Stakeholder Mapping Incorporated to Enterprise Resilience of Mobile Smart Grid and Automated Container Port

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ABSTRACT

The literature of *stakeholder mapping* has described how the influences of participants with a variety of interests and backgrounds must be accounted in enterprise and business processes. Meanwhile, recent developments in risk assessment and risk management have addressed the topic of system resilience in various application domains, including energy security (Thorisson et al. 2017; Hamilton et al. 2012; Karvetski and Lambert 2012), the biofuel industry (Connelly et al. 2015), climate change (Hamilton, Lambert, and Valverde Jr 2015; You et al. 2014; Lambert et al. 2012), and infrastructure domain (Lambert et al. 2011). However, a framework that could integrate stakeholder mapping with risk or resilience scenarios is sorely lacking (Cairns et al., 2016). Failing to incorporate the preferences of stakeholders into the analysis of enterprise resilience could introduce conflicts between stakeholders and create unbalanced outcomes (Talantsev 2017). This dissertation addresses this gap by developing and demonstrating a framework for resilience analytics that integrates (i) the influence of multiple stakeholders and (ii) the influence of scenarios. Thus, the innovation of this research is to improve enterprise resilience by integrating *stakeholder mapping* with *scenario-based preferences modeling*. The innovation is demonstrated in three case studies. The first case study supports the priority setting of smart grids to the influence only of scenarios. The second case study supports the priority setting of smart grids to the influences both of scenarios and of multiple stakeholders. The third case study supports priority setting of a maritime container port subject to the influences both of scenarios and of multiple stakeholders. The new approach provides owners/operators of engineering systems with an understanding of what sources of risk and opportunity matter most and least to priority setting, with an added essential emphasis on the evolving roles of multiple stakeholders. The approach guides owners/operators in how to better utilize their efforts and resources by emphasizing the

most robust and highly prioritized initiatives and the most disruptive scenarios for each group of stakeholders and for all the groups of stakeholders.

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ACRONYMS

AHP	Analytical Hierarchy Process
CIMT	Craney Island Marine Terminal
DOE	U.S. Department of Energy
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FERC	Federal Energy Regulatory Commission
ISO	Independent Systems Operator
KPI	Key Performance Indicators
MCDA	Multi-Criteria Decision Analysis
NIT	Norfolk International Terminals
NNMT	Newport News Marine Terminal
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
OEMs	Original Equipment Manufacturer
PEV	Plug-in Electric Vehicle
PJM	Pennsylvania–New-Jersey–Maryland Interconnection

PMT	Portsmouth Marine Terminal
POV	Port of Virginia
RMT	Richmond Marine Terminal
RTOs	Regional Transmission Organizations
UN	United Nations
V2G	Vehicle-to-Grid
VIG	Virginia International Gateway
VIP	Virginia Inland Port

CHAPTER 1. INTRODUCTION

1.1 Overview

This chapter introduces the topic of this dissertation. Section 1.2 describes the motivation for this research. Section 1.3 describes the purpose and the scope of this research. Section 1.4 summarizes the contributions of this research to theory, methodology, and practice in the field of risk analysis. Section 1.5 describes the organization of this dissertation.

1.2 Motivation

Systems engineering by its nature is an interdisciplinary field that deals with problems in complex systems which serve large groups of people who may have different levels of power, interest, and knowledge in many enterprise and business processes. Conflicts and disagreements often arise in projects that involve large groups of stakeholders who have diverse objectives, concerns, and interests. Current research in stakeholder management emphasizes the importance of addressing the risk associated with problems that involve networks of users, clients, suppliers, community residents, employees, organizations, and others. Addressing the risk associated with these kinds of complex problems requires addressing multiple perspectives that matter to large groups of stakeholders who affect or might be affected by the problems or the modeling outcomes.

In risk assessment and risk management, decisions that involve multiple stakeholders who have different backgrounds and different levels of power and interest are characterized by complexity, interdependency, interconnectedness, and uncertainty. The success of risk frameworks depends heavily on the ability of the stakeholders to provide preferences and tradeoffs for the decision problem (Hamilton 2014). However, stakeholders have different levels of influence and interest, which prevents action and generates conflicts (Mendelow 1981).

