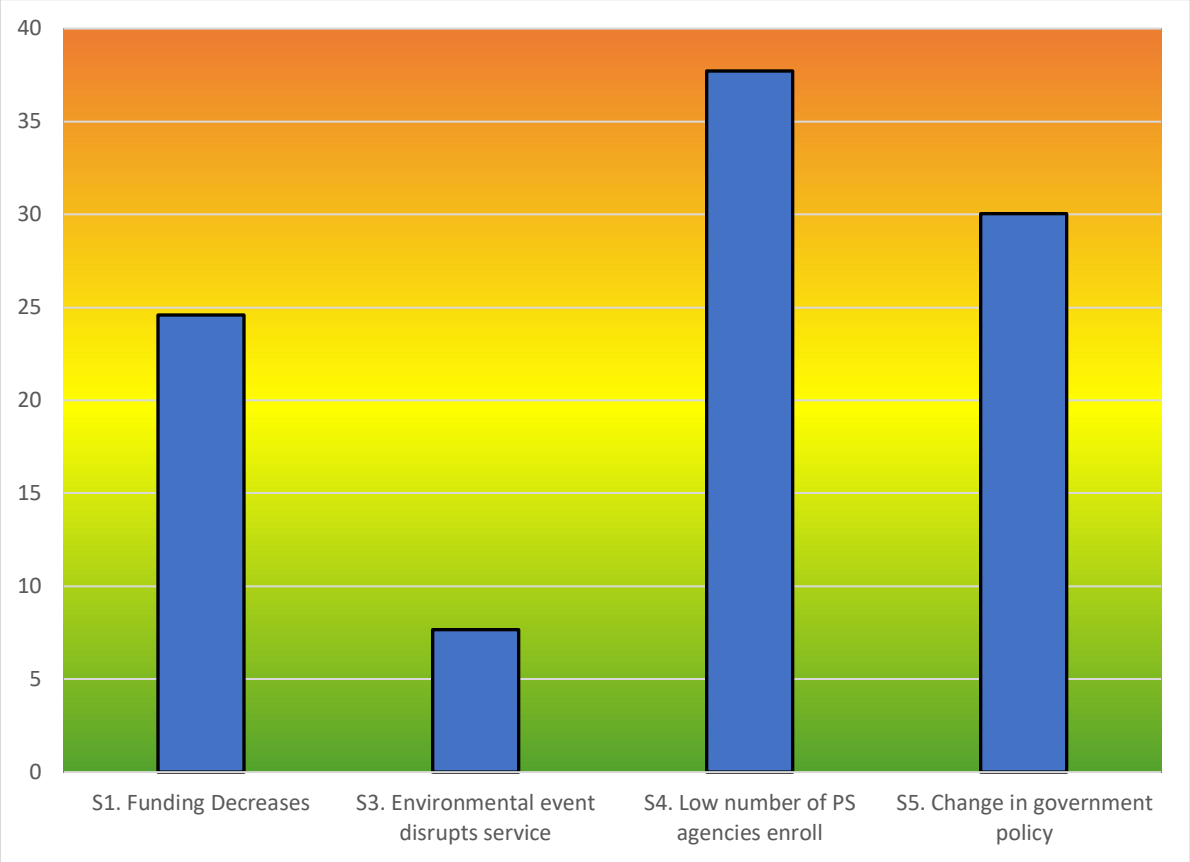

Figure 5 Iteration 1 normalized disruptive scores for each scenario under perspective p_1 Vendor for enterprise risk analysis

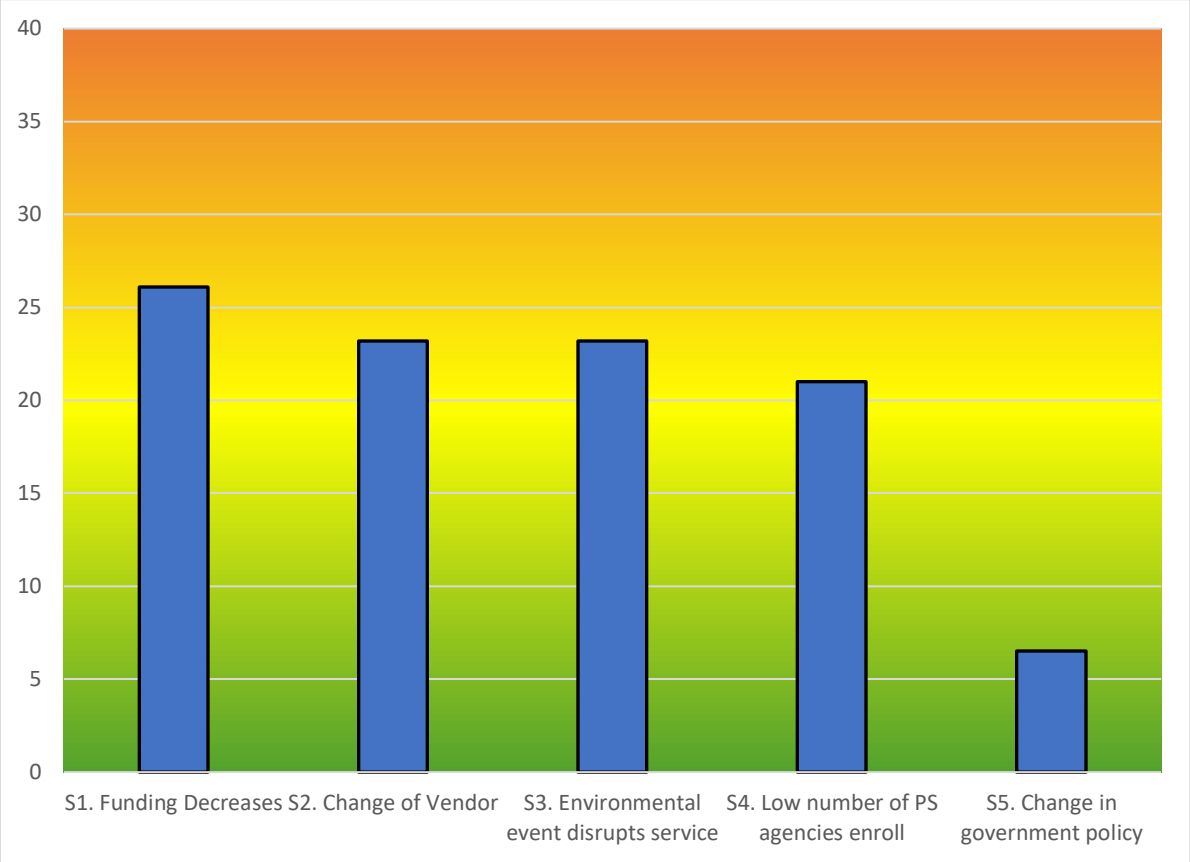

Figure 6 Iteration 1 normalized disruptive scores for each scenario under perspective p_2 Regulatory for enterprise risk analysis

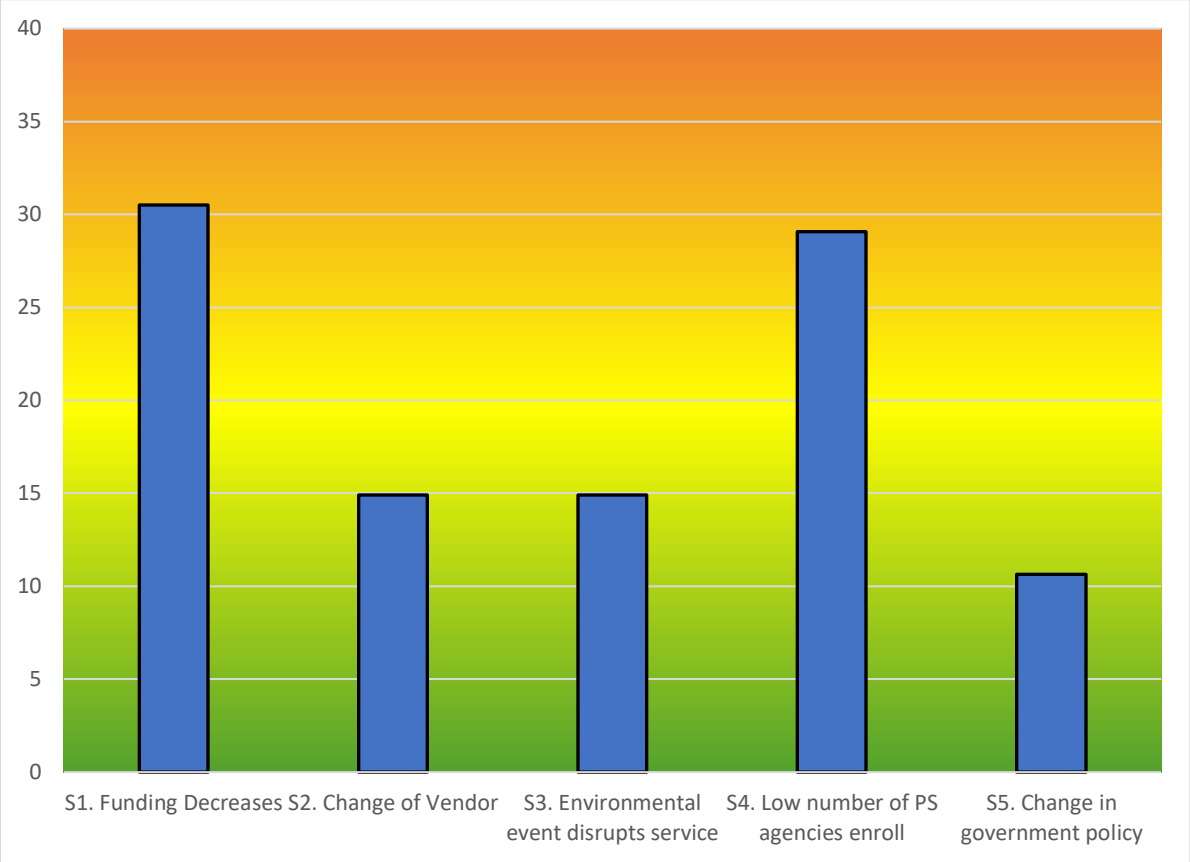

Figure 7 Iteration 1 normalized disruptive scores for each scenario under perspective p_3 Public Safety Agencies for enterprise risk analysis

4.3.7 Iteration 1: Reframing of model and revising for iteration

The results of Iteration 1 as discussed in the previous two sections are presented in Table 17. These results can be used to revise the input into further iterations. All inputs to the model including perspectives, criteria, initiatives, emergent conditions, and scenarios can be considered for reframing. Resilient and highly ranked initiatives such as initiative x_4: $Improve\ data\ source\ access$ can be kept and further evaluated against different scenarios. Initiatives such as x_5: $Develop\ automated\ alerts$ which consistently ranked low can be eliminated and others can be added. Scenarios as well can be clarified and updated pending stakeholder input and reframing questions. In general, the aspects of the model were evaluated based on the results from the assessment as well as from stakeholder input about the appropriateness of the various aspects. Table 18 outlines the reframing questions that were posed and the updates to the model for the next iteration.