For example, a survey published by the European Sea Ports Organization indicated that only 17% of stakeholders and local communities were involved in port development plans (Brooke 2002). The desired outcomes of such development plans could be disrupted if the participation of a particular stakeholder is delayed or neglected. De Langen (2006) published a framework for analyzing conflicts of interests in maritime container ports and found that at least five major conflicts of interests can arise, including those related to environmental protection, urban development, labor conditions, resident interests, and the overall economic impact. De Langen (2006) concluded that stakeholders have different levels of power and interest in different projects, and to satisfy the needs of all of the stakeholders, comprehensive research should be conducted that addresses multiple perspectives and interests. For instance, De Langen (2006) found a delay in port expansion projects as a result of conflicts of interest between environmentalism and economic impact. This problem is seen not only in container port development, but also in many fields of application when the participants have different levels of interest in and power over a certain problem.

The **first motivation** for this research is that recent research in risk communication emphasizes the negative impacts of missing participation of public and private parties (Gregory and Keeney 2017; Palma-Oliveira et al. 2017; Haimes 2015; Denktas-Sakar and Karatas-Cetin 2012; Brooke 2002). The contributions of stakeholders are key inputs for strategic phases of system development (Buede and Miller 2016). Several researchers have pointed out that analyzing complex systems cannot be achieved by considering only a single perspective, since the participating parties are essential to conducting an analysis (Barker et al. 2017; Cairns, Goodwin, and Wright 2016). They state that no party should be ignored, as each party adds different information, perspectives, and background to the risk analysis. Comprehensive research that addresses a wide range of interests and perspectives is required when the enterprise and business processes involve multiple stakeholders (Wright and Cairns 2011).

The **second motivation** for this research is that *disruptive events*—such as economic crises, natural disasters, terrorist attacks, accidents, and organizational upheavals, among others—can bring about rapid and significant changes in the preferences of stakeholders and the values of the public and policymakers (Thorisson et al. 2017; Connelly and Lambert 2016; Hamilton et al. 2016). These changes in the preferences of stakeholders and the values of the public will lead to sets of priorities, goals, and objectives that are different from the original sets of priorities, goals, and objectives before the disruption.

The **third motivation** for this research is that the levels of power and interest of the stakeholders are *not constant*, but rather *change across the influences of scenarios*. Stakeholder preferences are subject to change due to the influences of various conditions, including social, political, economic, and environmental conditions. From an enterprise perspective, changes in the preferences of stakeholders lead to changes in the strategies and policies of governments, organizations, and private industries (Connelly 2016; Starr, Newfrock, and Delurey 2003). Continuous assessment of the level of stakeholder participation is essential to address the resilience of business organizations (Fath, Dean, and Katzmair 2015; Walker et al. 2002). Little attention, however, has been given to resilience in enterprises, organizations, and business management (Hosseini, Barker, and Ramirez-Marquez 2016). Thus, resilience analytics for complex systems need to address the deep uncertainty that can arise, not only from natural disasters, economic slowdowns, and terrorist attacks, but also from stakeholder conflicts and disagreements in many enterprise and business processes. This fact highlights the need to address the influence of the participation level of each stakeholder to priorities across scenarios. Therefore, there is a need to fill this gap by addressing the influence of the dynamic behavior of stakeholders and their impact to priorities across the influences of scenarios.

1.3 Purpose and Scope

The purpose of this dissertation is to address the following research shortcomings for enterprise resilience, as discussed in the sections above:

- Stakeholders have different levels of influence.
- The influences of stakeholders change across scenarios.

This dissertation develops an enterprise resilience analytics framework to address the influences of two modes of disruptions—the influence of scenarios to priorities and the influence of stakeholders to priorities. It integrates two existing published approaches: (1) *stakeholder mapping* (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981) and (2) *scenario-based preferences in risk analysis* (Almutairi et al. 2017b; Collier et al. 2017; Thorisson et al. 2017; Collier et al. 2016; Hamilton et al. 2016; Connelly et al. 2015; Lambert et al. 2011). The influence of each stakeholder to the priority setting of initiatives will be based on the participation level of that stakeholder across all the scenarios. The framework presented in this dissertation addresses the deep uncertainties that can arise from the influences of scenarios and of stakeholders.

The framework is suitable to many application domains in which the influences of scenarios and of stakeholders have a significant impact on priority setting of enterprise initiatives. A computer software version of the framework was developed to minimize the cognitive load and to improve the stakeholder engagement. To complete the present study, the following research tasks were accomplished:

- Identified the research gap and defined the problem statement, philosophy, and overview (Chapter 1 and Chapter 2)
- Reviewed relevant literature (Chapter 2)
  - Stakeholder theory
  - Stakeholder mapping
  - Stakeholders priority-setting methodologies
  - Scenario-based preferences analysis
  - Stakeholders priority setting informed by scenario-based preferences
  - Resilience analysis
  - A research gap and associated opportunities
- Formulated the mathematical framework (Chapter 3)
- Demonstrated the framework in mobile smart grid strategic planning (Chapter 4 and Chapter 5)
- Demonstrated the framework in maritime container port strategic planning (Chapter 6)
- Validated the framework and stated the issues and limitations (Chapter 7)

The framework is demonstrated in three case studies. The first mobile smart grid case study evaluates the influences only of scenarios on the priority setting of the initiatives. The second mobile smart grid case study evaluates the influences both of scenarios and of multiple groups of stakeholders on priorities. In both of these case studies, the goal was to support grid stability and reliability by identifying the most robust initiatives, the most robust and high-ranked initiatives, the most disruptive scenarios, and the least disruptive scenarios. The third case study supports a maritime container port development and expansion program by evaluating the influences of two modes of disruptions: scenarios and multiple groups of stakeholders.

1.4 Summary of Contributions

The contributions of this research to theory, methodology, and practice of resilience and systems engineering and risk analysis can be summarized as follows:

- The **first contribution** is to identify the joint influences of scenarios and of stakeholders on enterprise resilience. This is a *major* contribution of this research.
- The **second contribution** is an integration of *stakeholder mapping* with *scenario-based preferences*. This is a *major* contribution of this research.
- The **third contribution** is the design and implementation of software, along with written instructions, to actualize and test the above contributions. This is a *minor* contribution of this research.
- The **fourth contribution** is the application to two case studies on the mobile smart grids technologies **(Almutairi et al. 2017b; Almutairi et al. 2017c).** This is a *minor* contribution of this research.

- The **fifth contribution** is the application to a case study on large-scale maritime container port development projects **(Almutairi et al. 2017a)**. This is a *minor* contribution of this research.

Chapter 8 discusses the contributions of this research in further detail.