Table 17 Iteration 1 summary of key results for enterprise risk analysis

Type of Result	Description
Most resilient initiative	The initiative x_4*: Improve data source access* is the most resilient initiative across all perspectives. It is highly prioritized in the baseline ranking and remains high for all scenarios.
Resilient initiatives	Initiative x_9*: Initiate pilot programs* is a nearly resilient initiative for perspective p_1 *Vendor*. Initiative x_7*: Develop information sharing and analysis center* is a nearly robust initiative for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies*.
Most disruptive scenarios	Scenario s_4*: Low number of public safety agencies enroll* is the most disruptive for perspective p_1 *Vendor*. Scenario s_1*: Funding decreases* is the most disruptive scenario for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies*.
Least disruptive scenarios	Scenario s_3*: Environmental event disrupts service* is the least disruptive for perspective p_1 *Vendor*. Scenario s_5*: Change in government policy* is the least disruptive for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies.*
Scenario with the most change between perspectives	Scenario s_5*: Change in government policy* has the most change between perspectives as it is the least disruptive for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies* and is second most disruptive for perspective p_1 *Vendor*.
Scenario with the least change between perspectives	Scenario s_1*: Funding decreases* has the least change between perspectives as it is the most disruptive scenario for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies* and a close third most disruptive for perspective p_1 *Vendor*.

Table 18 Iteration 1 reporting of perspectives, criteria, initiatives, emergent conditions, scenarios, intermediate output and reframing of scenario-based preference model for enterprise risk analysis

Input	Output	Reframing Questions	Reframing
Three Perspectives *p_1 Vendor* *p_2 Regulatory* *p_3 Public Safety Agencies*	N/A	Key stakeholders in the system are covered.	**Three perspectives maintained**
Ten Criteria *c_1 Availability* *c_2 Privacy* *c_3 Interoperability* *c_4 Usability* *c_5 Quality of Service* *c_6 Affordability* *c_7 Standards Based* *c_8 Flexibility* *c_9 Coverage/Ubiquity* *c_{10} Risk Aversion*	N/A	Recommended for a future iteration	**Ten criteria maintained**
Twelve Initiatives *x_1 Promote data integration* *x_2 Promote better network resilience* *x_3 Promote better data processing* *x_4 Improve data source access* *x_5 Develop automated alerts* *x_6 Software development* *x_7 Develop information sharing and analysis center* *x_8 Gap analysis of disparate databases* *x_9 Initiate pilot programs* *x_{10} Develop software analytics framework* *x_{11} Define device requirements* *x_{12} Develop data standards*	**One highly resilient initiative:** *Improve data source access* **One low ranked initiative:** *Develop automated alerts*	Initiatives considered are not fully representative of the current state and goals of the system.	Initiative list expanded. **One initiative removed:** *Develop automated alerts* **Eleven initiatives added:** *Strengthen cyber security* *Buildout rural network* *Upgrade to newest technological equipment for users* *Training programs for users* *Community engagement for understanding network* *Build framework for local, regional and national control* *Build backhaul network*

			Invest in public safety owned deployables *Invest in satellite services* *Invest in in-building solutions* *Invest in customer service centers*
Thirteen Emergent Conditions e_1 *Insufficient coverage/bandwidth for public safety emergency* e_2 *System outage during public safety emergency* e_3 *Funding revoked* e_4 *Too few public safety agencies enrolled* e_5 *Poor interoperability between public safety agencies* e_6 *FirstNet unable to meet unique public safety requirements* e_7 *Change of vendors* e_8 *Equipment becomes obsolete* e_9 *Natural disasters* e_{10} *Cyber security measures become outdated* e_{11} *Too much congestion on network* e_{12} *Government policy continues to support FirstNet* e_{13} *Government policy does not support FirstNet*	N/A	All relevant future risks and conditions are not adequately represented.	Emergent and future conditions list expanded **Fifteen emergent conditions added** *Allocated bandwidth cannot meet needs of new technology* *Cyber security unable withstand attack* *Population growth in urban areas* *Allocated bandwidth lowered* *Allocated bandwidth does not meet necessary requirements* *Failure to adapt to new technology* *Vendor infrastructure not able to meet needs* *Low overall demand for network* *High overall demand for network* *Rollout takes longer than expected* *Rollout goes over budget* *Customer expectations higher* *Difficulties in contract renewal* *Armed conflicts* *Vendor goes out of business*
Five Scenarios s_1 *Funding decreases* s_2 *Change of vendor* s_3 *Environmental event disrupts service* s_4 *Low number of public safety agencies enroll* s_5 *Change in government policy*	**Two influential scenarios:** *Funding decreases & Low number of public safety agencies enroll*	Scenarios do not represent the most pressing issues facing the system	**One scenario deleted:** *Low number of public safety agencies enroll* **One scenario added:** *Technology becomes obsolete* **One scenario revised:** *Environmental event disrupts service* becomes *Natural disaster*

4.3.8 Iteration 2: Identification of initiatives

The set of initiatives, $X = \{x_1, \dots, x_{22}\}$ was expanded and revised from the initial set in Iteration 1 through teleconferences with stakeholders, further analysis of third party literature and reading of FirstNet reports. The set was expanded from 12 initiatives to 22 initiatives which better reflects the inputs of various stakeholders and the potential projects of the system. The updated set is show in Table 19. Again, these initiatives represent sources of interest for many of the stakeholders involved and developed in collaboration with stakeholders. The set has been updated and revised but there is room for further iteration as well. The initiatives include strategies for laying out the system as well as physical programs to develop the broadband network.

Table 19 Iteration 2 revised initiatives of the FirstNet model assessed to identify the scenarios that most and least matter in enterprise risk analysis

Index	Initiative	Source
x_1	Promote data integration	(Benson & Feldman, 2017)
x_2	Promote better network resilience	(Benson & Feldman, 2017)
x_3	Promote better data processing	(Benson & Feldman, 2017)
x_4	Improve data source access	(Benson & Feldman, 2017)
x_5	Strengthen cyber security	(First Responder Network Authority, n.d.-b)
x_6	Software development	(Felts et al., 2016)
x_7	Develop information sharing and analysis center	(Felts et al., 2016)
x_8	Gap analysis of disparate databases	(Felts et al., 2016)
x_9	Initiate pilot programs	(Felts et al., 2016)
x_{10}	Develop software analytics framework	(Felts et al., 2016)
x_{11}	Define device requirements	(Felts et al., 2016)
x_{12}	Develop data standards	(Felts et al., 2016)
x_{13}	Buildout rural network	(First Responder Network Authority, n.d.-b)
x_{14}	Upgrade to newest technological equipment for users	(First Responder Network Authority, n.d.-b)

Index	Initiative	Source
x_{15}	Training program for users	(First Responder Network Authority, n.d.-b)
x_{16}	Community engagement for understanding network	(First Responder Network Authority, n.d.-b)
x_{17}	Build framework for local, regional and national control	(First Responder Network Authority, n.d.-b)
x_{18}	Build backhaul network	(First Responder Network Authority, n.d.-b)
x_{19}	Invest in public safety owned deployables	(First Responder Network Authority, n.d.-a)
x_{20}	Invest in satellite services	(First Responder Network Authority, n.d.-a)
x_{21}	Invest in in-building solutions	(First Responder Network Authority, n.d.-a)
x_{22}	Invest in customer service centers	(First Responder Network Authority, n.d.-b)
x_n	Others	To be defined in later iterations

4.3.9 Iteration 2: Identification of emergent and future conditions and scenarios

The set $E = \{e_1, \dots, e_{26}\}$ represents the 26 expanded emergent conditions, listed in Table 20. These emergent conditions again represent stressors that could disrupt the prioritization of initiatives. These emergent conditions were sourced from a variety of third-party analyses, including Ernst & Young, 2014 and Magellan Advisors, 2017 as before and the expanded list includes emergent conditions derived from teleconferences with stakeholders as well as further literature review (First Responder Network Authority, n.d.-a, n.d.-b). It should be noted that this is not a complete or exhaustive list of conditions.

From these emergent conditions a new set, $S = \{s_1, \dots, s_5\}$, is formed by combining one or more emergent conditions, listed in Table 21. Thus, we have a set of new scenarios such that many combinations of conditions can be assembled to represent a variety of future scenarios. They are inspired by the different perspectives considered as well as stakeholder input. The emergent conditions included in each scenario is displayed in Table 22.

Table 20 Iteration 2 revised emergent conditions used to create sets of scenarios for enterprise risk analysis

Index	Emergent Condition
e_1	Insufficient coverage/bandwidth for public safety emergency
e_2	Allocated bandwidth cannot meet needs of new technology
e_3	Funding decreases
e_4	Too few public safety agencies enrolled
e_5	Poor interoperability between public safety agencies
e_6	FirstNet unable to meet unique public safety requirements
e_7	Change of vendors
e_8	Equipment becomes obsolete
e_9	Natural disasters
e_{10}	Cyber security measures become outdated
e_{11}	Too much congestion on network
e_{12}	Cyber security unable to withstand attack
e_{13}	Government policy changes
e_{14}	Population growth in urban area
e_{15}	Allocated bandwidth lowered

Index	Emergent Condition
e_{16}	Allocated bandwidth does not meet necessary requirements
e_{17}	Failure to adapt to new technology
e_{18}	Vendor infrastructure not able to meet needs
e_{19}	Low overall demand for network
e_{20}	High overall demand for network
e_{21}	Rollout takes longer than expected
e_{22}	Rollout goes over budget
e_{23}	Customer expectation higher
e_{24}	Difficulties in contract renewal
e_{25}	Armed conflicts
e_{26}	Vendor goes out of business
e_i	Others

Table 21 Iteration 2 scenarios developed from emergent conditions for enterprise risk analysis

Index	Scenario
s_1	Funding Decreases
s_2	Change of Vendor
s_3	Natural disaster
s_4	Technology becomes obsolete
s_5	Change in government policy
s_k	Others

Table 22 Iteration 2 emergent conditions comprising scenarios for enterprise risk analysis

	Scenarios					
Emergent Conditions		s_1	s_2	s_3	s_4	s_5
	e_1			x		
	e_2					
	e_3	x	x			
	e_4	x				
	e_5		x			
	e_6			x		
	e_7	x	x			
	e_8				x	
	e_9			x		
	e_{10}				x	
	e_{11}					
	e_{12}		x			
	e_{13}	x				x
	e_{14}					
	e_{15}					
	e_{16}					
	e_{17}			x	x	
	e_{18}					
	e_{19}					
	e_{20}					
	e_{21}					
	e_{22}	x				
	e_{23}					
	e_{24}		x			
	e_{25}					
	e_{26}		x			

4.3.10 Iteration 2: Prioritization of initiatives

The prioritization of initiatives for Iteration 2 utilizes some of the same assessment as before. The baseline relevance of each criterion for each perspective, shown in Table 7-Table 9, is not updated as neither the criteria or perspectives were updated. An updated assessment of whether each criterion is addressed by the given initiative is shown in Table 23. Again, this assessment is the same across all perspectives. The scenarios described in Chapter 4.3.9 may disrupt or upset the prioritization of initiatives and the degree to which the scenarios affect the prioritization is modeled through the effect they have on the criteria. For each perspective and each scenario, Table 24-Table 26 show the reweighting of criteria. The tables are read as follows: *The criterion c_j (row) changes (decreases, decreases somewhat, increases somewhat, increases, or no change) under scenario s_k (column) relative to the baseline scenario relevance.* The baseline relevance for each criterion is included as the final column in each table for reference. It should be noted that the scenario s_2: $Change\ of\ Vendor$ is not included in the reweighting and analysis of perspective p_1 *Vendor* as this scenario invalidates the perspective of the current vendor.