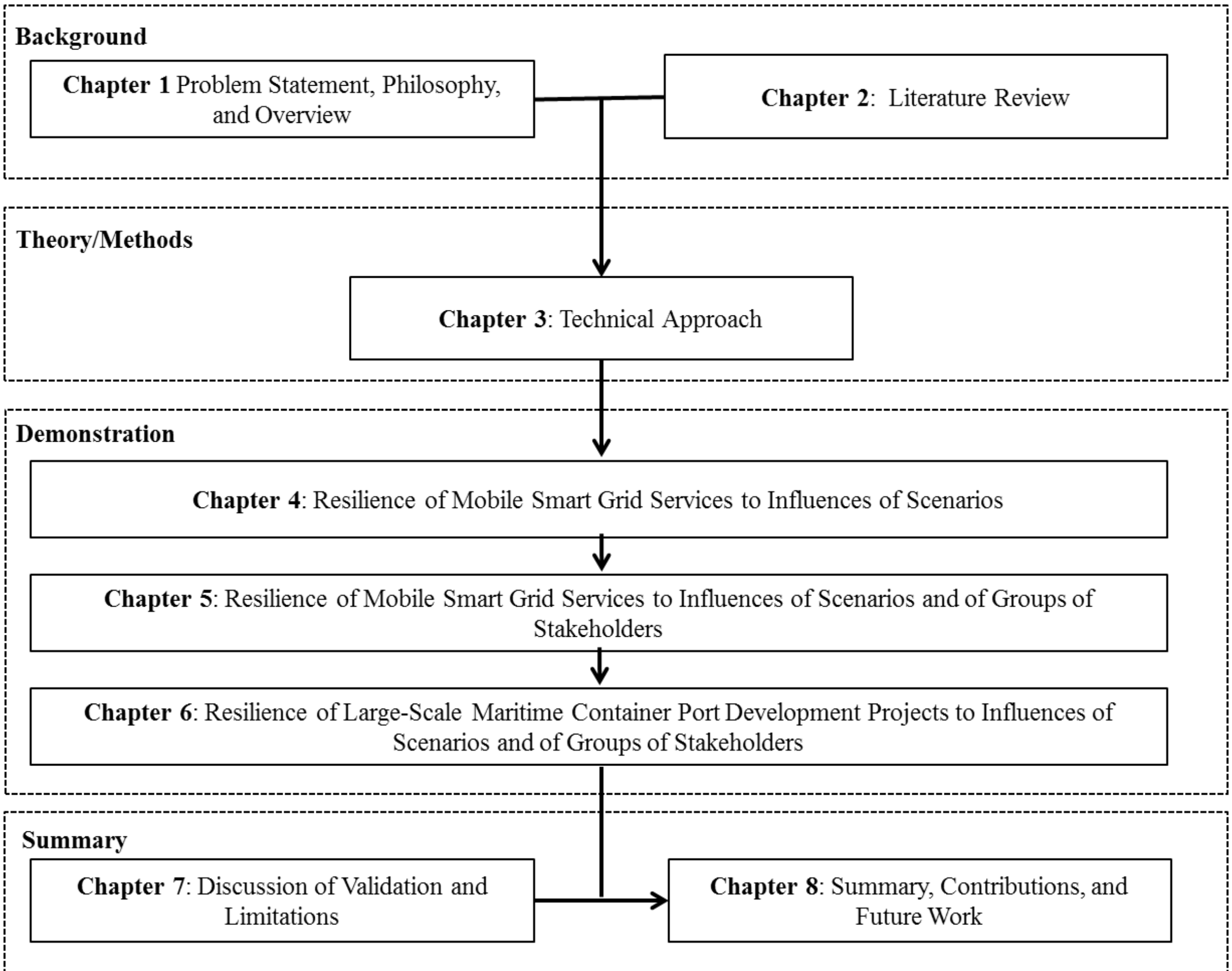


Figure 1. Diagram of the dissertation structure with the organization of the chapters

1.5 Plan of the Dissertation

The dissertation is structured as shown in Figure 1 and can be described as follows. Chapter 2 reviews the literature relevant to the scope of this research, including stakeholder theory, stakeholder mapping, scenario-based preferences, and resilience analytics. Chapter 3 presents the methodology used in this dissertation. Chapter 4 presents the first case study of a mobile smart grid that supports the stability and reliability of the grid system by addressing the influence of scenarios to priorities. Chapter 5 presents the second case study of the mobile smart grid that addresses the influences both of scenarios and of stakeholders on priorities. Chapter 6 presents a case study that considers the influences of scenarios and of stakeholders on the prioritization of maritime container port development and expansion projects. Chapter 7 reviews the literature on validating rational decision models, validates the methodology of this dissertation, and summarizes the limitations of the method. Chapter 8 provides a summary of the dissertation, describes the key contributions of this research, and suggests topics for future research.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Overview

This chapter characterizes the relevant literature, particularly which related to stakeholder theory, scenario-based preferences modeling, and resilience analysis. This chapter is organized as follows: Section 2.2 reviews the literature on stakeholder theory; Section 2.3 reviews the literature on stakeholder mapping; Section 2.4 reviews the literature on stakeholders' priority setting methodologies; Section 2.5 reviews the literature on scenario-based preferences; Section 2.6 reviews the literature on integrating the analysis of stakeholders' priority setting with scenario-based preferences modeling; Section 2.7 reviews the literature on resilience analysis; and Section 2.8 summarizes the research gap and opportunities to address this gap.

2.2 Stakeholder Theory

Stakeholder theory has a gap when it comes to addressing the uncertainty in stakeholder negotiations and decision model processes (Gregory and Keeney 2017). Understanding the objectives, goals, and beliefs of stakeholders is essential for effective risk assessment and risk management analyses (Wood et al. 2012). Stakeholder contributions are key inputs for successful system development (Buede and Miller 2016). However, stakeholders might have various interests, strategies, and expectations may or may not support the development of their systems.

Applying a single perspective is insufficient for analyzing complex systems (Barker et al. 2017; Cairns, Goodwin, and Wright 2016; Haimes 2015, 2012, 2009a). A major aspect of scenario development that involves various groups of stakeholders is the wide range of interests and perspectives that need to be included in the analysis (Cairns, Goodwin, and Wright 2016).

A *stakeholder* has been defined as "an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project" (Freeman 1984, 5). The diversity of stakeholders' interests is vital to enterprise and business processes, and failing to address the stakeholders' interests has a harmful impact on the performance of the system (Greenley and Foxall 1997). However, Cairns, Goodwin, and Wright (2016) note that existing scenario planning methods fail to address the impact of the future behaviors of multiple stakeholders, and thus they integrate the stakeholder power–interest approach into scenario planning analysis. Wright and Cairns (2011) developed a scenario-based methodology that integrates the behavior of stakeholders with the scenario analysis.

2.3 Stakeholder Mapping

Mendelow (1981) published one of the famous stakeholder classification approach, called *stakeholder mapping*. The approach maps stakeholders through a power–interest matrix. The concept of power is a well-known concept in the social sciences (Kabeer 1999). It has been defined as "the ability to make choices" (Kabeer 1999), and "the probability of being able to implement a strategy in a given scenario" (Wright and Cairns 2011). The stakeholder mapping approach has been combined with multi-criteria evaluation to support energy planning (Rosso et al. 2014). A scenario planning approach has been integrated with the stakeholder mapping approach to analyze stakeholder objectives across scenarios (Cairns, Goodwin, and Wright 2016). Stakeholder mapping has been used as a visualization tool to help project managers to improve stakeholder engagement (Walker, Bourne, and Shelley 2008). A stakeholder influence identification model has been used to evaluate the influences of stakeholders in organizational survival using the concept of power (Pajunen 2006).

The stakeholder mapping technique groups stakeholders into four quadrants based on their levels of power and interest (Rosso et al. 2014; Wright and Cairns 2011; Mendelow 1981) as shown in Figure 2. The groups that have high levels of power and interest are located in the *Key Players* quadrant. These groups have high levels of participation and direct impact on the decision-making problem. The groups that have high levels of power and low levels of interest are located in the *Keep Satisfied* quadrant. It is recommended that the satisfaction of those groups with the decisions or course of actions be maintained, since they already have high levels of power to impact the course of action, and they may have high levels of interest on the course of action in the future. The groups that have low levels of power and high levels of interest are located in the *Keep Informed* quadrant. Members of this group do not have power over the current course of action or decisions, but they are interested in them. Thus, they need to be kept informed, since their levels of power might increase across scenarios. Finally, members of the group that has low levels of power and of interest are located in the *Minimal Effort* quadrant. It is worth mentioning that the roles of participants in each group are subject to change across the scenarios. For instance, the group of stakeholders that was located in the *Keep Satisfied* quadrant in the baseline scenario might be located in the *Key Players* quadrant at the present of other scenario s_k (say, *Traffic Congestion*).