Table 23 Iteration 2 assessment of initiatives against criteria used for the prioritization of initiatives for enterprise risk analysis

	x01. Promote data integration	*x02. Promote better network resilience*	*x03. Promote better data processing*	*x04. Improve data source access*	*x05. Develop automated alerts*	*x06. Software development*	*x07. Develop information sharing and analysis center*	*x08. Gap analysis of disparate databases*	*x09. Initiate pilot programs*	*x10. Develop software analytics framework*	*x11. Define device requirements*	*x12. Develop data standards*
C.01 Availability is addressed by this initiative.	●	○	○	●		◐	◐	◐	◐			
C.02 Privacy is addressed by this initiative.	○	●	◐	◐	○	○	○		○		◐	◐
C.03 Interoperability is addressed by this initiative.	●		●	●		◐	●	●			◐	◐
C.04 Usability is addressed by this initiative.	◐	◐	●	◐	◐	●	◐	◐	●	◐	◐	◐
C.05 Quality of Service is addressed by this initiative.	◐	◐	●	●	◐	○		○	●	○	○	○
C.06 Affordability is addressed by this initiative.				●		◐	○		◐		○	○
C.07 Standards Based is addressed by this initiative.	○	◐	◐		◐	○	◐	◐		●	●	●
C.08 Flexibility is addressed by this initiative.	◐	●	◐	◐	◐		◐	○	○			
C.09 Coverage/Ubiquity is addressed by this initiative.				○		◐	◐	◐	◐	◐	○	○
C.10 Risk Aversion is addressed by this initiative.	○	●	◐	◐	●		○	○	◐	●	●	●

	x13: Buildout rural network	*x14: Upgrade to newest technological equipment for users*	*x15: Training programs for users*	*x16: Community engagement for understanding network*	*x17: Build framework for local, regional and national control*	*x18: Build backhaul network*	*x19: Invest in public safety owned deployables*	*x20: Invest in satellite services*	*x21: Invest in in-building solutions*	*x22: Invest in customer service centers*
C.01 Availability is addressed by this initiative.	●	○			○	●	◐	●	●	
C.02 Privacy is addressed by this initiative.					○					
C.03 Interoperability is addressed by this initiative.	○	○	●	◐	●				○	◐
C.04 Usability is addressed by this initiative.	◐	○	●	○	◐	○	○		◐	◐
C.05 Quality of Service is addressed by this initiative.	◐	◐	○	○	◐	◐		◐	◐	●
C.06 Affordability is addressed by this initiative.										
C.07 Standards Based is addressed by this initiative.	○				○	○		○		
C.08 Flexibility is addressed by this initiative.	◐		○	○	◐	●	●	◐	◐	○
C.09 Coverage/Ubiquity is addressed by this initiative.	◐	◐					◐	◐	●	
C.10 Risk Aversion is addressed by this initiative.					○	●	◐			◐

Table 24 Iteration 2 reweighting of criteria under each scenario for perspective p_1 Vendor in comparison to the baseline relevance for enterprise risk analysis

p_1 Vendor	***S1. Funding Decreases***	***S2. Change of Vendor***	***S3. Natural Disaster***	***S4. Technology becomes obsolete***	***S5. Government policy changes***	***S0. Baseline***
C.01 Availability	Decreases Somewhat	-	Increases	Decreases Somewhat	Decreases	*high*
C.02 Privacy	Decreases	-	Decreases Somewhat	-	Decreases Somewhat	*low*
C.03 Interoperability	Decreases Somewhat	-	-	Increases Somewhat	-	*medium*
C.04 Usability	-	-	Increases Somewhat	Increases	Increases Somewhat	*high*
C.05 Quality of Service	Decreases Somewhat	-	-	Increases Somewhat	-	*high*
C.06 Affordability	Increases	-	Decreases	Increases	Increases	*medium*
C.07 Standards Based	Decreases	-	Decreases	-	Decreases	*low*
C.08 Flexibility	Increases Somewhat	-	Increases Somewhat	Increases Somewhat	Increases Somewhat	*low*
C.09 Coverage/Ubiquity	Decreases Somewhat	-	Decreases Somewhat	-	-	*high*
C.10 Risk Aversion	Decreases Somewhat	-	Increases Somewhat	-	-	*low*

Table 25 Iteration 2 reweighting of criteria under each scenario for perspective p_2 Regulatory in comparison to the baseline relevance for enterprise risk analysis

p_2 Regulatory	***S1. Funding Decreases***	***S2. Change of Vendor***	***S3. Natural Disaster***	***S4. Technology becomes obsolete***	***S5. Government policy changes***	***S0. Baseline***
C.01 Availability	-	Increases Somewhat	Increases	Increases Somewhat	-	*high*
C.02 Privacy	Decreases Somewhat	-	Decreases	-	-	*low*
C.03 Interoperability	-	Increases	Increases Somewhat	Increases	Increases Somewhat	*high*
C.04 Usability	Increases Somewhat	-	Increases Somewhat	Increases Somewhat	Decreases Somewhat	*medium*
C.05 Quality of Service	Decreases	Increases Somewhat	Increases Somewhat	Increases	-	*low*
C.06 Affordability	Increases	-	Decreases	Increases Somewhat	Increases	*high*
C.07 Standards Based	Decreases	Increases Somewhat	Decreases	Decreases Somewhat	-	*low*
C.08 Flexibility	Increases Somewhat	Increases Somewhat	-	Increases	Increases	*medium*
C.09 Coverage/Ubiquity	Decreases Somewhat	Decreases Somewhat	Decreases	-	Increases Somewhat	*high*
C.10 Risk Aversion	Increases Somewhat	-	-	-	Increases Somewhat	*medium*

Table 26 Iteration 2 reweighting of criteria under each scenario for perspective p_3 Public Safety Agencies in comparison to the baseline relevance for enterprise risk analysis

p_3 Public Safety Agencies	***S1. Funding Decreases***	***S2. Change of Vendor***	***S3. Natural Disaster***	***S4. Technology becomes obsolete***	***S5. Government policy changes***	***S0. Baseline***
C.01 Availability	-	Increases Somewhat	Increases	Increases Somewhat	-	*high*
C.02 Privacy	Decreases Somewhat	-	Decreases Somewhat	-	-	*medium*
C.03 Interoperability	Increases Somewhat	Increases	Increases	Increases	Increases	*high*
C.04 Usability	-	-	-	Increases Somewhat	Increases Somewhat	*high*
C.05 Quality of Service	Decreases Somewhat	Increases Somewhat	Increases Somewhat	-	Increases Somewhat	*low*
C.06 Affordability	Increases	Increases Somewhat	Decreases Somewhat	Increases	Increases	*medium*
C.07 Standards Based	-	Decreases Somewhat	Decreases Somewhat	Decreases	Decreases	*low*
C.08 Flexibility	Increases Somewhat	Increases Somewhat	Increases Somewhat	Increases Somewhat	Increases Somewhat	*medium*
C.09 Coverage/Ubiquity	Decreases Somewhat	Increases Somewhat	Decreases	Decreases Somewhat	-	*high*
C.10 Risk Aversion	Increases Somewhat	Decreases Somewhat	-	-	Decreases Somewhat	*high*

Table 27 shows the rankings and value scores for each initiative under perspective p_1 *Vendor*. Table 28 shows the rankings and value scores for each initiative under perspective p_2 *Regulatory*. Table 29 shows the rankings and value scores for each initiative under perspective p_3 *Public Safety Agencies*. Under each perspective, initiative x_4 *Improve data source access* is again ranked 1 across all scenarios. The median rank for each initiative is again shown. Figure 8-Figure 10 show a visualization of the rankings for each of the respective perspectives. The highest rank an initiative receives under a scenario is illustrated by the blue bars, the baseline rank is illustrated by the black bar and the lowest rank an initiative receives is illustrated by a red bar. The blue and red bars are not included if the baseline rank is the highest or lowest rank received, respectively. Initiative x_4: $Improve\ data\ source\ access$ again ranks consistently as the highest for each perspective and there is no variation of rank under any scenario. This implies that this initiative is highly resilient. Initiative x_7: $Develop\ information\ sharing\ and\ analysis\ center$ is highly ranked for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies* and is very resilient, with a lowest rank of 4 and highest of 2, but it is neither highly ranked or resilient for perspective p_1 *Vendor*. Initiative x_{16}: $Community\ engagement\ for\ understanding\ network$ has the lowest baseline rank across all perspectives and is fairly resilient to these low ranks. The highest rank it received was 16. Initiative x_5: $Strengthen\ cyber\ security$ is another consistently lower ranked initiative across perspectives though it has more sensitivity to different scenarios. Initiative x_6: $Software\ development$ is the only other initiative that is somewhat consistently ranked highly. For perspective p_1 *Vendor*, it has a baseline rank of 4, highest rank of 3 and lowest rank of 8. For perspective p_2 *Regulatory*, it has a baseline and highest rank of 3 and lowest rank of 9. For perspective p_3 *Public Safety Agencies*, it has a baseline and highest rank of 4 and lowest rank of 9. Initiatives $x_1, x_3, x_9, x_{13}, x_{21}$ are generally ranked in the top half of initiatives across perspectives with varying levels of sensitivity. There is not significant agreement about many of the other initiatives. This prioritization is again not meant to be prescriptive, but rather its primary

role is to be used to investigate the disruptiveness of scenarios in Iteration 2 as described in the following section and is also used to reframe and revise the model in further iterations.