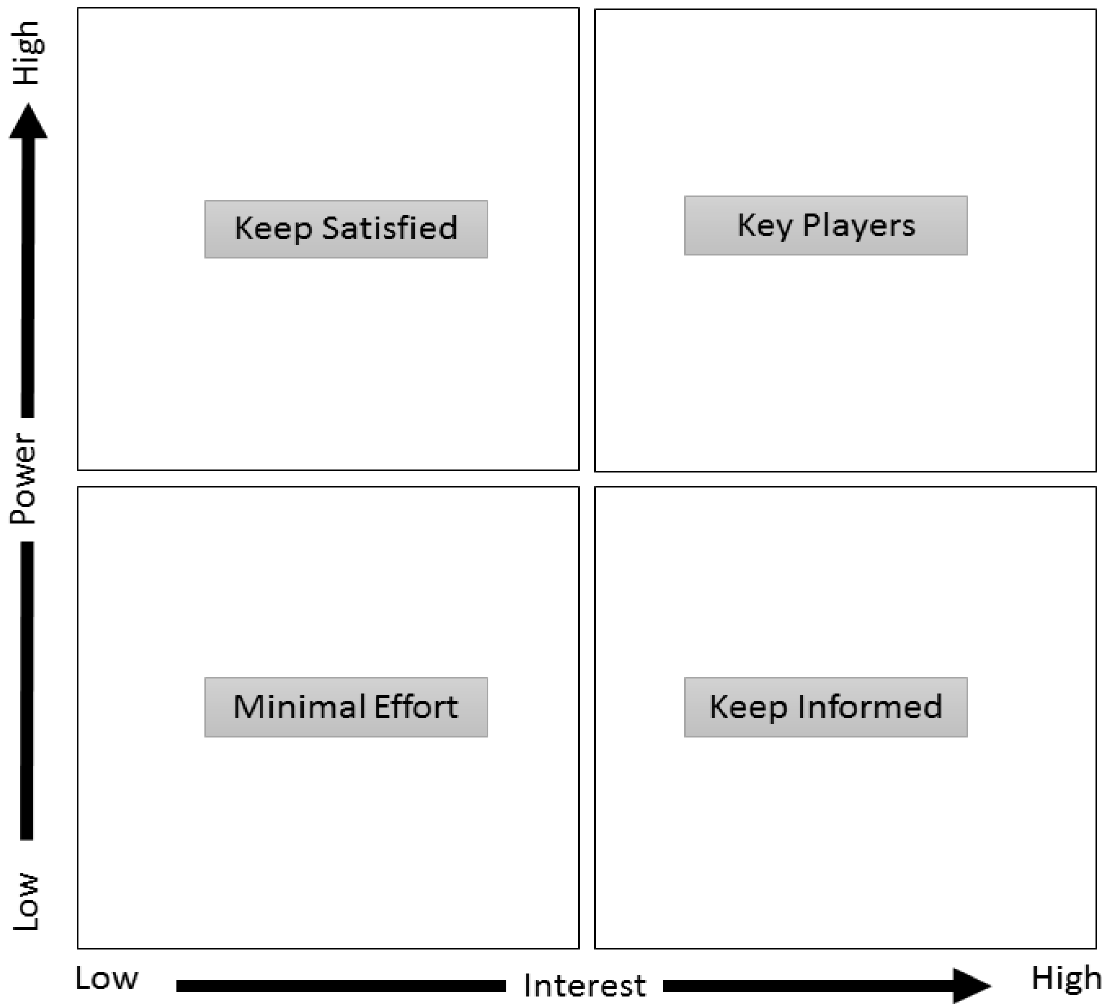


Figure 2. Power-interest matrix for groups of stakeholders (Cairns et al., 2016; Rosso et al., 2014; Mendelow, 1981)

2.4 Stakeholders Priority Setting Methodologies

Systems that involve multiple stakeholders who have a variety interests and backgrounds are characterized by complexity, interdependency, interconnectedness, and high levels of uncertainties. Priority setting for these systems involves the multiple objectives, concerns, and needs of multiple stakeholders. Priority setting is often influenced by many emergent and future conditions, such as climate changes, economic crises, and terrorist attacks, among others. A multi-criteria approach to priority setting is a well-known management approach that can be applied to many complex systems. It is an appropriate approach to prioritizing different alternatives under conditions of uncertainty for a complex system that has multiple objectives, multiple stakeholders and interests, and complex data (Wang et al. 2009). Complex strategy decisions can be made by applying multi-criteria analysis to the prioritizing of initiatives, alternatives, projects, and other factors (Keeney 1992). Setting priorities for different alternatives enables the risk analyst to make tradeoffs between many alternatives across many conflicting criteria (McDermid 2000).

Greco, Figueira, and Ehrgott (2005) note that multi-criteria analysis for priority setting has been widely and successfully applied to many scientific disciplines and real-world problems. It has been used for solving complex decision-making problems related to technical, economic, environmental, financial, and other research areas. Despite the wide variety of research areas in which the multi-criteria analysis has been applied, scientists have all agreed on the key phases of the prioritization process. Belton and Stewart (2002) define the three key phases of the prioritization process as (1) problem identification and structuring, (2) model building and use, and (3) the development of action plans.

Multi-criteria priority analysis for priority setting has been used in risk assessment for prioritizing a large set of interconnected alternatives or future projects (Montibeller and Franco

2010). It is an appropriate form of analysis when the decision problem involves high uncertainty, multiple stakeholders, complex constraints, limited resources, and long-term impacts (Johnson, Scholes, and Whittington 2008). However, it has shortcomings when used for strategic decisions. First, it assumes that the set of alternatives or options available are mutually exclusive and collectively exhaustive (Montibeller and Franco 2010), and this assumption does not always hold when there is a lack of knowledge about the parameters and constraints of the decision problem. The second shortcoming is that it assumes that the likelihood of occurrence of each option or alternative is known. This, however, is not always true in enterprise and business processes, since the probability of occurrence for extreme case scenarios may not be predictable, especially if there is a lack of information about these extreme scenarios.

2.5 Scenario-Based Preferences Analysis

The literature is rich with various approaches for scenario analysis (Wade 2012; Godet 2011; van der Heijden 1996; Huss 1988). Scenario-based preferences support enterprise and business processes that involves high uncertainties (Postma and Liebl 2005). van der Heijden (1996) defines three categories of uncertainties that need to be assessed before making decisions: risk-related, structural, and unknowable uncertainties. Risk can be forecasted by using probabilities derived from historical data. Structural uncertainties exist when multiple interpretations describe multiple events with no basis for estimating the probability of these events. van der Heijden (1996) states that scenario-based preferences modeling is sufficient to assess events that involve structural uncertainties as it helps risk analyst to make reasonable and robust decisions without estimating the probabilities of these events, while the unknowable uncertainties come from unexpected events. Dealing with unexpected events requires highly skilled decision makers (van der Heijden 1996).