Table 27 Iteration 2 ranking and value scores for each initiative under each scenario for perspective p_1 Vendor for enterprise risk analysis

p_1 Vendor	***x01: Promote data integration***	***x02: Promote better network resilience***	***x03: Promote better data processing***	***x04: Improve data source access***	***x05: Strengthen cyber security***	***x06: Software development***	***x07: Develop information sharing and analysis center***	***x08: Gap analysis of disparate databases***	***x09: Initiate pilot programs***	***x10: Develop software analytics framework***	***x11: Define device requirements***	***x12: Develop data standards***
Ranking of Initiatives												
S0. Baseline	**7**	**10**	**4**	**1**	**20**	**4**	**8**	**8**	**2**	**17**	**14**	**14**
S1. Funding Decreases	**13**	**5**	**6**	**1**	**15**	**3**	**4**	**17**	**2**	**21**	**7**	**7**
S2. Change of Vendor	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
S3. Environmental event disrupts service	**2**	**11**	**7**	**1**	**16**	**8**	**9**	**10**	**3**	**20**	**18**	**18**
S4. Low number of PS agencies enroll	**6**	**15**	**2**	**1**	**16**	**4**	**12**	**11**	**3**	**18**	**13**	**13**
S5. Change in government policy	**12**	**11**	**4**	**1**	**16**	**3**	**5**	**14**	**2**	**17**	**8**	**8**
Median Ranking	**7**	**11**	**4**	**1**	**16**	**4**	**8**	**11**	**2**	**18**	**13**	**13**
Value Score of Initiatives												
S0. Baseline	**54**	**43**	**58**	**75**	**33**	**58**	**53**	**53**	**67**	**36**	**42**	**54**
S1. Funding Decreases	**29**	**34**	**33**	**86**	**26**	**56**	**47**	**22**	**64**	**13**	**31**	**29**
S2. Change of Vendor	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
S3. Environmental event disrupts service	**56**	**63**	**67**	**90**	**80**	**73**	**58**	**38**	**47**	**88**	**44**	**56**
S4. Low number of PS agencies enroll	**56**	**47**	**76**	**83**	**44**	**64**	**48**	**49**	**75**	**35**	**48**	**56**
S5. Change in government policy	**44**	**45**	**61**	**77**	**41**	**70**	**53**	**43**	**77**	**37**	**46**	**44**

p_1 Vendor cont.	x13: Buildout rural network	x14: Upgrade to newest technological equipment for users	x15: Training programs for users	x16: Community engagement for understanding network	x17: Build framework for local, regional and national control	x18: Build backhaul network	x19: Invest in public safety owned deployables	x20: Invest in satellite services	x21: Invest in in-building solutions	x22: Invest in customer service centers
Ranking of Initiatives										
S0. Baseline	6	17	21	22	10	10	19	10	3	16
S1. Funding Decreases	11	22	16	20	14	9	12	19	10	18
S2. Change of Vendor	-	-	-	-	-	-	-	-	-	-
S3. Environmental event disrupts service	5	21	15	22	14	6	12	13	3	17
S4. Low number of PS agencies enroll	10	19	8	20	7	17	22	21	9	5
S5. Change in government policy	10	20	6	21	13	18	19	22	7	15
Median Ranking	10	20	15	21	13	10	19	19	7	16
Value Score of Initiatives										
S0. Baseline	57	36	32	18	43	43	35	43	61	38
S1. Funding Decreases	29	9	23	13	27	30	29	19	30	20
S2. Change of Vendor	-	-	-	-	-	-	-	-	-	-
S3. Environmental event disrupts service	46	0	0	0	0	0	0	0	0	0
S4. Low number of PS agencies enroll	50	34	55	29	56	35	21	24	51	57
S5. Change in government policy	46	25	51	22	44	32	31	17	48	42

Table 28 Iteration 2 ranking and value scores for each initiative under each scenario for perspective p_2 Regulatory for enterprise risk analysis

p_2 Regulatory	***x01: Promote data integration***	***x02: Promote better network resilience***	***x03: Promote better data processing***	***x04: Improve data source access***	***x05: Strengthen cyber security***	***x06: Software development***	***x07: Develop information sharing and analysis center***	***x08: Gap analysis of disparate databases***	***x09: Initiate pilot programs***	***x10: Develop software analytics framework***	***x11: Define device requirements***	***x12: Develop data standards***
Ranking of Initiatives												
S0. Baseline	6	15	8	1	21	3	2	5	4	17	10	10
S1. Funding Decreases	11	7	8	1	10	3	4	14	2	18	5	5
S2. Change of Vendor	2	17	4	1	21	9	3	5	16	22	13	13
S3. Environmental event disrupts service	2	17	4	1	21	9	3	5	16	22	13	13
S4. Low number of PS agencies enroll	2	17	4	1	21	5	3	6	9	22	13	13
S5. Change in government policy	10	15	9	1	21	3	2	5	4	19	6	6
Median Ranking	4	16	6	1	21	4	3	5	7	21	12	12
Value Score of Initiatives												
S0. Baseline	51	36	49	76	25	55	60	52	53	29	43	43
S1. Funding Decreases	37	44	44	84	37	51	49	30	63	27	44	44
S2. Change of Vendor	81	36	69	86	22	52	71	67	37	13	39	39
S3. Environmental event disrupts service	81	36	69	86	22	52	71	67	37	13	39	39
S4. Low number of PS agencies enroll	66	33	59	89	21	58	64	55	50	13	36	36
S5. Change in government policy	38	28	40	77	21	50	60	46	48	26	42	42

p_2 Regulatory cont.	x13: Buildout rural network	x14: Upgrade to newest technological equipment for users	x15: Training programs for users	x16: Community engagement for understanding network	x17: Build framework for local, regional and national control	x18: Build backhaul network	x19: Invest in public safety owned deployables	x20: Invest in satellite services	x21: Invest in in-building solutions	x22: Invest in customer service centers
Ranking of Initiatives										
S0. Baseline	9	20	18	22	12	13	14	16	6	18
S1. Funding Decreases	17	22	19	21	13	9	12	20	16	15
S2. Change of Vendor	7	20	11	19	6	10	18	12	8	15
S3. Environmental event disrupts service	7	20	11	19	6	10	18	12	8	15
S4. Low number of PS agencies enroll	10	20	11	19	7	12	18	16	8	15
S5. Change in government policy	13	20	18	22	12	14	11	16	8	17
Median Ranking	10	20	15	20	10	11	16	16	8	15
Value Score of Initiatives										
S0. Baseline	47	27	28	17	40	39	37	36	51	28
S1. Funding Decreases	28	9	26	14	33	42	35	16	29	30
S2. Change of Vendor	56	27	45	31	63	50	34	43	54	38
S3. Environmental event disrupts service	56	27	45	31	63	50	34	43	54	38
S4. Low number of PS agencies enroll	50	25	42	27	53	42	32	35	51	36
S5. Change in government policy	35	23	26	19	36	29	37	27	41	26

Table 29 Iteration 2 ranking and value scores for each initiative under each scenario for perspective p_3 Public Safety Agencies for enterprise risk analysis

p_3 Public Safety Agencies	***x01: Promote data integration***	***x02: Promote better network resilience***	***x03: Promote better data processing***	***x04: Improve data source access***	***x05: Strengthen cyber security***	***x06: Software development***	***x07: Develop information sharing and analysis center***	***x08: Gap analysis of disparate databases***	***x09: Initiate pilot programs***	***x10: Develop software analytics framework***	***x11: Define device requirements***	***x12: Develop data standards***
Ranking of Initiatives												
S0. Baseline	**5**	**13**	**3**	**1**	**20**	**4**	**2**	**5**	**5**	**18**	**10**	**10**
S1. Funding Decreases	**4**	**14**	**3**	**1**	**16**	**9**	**2**	**6**	**12**	**20**	**7**	**7**
S2. Change of Vendor	**5**	**19**	**8**	**1**	**22**	**6**	**2**	**4**	**10**	**21**	**16**	**16**
S3. Environmental event disrupts service	**5**	**19**	**8**	**1**	**22**	**6**	**2**	**4**	**10**	**21**	**16**	**16**
S4. Low number of PS agencies enroll	**2**	**16**	**4**	**1**	**21**	**5**	**3**	**6**	**11**	**22**	**13**	**13**
S5. Change in government policy	**4**	**15**	**2**	**1**	**17**	**5**	**3**	**8**	**9**	**21**	**10**	**10**
Median Ranking	**5**	**16**	**4**	**1**	**21**	**6**	**2**	**6**	**10**	**21**	**12**	**12**
Value Score of Initiatives												
S0. Baseline	**55**	**44**	**58**	**73**	**31**	**56**	**62**	**55**	**55**	**33**	**46**	**46**
S1. Funding Decreases	**58**	**39**	**63**	**85**	**32**	**46**	**65**	**52**	**41**	**22**	**51**	**51**
S2. Change of Vendor	**61**	**25**	**51**	**81**	**14**	**58**	**68**	**63**	**47**	**18**	**34**	**34**
S3. Environmental event disrupts service	**61**	**25**	**51**	**81**	**14**	**58**	**68**	**63**	**47**	**18**	**34**	**34**
S4. Low number of PS agencies enroll	**72**	**36**	**67**	**88**	**24**	**65**	**70**	**61**	**51**	**17**	**41**	**41**
S5. Change in government policy	**65**	**36**	**73**	**85**	**29**	**64**	**67**	**59**	**51**	**21**	**48**	**48**

p_3 Public Safety Agencies cont.	x13: Buildout rural network	x14: Upgrade to newest technological equipment for users	x15: Training programs for users	x16: Community engagement for understanding network	x17: Build framework for local, regional and national control	x18: Build backhaul network	x19: Invest in public safety owned deployables	x20: Invest in satellite services	x21: Invest in in-building solutions	x22: Invest in customer service centers
Ranking of Initiatives										
S0. Baseline	9	21	16	22	12	14	15	17	8	19
S1. Funding Decreases	16	22	10	19	5	13	15	21	18	11
S2. Change of Vendor	7	15	13	20	9	14	12	11	3	18
S3. Environmental event disrupts service	7	15	13	20	9	14	12	11	3	18
S4. Low number of PS agencies enroll	10	20	8	18	7	12	17	19	9	15
S5. Change in government policy	14	19	7	16	6	18	20	22	13	12
Median Ranking	10	20	12	20	8	14	15	18	9	17
Value Score of Initiatives										
S0. Baseline	50	28	35	19	45	40	38	35	54	32
S1. Funding Decreases	32	15	43	29	55	40	33	17	32	42
S2. Change of Vendor	56	34	36	25	48	36	39	45	63	29
S3. Environmental event disrupts service	56	34	36	25	48	36	39	45	63	29
S4. Low number of PS agencies enroll	53	24	53	30	58	41	33	29	53	38
S5. Change in government policy	45	27	62	35	62	28	25	19	46	47

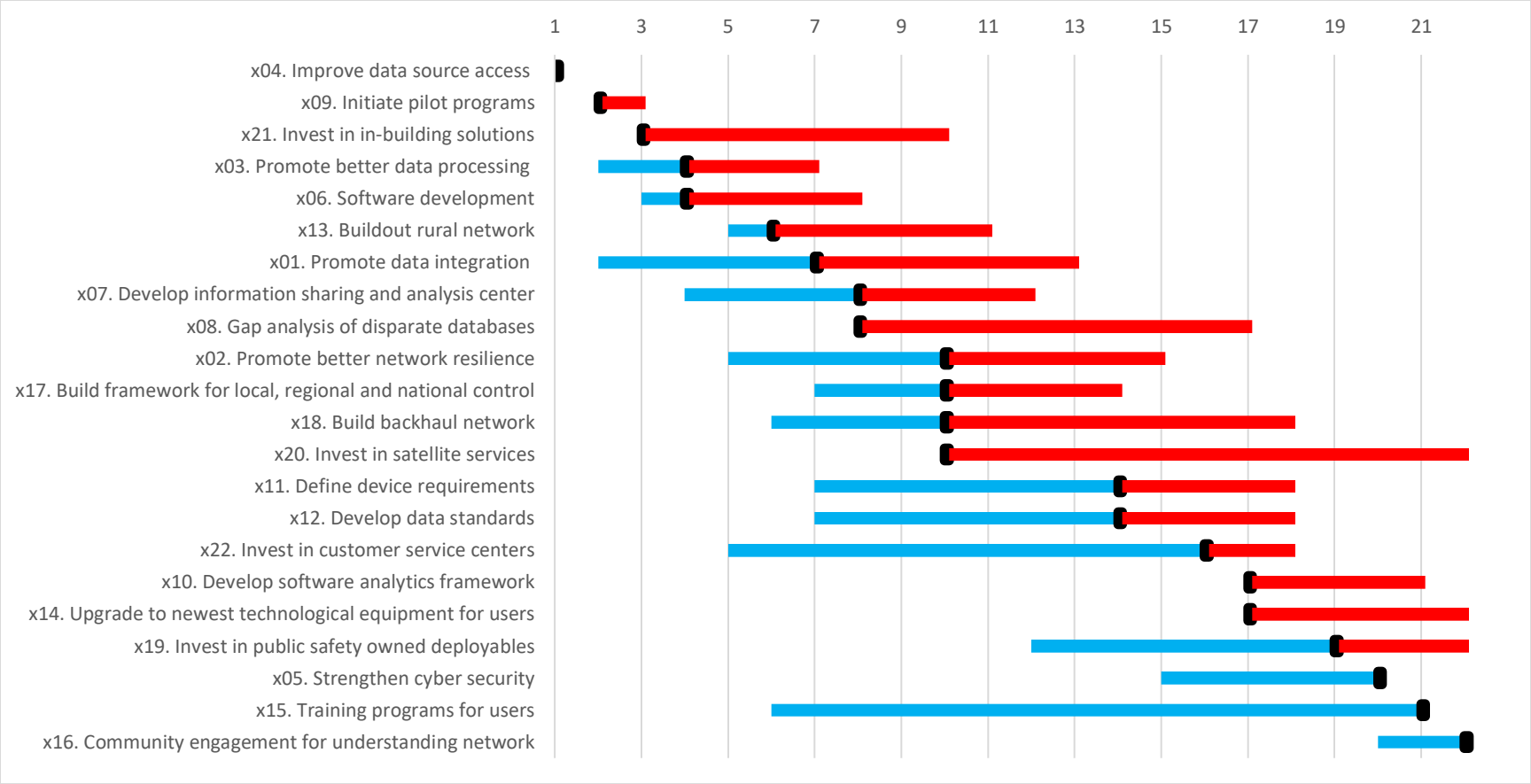

Figure 8 Iteration 2 prioritization of initiatives for perspective p_1 Vendor showing the baseline rank and the high and low ranks for enterprise risk analysis

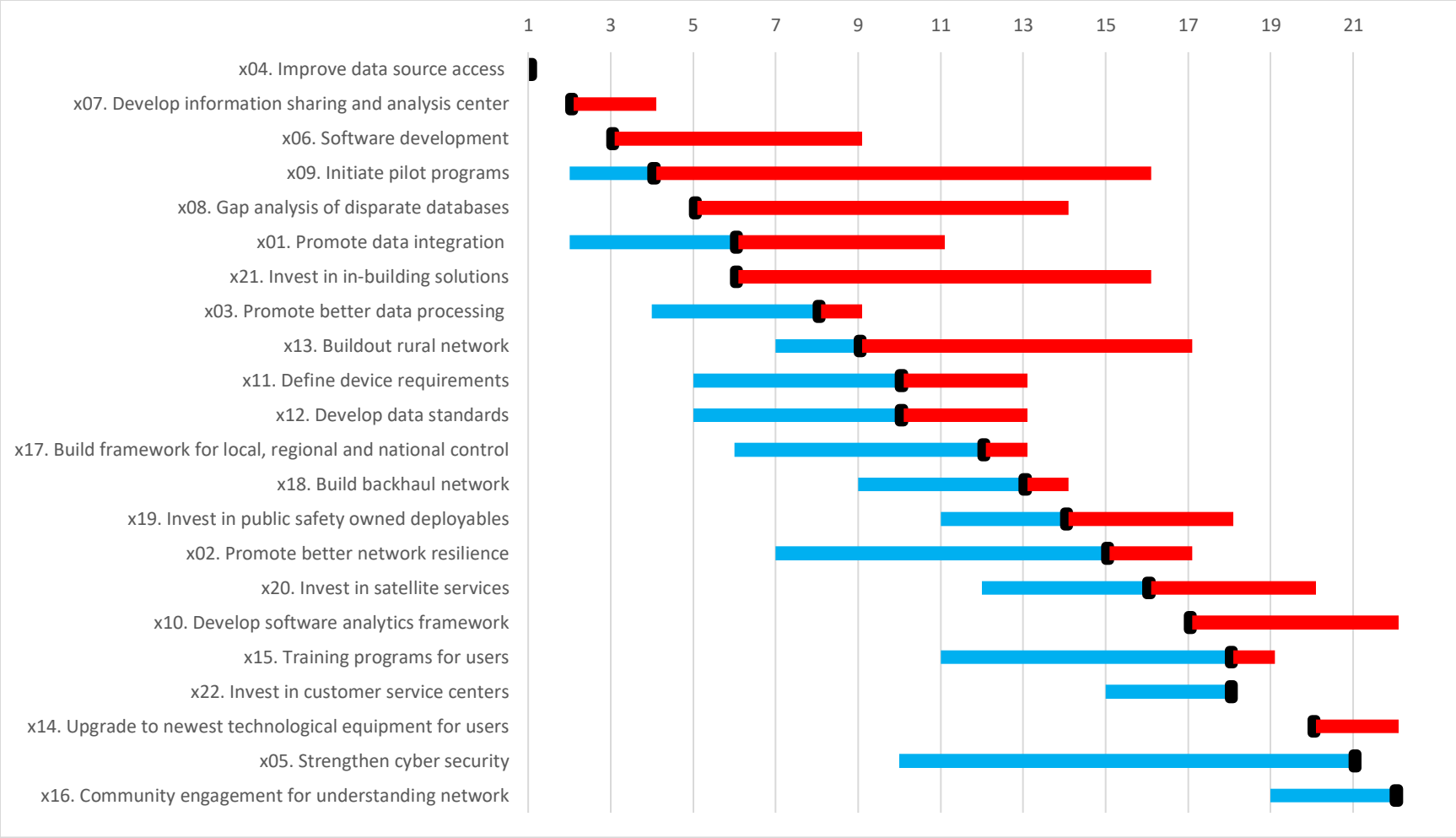

Figure 9 Iteration 2 prioritization of initiatives for perspective p_2 Regulatory showing the baseline rank and the high and low ranks for enterprise risk analysis

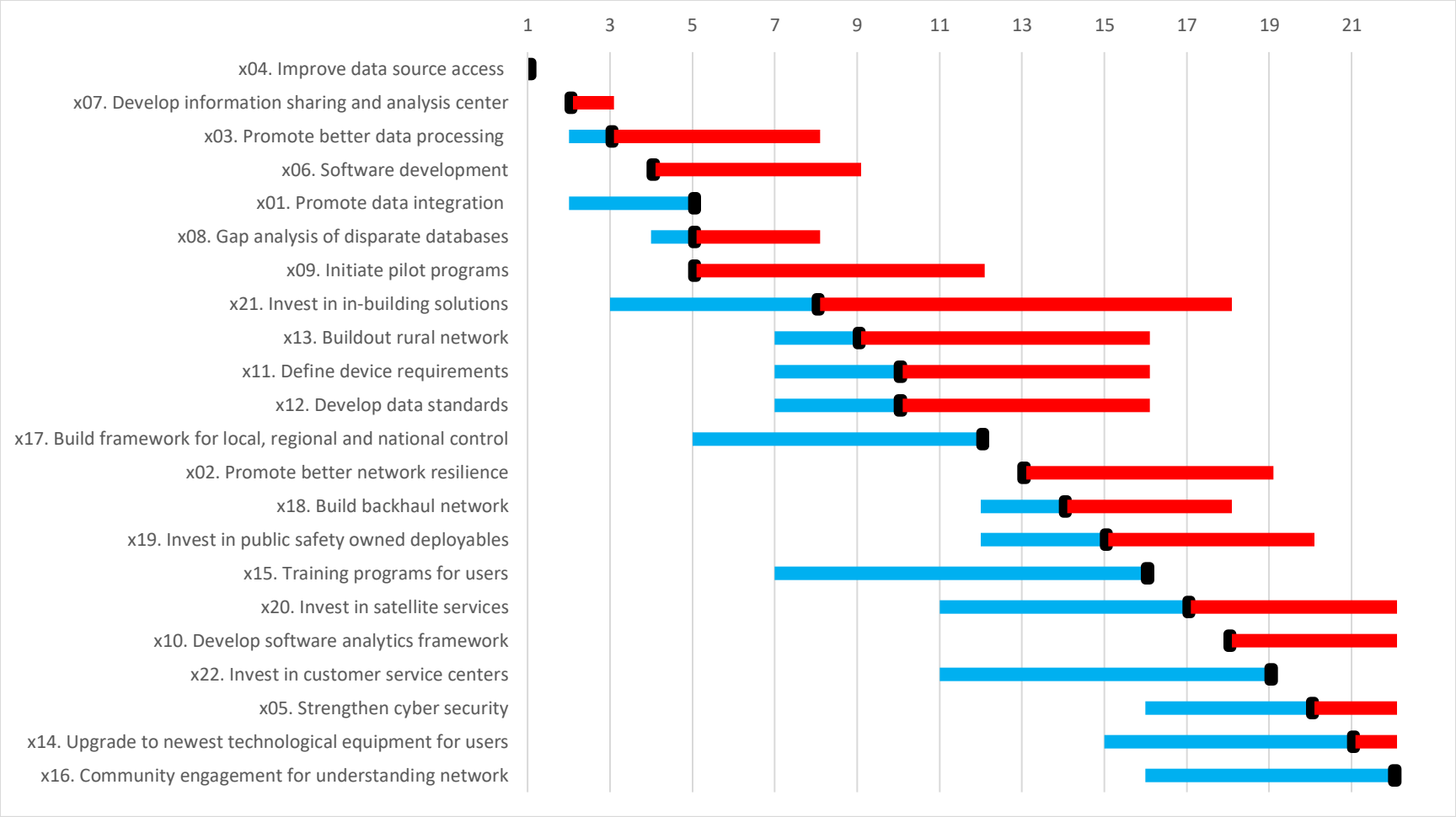

Figure 10 Iteration 2 prioritization of initiatives for perspective p_3 Public Safety Agencies showing the baseline rank and the high and low ranks for enterprise risk analysis