Scenario planning differs from other planning methods that are available today. Schoemaker (1995) describes the differences among scenario planning and contingency planning, sensitivity analysis, and computer simulation as follows: contingency planning examines only one uncertainty, whereas scenario planning examines joint uncertainties; sensitivity analysis examines the impact of changing the value of one variable while assuming the other variables do not change, whereas scenario planning examines the impact of multiple variables changing; computer simulation examines different scenarios that may come from different patterns or clusters, but include scenarios that cannot be modeled, such as new regulations, which can be addressed by subjective interpretation in scenario planning. Peterson, Cumming, and Carpenter (2003) note that the main usefulness of scenario planning is that it increases the understanding of the important uncertainties, incorporates multiple alternatives in the analysis, and provides robust initiatives to the influences of different events.

2.6 Risk Analysis Informed by the Integration of Priority Setting with Scenario-Based Preferences

The integration of scenario-based preferences with priority setting approaches enables the risk analyst to identify which strategies are most robust or most sensitive across various scenarios, and which scenarios are most disruptive to the priorities of stakeholders. Stewart, French, and Rios (2013) suggested following guidelines for constructing scenarios for multi-criteria priority setting analysis:

- Constructing four to six scenarios is recommended.
- Define scenarios based on exogenous drivers (i.e., future and emergent conditions).
- Expected outcomes and key associations between variables should be covered by scenarios.

- A scenario should represent different ideal worlds when there are substantial differences in the fundamental values of stakeholders.

A scenario has been defined as an emergent condition or a combination of emergent conditions (**Almutairi et al. 2017; Thorisson et al. 2017a**; Connelly and Lambert 2016; Connelly et al. 2016; Karvetski, Lambert, and Linkov 2009). This definition of scenario is aimed to represent extreme cases which do not partition the space of all the future scenarios. In other words, it is not possible to define all the extreme events due to a lack of information and background data about these events. A scenario-based preferences model has been applied to many engineering fields to prioritize complex decisions when the occurrence of scenarios cannot be predicted. It has been applied to various domains, such as those of energy mobility (**Almutairi et al. 2017; Thorisson et al. 2017a**), energy security (Thorisson et al. 2017b; Hamilton et al. 2012; Karvetski et al. 2011), the biofuel industry (Connelly et al. 2015), climate change (Hamilton, Lambert, and Valverde 2015; You et al. 2014; Lambert et al. 2012), and infrastructure systems (Lambert et al. 2011). Goodwin and Wright (2001) pointed out the usefulness of scenario-based preferences modeling as a management technique to address a variety of conditions without needing to estimate the probability of each of those conditions' occurrence.

Hamilton (2014) extended the static scenario-based preferences methodology to an iterative risk assessment approach across multiple timeframes. Each timeframe $I^t \in I$, where $I = \{ I^1, I^2, \dots, I^m\}$, represents a static scenario-based preferences approach with the 3-tuple $\{ X^t, Z^t, A^t\}$, where X^t is the set of available initiatives at timeframe t, Z^t is the set of criteria at timeframe t, and A^t is a value score assessment matrix which shows the score of each initiative in satisfying the objective of each criterion at the timeframe t. S^t is the set of all the possible scenarios that may influence stakeholder priorities at time t.

The 3-tuple $\{X^{t+1}, Z^{t+1}, A^{t+1}\}$ at timeframe $t+1$ is directly influenced by the outputs of the scenario-based preferences model at time frame t. At the end of each timeframe, the risk analyst is in charge of reframing the scenario-based model parameters based on a current analysis using reframing questions (Hamilton 2014). The stakeholders will be able to add, eliminate, or combine some of the initiatives by comparing their ranks across all the scenarios, including the baseline scenario. A robust or near-robust initiative is an initiative that has almost the same rank across the influence of all the scenarios. A stakeholder may want to eliminate the low-ranking initiatives and the dominated initiatives. An initiative x_i is a low-ranking initiative if the initiative rank $v(x_i)^q$ for all the $q+1$ scenarios is considered low, and it is considered to be a dominated initiative if the $v(x_i)^q < v(x_j)^q$ for all the $j = 1, \dots, m$. From a scenario-focused perspective, a disruptive scenario is a scenario that has a high influence to a stakeholder's priorities. The stakeholder may focus on the disruptive scenarios in the next timeframe. Thus, more detailed descriptions of the emergent conditions that form the scenario are needed in the next frame.