4.3.11 Iteration 2: Disruption of scenarios to the prioritization of initiatives

From the results in Chapter 4.3.10, we are able to use the sum of square rankings change to again calculate the disruptive scores for the different scenarios. The normalized disruptive scores are calculated for each perspective. Figure 11 shows the disruptive scores for perspective p_1 *Vendor*. Figure 12 shows the disruptive scores for perspective p_2 *Regulatory*. Figure 13 shows the disruptive scores for perspective p_3 *Public Safety Agencies*. The scores for each scenario are out of 100. For perspective p_1 *Vendor* s_5: $Government\ policy\ changes$ is just barely the most disruptive scenario followed closely by s_1: $Funding\ decreases$. The least disruptive scenario for perspective p_1 *Vendor* is s_3: $Natural\ disaster$. For perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies,* scenario s_1: $Funding\ Decreases$ is the most disruptive. Scenario s_5: $Government\ policy\ changes$ is largely the least disruptive scenario for perspective p_2 *Regulatory*. Whereas, s_4: $Technology\ becomes\ obsolete$ is the least disruptive scenario for perspective p_3 *Public Safety Agencies*, but it is not as significantly less disruptive as scenario s_5 is for perspective p_2 *Regulatory*.

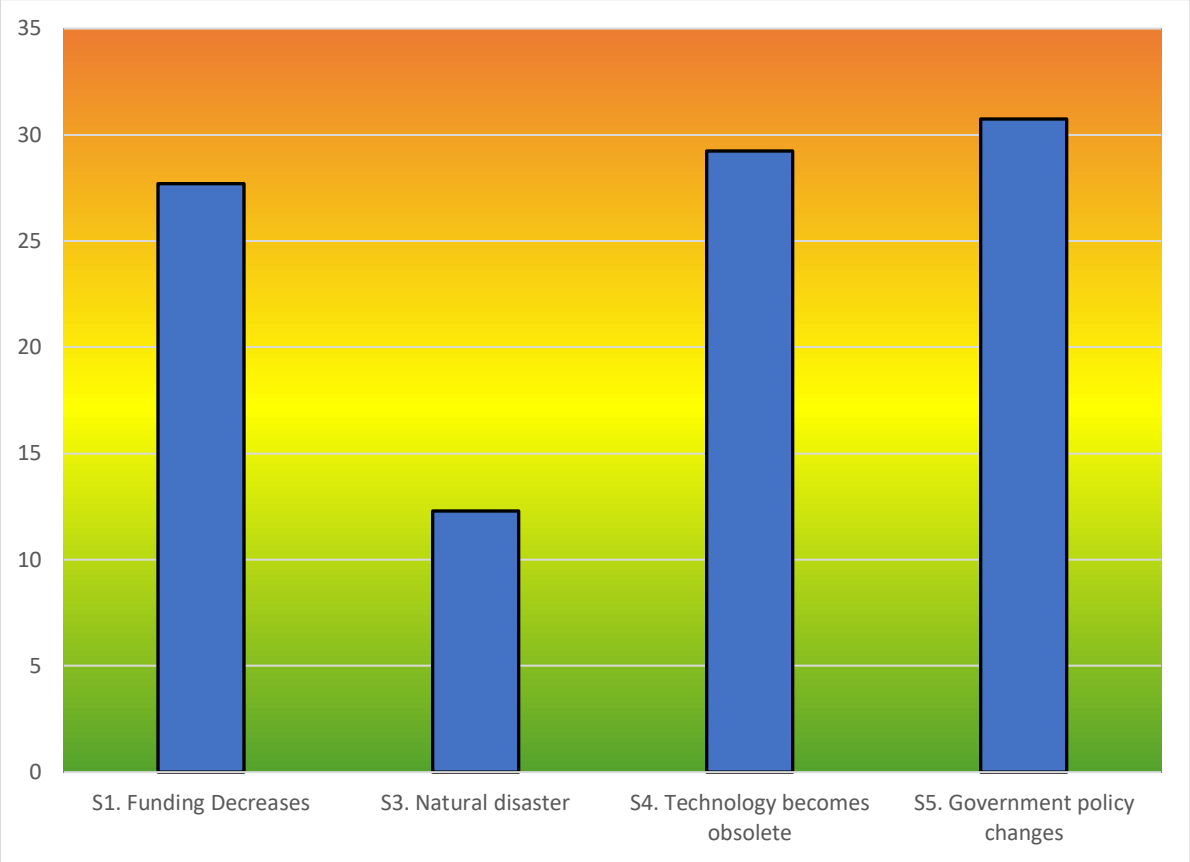

Figure 11 Iteration 2 normalized disruptive scores for each scenario under perspective p_1 Vendor for enterprise risk analysis

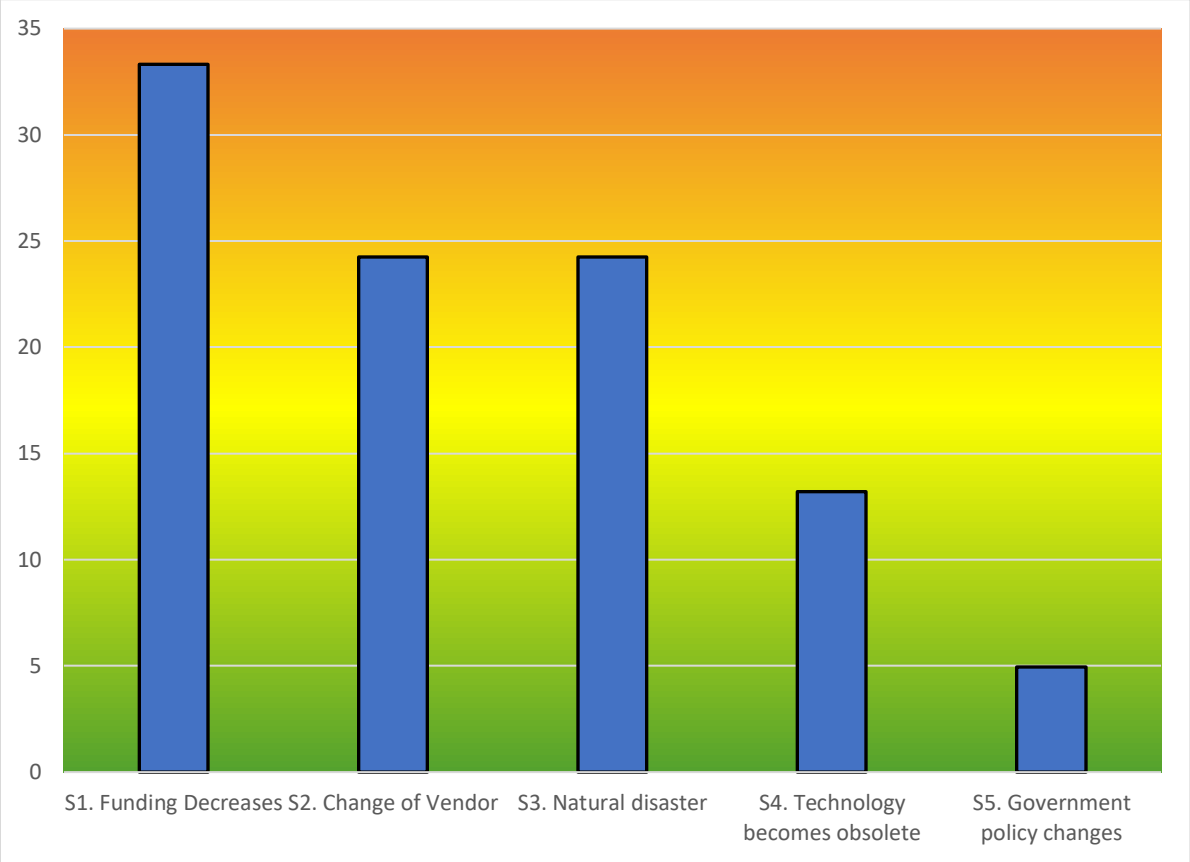

Figure 12 Iteration 2 normalized disruptive scores for each scenario under perspective p_2 Regulatory for enterprise risk analysis

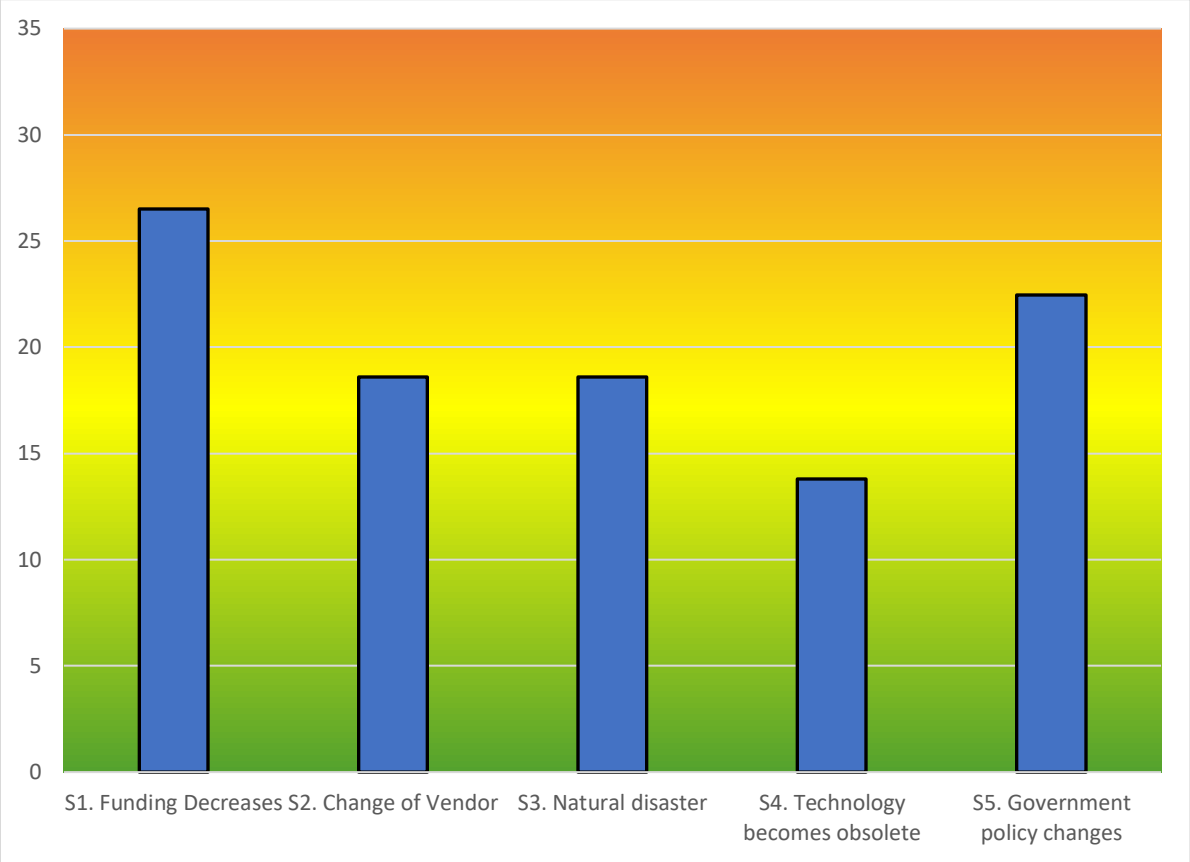

Figure 13 Iteration 2 normalized disruptive scores for each scenario under perspective p_3 Public Safety Agencies for enterprise risk analysis

4.3.12 Iteration 2: Reframing of model and revising for iteration

The results of Iteration 2 as discussed in the previous two sections are presented in Table 30.The results of Iteration 2 can further be used to revise and iterate the model for the developing system. Sensitive initiatives such as $x_1, x_3, x_9, x_{13}, x_{21}$ can be broken up into component parts to further investigate their sensitivity. Scenarios with large variation in disruptiveness across perspectives such as s_5: $Government\ policy\ changes$ can also be further investigated. Additionally, as the system continues to develop and goals change further revising should be done for criteria and perspectives. The inputs, outputs, and suggested reframing questions for the next iteration are shown in Table 31.

Table 30 Iteration 2 summary of key results for enterprise risk analysis

Type of Result	Description
Most resilient initiative	The initiative x_4: $Improve\ data\ source\ access$ is the most resilient initiative across all perspectives. It is highly prioritized in the baseline ranking and remains high for all scenarios.
Resilient initiatives	Initiatives $x_1, x_3, x_6, x_9, x_{13}, x_{21}$ are fairly resilient. They generally rank in the top half of initiatives in all perspectives.
Most disruptive scenarios	Scenario s_5: $Change\ in\ government\ policy$ is just barely the most disruptive for perspective p_1 *Vendor* followed closely by s_1: $Funding\ decreases$. Scenario s_1: $Funding\ decreases$ is the most disruptive scenario for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies*.
Least disruptive scenarios	Scenario s_3: $Natural\ disaster$ is the least disruptive for perspective p_1 *Vendor*. Scenario s_5: $Change\ in\ government\ policy$ is the least disruptive for perspective p_2 *Regulatory.* Scenario s_4: $Technology\ becomes\ obsolete$ is the least disruptive for perspective p_3 *Public Safety Agencies*
Scenario with the most change between perspectives	Scenario s_5: $Change\ in\ government\ policy$ has the most change between perspectives as it is the least disruptive for perspective p_2 *Regulatory,* most disruptive for perspective p_1 *Vendor* and second most disruptive for perspective p_3 *Public Safety Agencies*
Scenario with the least change between perspectives	Scenario s_1: $Funding\ decreases$ has the least change between perspectives as it is the most disruptive scenario for perspectives p_2 *Regulatory* and p_3 *Public Safety Agencies* and a close second most disruptive for perspective p_1 *Vendor*.

Table 31 Iteration 2 reporting of perspectives, criteria, initiatives, emergent conditions, scenarios, intermediate output and reframing of scenario-based preference model for enterprise risk analysis

Input	Output	Reframing Questions	Reframing
Three Perspectives *p_1 Vendor* *p_2 Regulatory* *p_3 Public Safety Agencies*	N/A	Recommend reevaluation as the system develops	*Recommended for subsequent iteration*
Ten Criteria *c_1 Availability* *c_2 Privacy* *c_3 Interoperability* *c_4 Usability* *c_5 Quality of Service* *c_6 Affordability* *c_7 Standards Based* *c_8 Flexibility* *c_9 Coverage/Ubiquity* *c_{10} Risk Aversion*	N/A	Recommend reevaluation as the system develops	*Recommended for subsequent iteration*
Twenty-Two Initiatives *x_1 Promote data integration* *x_2 Promote better network resilience* *x_3 Promote better data processing* *x_4 Improve data source access* *x_5 Strengthen cyber security* *x_6 Software development* *x_7 Develop information sharing and analysis center* *x_8 Gap analysis of disparate databases* *x_9 Initiate pilot programs* *x_{10} Develop software analytics framework* *x_{11} Define device requirements* *x_{12} Develop data standards* *x_{13} Buildout rural network*	**One highly resilient initiative:** *Improve data source access* **No other consistently resilient initiatives** **One low ranked initiative:** *Community engagement for understanding network*	Initiatives could be updated to include projects planned past the deployment stage. Lower ranked initiatives could be eliminated and sensitive initiatives could be broken up into component parts.	*Recommended for subsequent iteration*

x_{14} Upgrade to newest technological equipment for users *x_{15} Training programs for users* *x_{16} Community engagement for understanding network* *x_{17} Build framework for local, regional and national control* *x_{18} Build backhaul network* *x_{19} Invest in public safety owned deployables* *x_{20} Invest in satellite services* *x_{21} Invest in in-building solutions* *x_{22} Invest in customer service centers*			
Twenty-Six Emergent Conditions *e_1 Insufficient coverage/bandwidth for public safety emergency* *e_2 Allocated bandwidth cannot meet needs of new technology* *e_3 Funding decreases* *e_4 Too few public safety agencies enrolled* *e_5 Poor interoperability between public safety agencies* *e_6 FirstNet unable to meet unique public safety requirements* *e_7 Change of vendors* *e_8 Equipment becomes obsolete* *e_9 Natural disasters* *e_{10} Cyber security measures become outdated* *e_{11} Too much congestion on network* *e_{12} Cyber security unable withstand attack* *e_{13} Government policy changes* *e_{14} Population growth in urban areas* *e_{15} Allocated bandwidth lowered* *e_{16} Allocated bandwidth does not meet necessary requirements*	N/A	Recommend revising list to include and newly developed risks for the system	*Recommended for subsequent iteration*

e_{17} Failure to adapt to new technology *e_{18} Vendor infrastructure not able to meet needs* *e_{19} Low overall demand for network* *e_{20} High overall demand for network* *e_{21} Rollout takes longer than expected* *e_{22} Rollout goes over budget* *e_{23} Customer expectations higher* *e_{24} Difficulties in contract renewal* *e_{25} Armed conflicts* *e_{26} Vendor goes out of business*			
Five Scenarios *s_1 Funding decreases* *s_2 Change of vendor* *s_3 Natural Disaster* *s_4 Technology becomes obsolete* *s_5 Change in government policy*	**One influential scenarios:** *Funding decreases*	Further investigation into *Government policy changes* for the various perspectives. Expansion of scenario list.	*Recommended for subsequent iteration*

4.4 Chapter summary

This chapter has demonstrated the methods presented in Chapter 3 to the First Responder Network Authority system and its deployment. In summary, there is a need to understand the uncertainties that various scenarios present to projects and planning undertaken by the FirstNet system. This demonstration has presented two iterations of priority setting for the uncertainties of FirstNet. The disruptiveness of various scenarios was quantified and several prioritizations of initiatives were presented. The model was run for two iterations: Iteration 1 and Iteration 2. The key results for Iteration 1 are outlined in Table 17 and the key results for Iteration 2 are outlined in Table 30. The scenario that most disrupted the prioritization of initiatives through both iterations was the scenario *Funding decreases*. The reframing for each iteration was outlined in Table 18 and Table 31. The selection of perspectives, criteria, initiatives, and scenarios should be revised as the system develops and moves past the deployment stage. In summary, there is a need to understand the uncertainties that various scenarios present to projects and planning undertaken by the FirstNet system. This demonstration has presented two iterations of priority setting for the uncertainties of FirstNet.

5 Discussion and Conclusions

5.1 Chapter overview

This chapter describes selected issues and concerns that were encountered in the methodology and demonstration. The methods used in this thesis are compared to previous research in risk filtering and scenario-based preference modeling. The challenges and limitations of this methodology are also discussed, as well as the suitable interpretation of the provided results. The current state of the FirstNet system will also be discussed. This chapter also summarizes the contributions and accomplishments made in progress towards this thesis to date and discusses future research directions.

5.2 Findings and considerations

The methods presented in this thesis should be used as a complement to traditional risk analysis. Haimes et al. (2002) after using Hierarchical Holographic Modeling to develop projected scenarios and risks used the RFRM model to filter scenarios by likelihood and consequences, as well as their ability to defeat three defensive properties of the system (redundancy, resilience and robustness). This methodology

complements the technique presented in this thesis because it further filters scenarios by their ability to disrupt the priority of initiatives, thus addressing how scenarios affect the time horizon of initiatives. The methods used are able to quantify the disruption of various scenarios through their disruption to the baseline ranking of initiatives.

Thorisson et al. (2017) show examples of this timeline disruption in Figure 14. Figure 14(a) shows the baseline scenario of the system with the planned timeline. This would be the baseline ranking of the initiatives. Figure 14(b) and Figure 14(c) show the disruption to this timeline where the disruptiveness is measured as the distance between the original timeline and the timeline under a different scenario. This is measured as the change in ranking from the baseline case for the initiatives. In some cases (Figure 14(b)) the system will return to the originally planned timeline after a disruption and in others (Figure 14(c)) the system deviates from the original path and does not return. Each of these timelines could be replicated for different perspectives and each perspective could have a different start and end point.

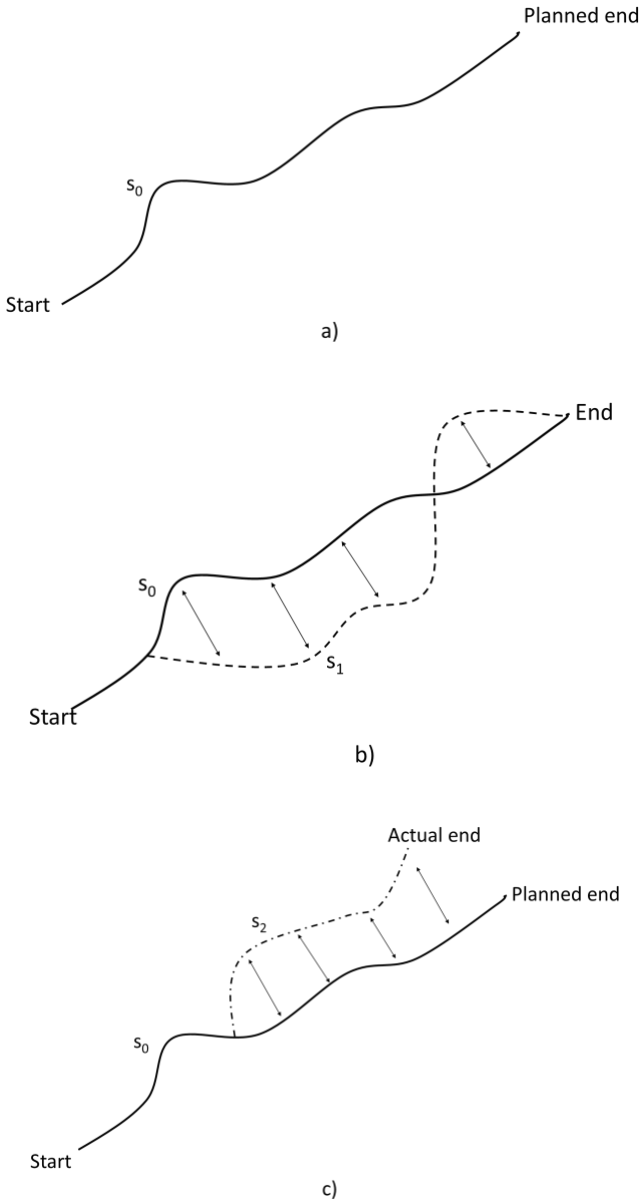

Figure 14 Illustration of the disruption of a timeline of priorities (Thorisson et al., 2017)

The prioritizations of initiatives presented in this thesis are not meant to be the key findings of this analysis, but instead which scenarios most and least matter and how the scenarios disrupt the prioritization of initiatives is the main result. The disruptive measures of scenarios across different perspectives can be used as a stepping stone in the discussion of how to best build a system that is resilient and robust to various future conditions. In general, the results of the analysis are not meant to be prescriptive, but rather to promote understanding of where further investigation should occur. In order for the prioritization of initiatives to be of significant value to the stakeholders there would need to be more investigation into the overlap of initiatives. Some initiatives may be dependent on the completion of another initiative and others may no longer be relevant to the system because it has moved past the deployment stage. Unfortunately, the data available to this thesis was limited and this type of analysis could not be made.

Some other limitations to this methodology are the availability of data and the amount of stakeholder engagement. This analysis required significant stakeholder engagement for the assessment of criteria and initiatives and would require continued conversations throughout the lifetime of the model. The assessment of criteria and initiatives by nature is somewhat subjective. The subjectivity of stakeholder opinions places limitations on how valid the results might be due to stakeholder bias. While this might be considered a limitation it also adds value to the model because it does account for bias in the model and the model will better reflect the needs and desires of the interested parties.

By separating out the different perspectives this methodology in some ways makes it more difficult to present conclusive results as the different perspectives do not always agree on the scenarios that most and least matter, but it is valuable to be able to understand the different priorities of the major stakeholders in the system and the iterative process allows for the disagreement between stakeholders to be addressed and further investigated to better meet the needs of the system as a whole.

5.3 Contributions

The main contribution of this thesis to the literature of risk analysis and systems engineering will be as follows and Figure 15 describes the contributions in the context of current literature.

Contribution 1: Exercising of the scenario-based risk analysis model with iterative and multi-perspective extension. This thesis extends current research on disruption of priorities with scenario-based preferences to include multiple stakeholder perspectives. Additionally, applying this approach was applied iteratively to develop a model that accurately depicts the interests of the stakeholders and is able to update as the system progresses from deployment stage to a functioning system.

Contribution 2: Demonstration to FirstNet in the Commonwealth of Virginia. This thesis demonstrates the methods on planning efforts for First Responder Network Authority in the Commonwealth, working with state government and collaborators at George Mason University and Old Dominion University.

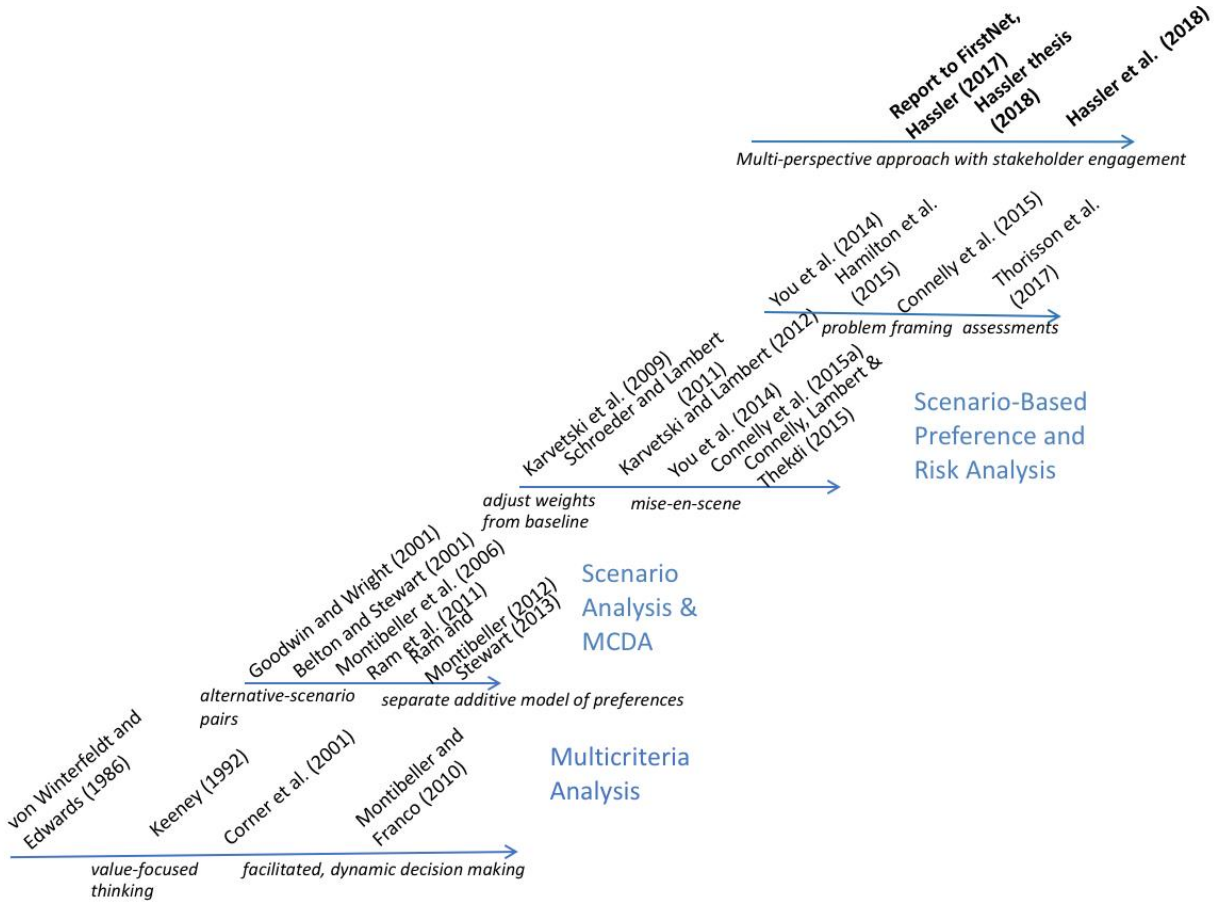

Figure 15 Innovations of this thesis to theory and methodology of systems engineering and risk analysis

In addition to the thesis, the following academic activities are directly relevant to this research:

- ***Co-author of a paper being prepared for Reliability Engineering & System Safety journal.***

  Hassler, M. L., Lambert, J. H. "Multi-Perspective Scenario-Based Preferences in Enterprise Risk Analysis Wireless Broadband Network." In progress.

- ***Presenter of the work at the Annual Meeting of the Society for Risk Analysis (SRA) in December 2017.***

  Hassler, M. L., Collier, Z.A., Bier. V., Lambert, J.H. "Resilience of Food, Energy, and Water Infrastructure for Coastal Cities and Displaced Populations." Presented at the Society for Risk Analysis Annual Meeting in Arlington, VA. December 2017.

- ***Co-author of a conference paper for the International Conference on Systems Engineering 2017.***

  Lambert, J. H., Collier, Z. A., Hassler, M. L., Ganin, A., Wu, D., & Bier, V. M. (2017). Systems Engineering of Interdependent Food, Energy, and Water Infrastructure for Cities and Displaced Populations. International Conference on Systems Engineering, Las Vegas, NV.

- ***Co-author of a book chapter in progress for the series Risk Systems and Decisions.***

  Collier, Z. A., Hassler, M. L., Lambert, J. H., Dimase, D., & Linkov, I. (2019). Supply Chains. In A. Kott & I. Linkov (Eds.), *Cyber Resilience of Systems and Networks*. Springer International Publishing.

Table 32 summarizes activities undertaken in the progress towards this thesis defense.

Table 32 Summary of research milestones

	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18
1. Literature Review												
2. Teleconferences with stakeholders and collaborators												
3. Present paper ICSEng Conference												
4. Identify success criteria, initiatives and scenarios												
5. Build scenario analysis model for Iteration 1												
6. Deliver a report to stakeholders												
7. Evaluate and revise Iteration 1												
8. Present research at SRA Annual Meeting												
9. Thesis proposal												
10. Build scenario analysis model for Iteration 2												
11. Thesis Defense												
12. Submit and revise journal paper												

5.4 Future work

There is ample opportunity to expand this research. The multiple perspective scenario-based preference model is applicable to many different domains and its iterative capability makes it useful to extend throughout a system's lifetime. The use of the iterative approach should be explored further and applied to more cases and the possibility for a more formal process of updating the model could be developed. One suggested next step to formalize the updating process is a risk analysis of criterion coverage. This analysis would in addition to looking at how well initiatives are covered by criteria would look at how well criteria are covered by initiatives. As criteria represent goals or objectives of the system if a criterion is now well covered it could motivate the revision or addition of initiatives to better meet the needs of the system or the revision of scenarios to better challenge the goals of the system. These steps would contribute to the validity of the iteration and formalize it so that it is slightly less qualitative.

5.5 Chapter Summary

This chapter discussed the key findings of the analysis of identifying the scenarios that most and least matter. It addressed the fact that the method is not meant to be prescriptive but a jumping off point for further investigation. The limitations of the methodology were discussed and addressed. This chapter also summarized the contributions of this thesis to the systems engineering and risk analysis body of knowledge. Two major contributions were claimed: exercising the scenario-based risk analysis in combination with a multiple perspective and iterative approach and application to FirstNet, the public safety wireless broadband network. In addition, future areas of research were identified and discussed.

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