You et al. (2014) extended the single perspective methodology for the scenario-based preferences model to incorporate multiple perspectives. An integrated multi-perspective vulnerability assessment is defined as the 2-tuple $\{S_c, P\}$ where $P = \{P^1, P^2, \dots, P^k\}$ is the set of different perspectives and S_c is the set of scenarios which are considered as potential stressors to the system. Each individual perspective $P^k \in P$ has a similar scenario-based preferences methodology structure. Furthermore, each individual perspective P^k presents the methodology for prioritizing the available set of initiatives according to the interests of a single stakeholder. Thus, a multi-perspective vulnerability profile can be attained by replicating the scenario-based preferences model methodology for each perspective $P^k \in P$. This profile can be used to analyze the influences of scenarios to priorities from multiple perspectives.

2.7 Resilience Analysis of Engineering Systems

The concept of resilience is found in many domains, and it's original conception was defined with respect to ecology and the natural environment (Holling 1973). It has been found in ecology, child psychology, psychiatry, infrastructure systems, and others (Ayyub 2014). The majority of the resilience research has been focus on the environment and human psychology, and a little attention has been given to the resilience in enterprises, organizations, business management, and logistics engineering (Hosseini, Barker, and Ramirez-Marquez 2016).

It has been defined as "the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within acceptable time, and composite costs, and risks" (Haimes 2009b). A broad definition of resilience that most scholars agree with is the ability of the system to withstand, adapt, and recover from a disruption (Barker et al. 2017; Haimes 2015; Ayyub 2014; Aven 2011; Haimes 2009b). Additionally, Haimes (2015; 2009b) defines resilience as a state of the system that might represent the quality of the system at any time.

Disruptions that could impact infrastructure systems can impact other important systems, including community and service systems (Barker et al. 2017). Ayyub (2014) states that massive savings could be generated from improving system resilience at different levels, including the structural, network, and community levels, and this savings could be preserved by an appropriate definition of resilience.

Barker et al. (2017) define resilience analytics as "the systematic use of advanced data-driven methods to understand, visualize, design, and manage interdependent infrastructures to enhance their resilience and the resilience of the communities and services that rely upon them," and they provide three research directions for resilience analytics: descriptive, predictive, and prescriptive analytics. Descriptive analytics are used to describe and visualize the performance of interdependent systems before, during, and after disruptions, predictive analytics are used to predict complex patterns and interdependent variables to forecast the likelihood of disruptive events and reduce their associated uncertainty, and prescriptive analytics are used to provide guidelines for courses of actions that help to reduce the impacts of disruptive events (Barker et al. 2017).

Connelly (2016) point outs that, although the literature has a wide range of research that addresses the importance of the concept of resilience in improving the performance of systems, there is still a lack of research that addresses the enterprise resilience. Connelly (2016) constructs a resilience analytics framework for studying the influence of scenarios to priorities in strategic planning programs. The framework has been applied to various application domains, including the supply chain, life cycle assessment, aviation of biofuel, and R&D planning initiative domains (Connelly 2016; Connelly and Lambert 2016; Connelly et al. 2016; Connelly et al. 2015). Thorisson et al. (2017b) adopted the same concept of resilience of strategic planning for the electric power sector in Afghanistan to determine the influences of scenarios to priorities. Almutairi et al. (2017) extended the framework by performing a detailed risk assessment for the most robust and high-ranked initiatives using a simulation modeling approach to support grid stability and reliability.

2.8 A Research Gap and Associated Opportunities

This section highlights a current research gap in system resilience and risk analysis—specifically, a failure to address the influence of stakeholders to priority setting across different disruptive scenarios. In risk analysis, little or no attention has been given to enterprise resilience (Connelly 2016). The resilience analytics approaches discussed in this chapter focus on the influence of scenarios to priorities; however, they fail to address the influence of stakeholders to priorities in various research and development projects, particularly when those stakeholders have conflicting interests, strategies, and objectives. Intuitively, a stakeholder who has high levels of power and interest in a project will have a direct and immediate impact on other stakeholders who have lower levels of power and interest on that project.

In addition, the participation levels (i.e., levels of powers and interest) of stakeholders are not constant, since their preferences and priorities change across scenarios. For example, the 2008 financial crises had a negative impact on the global economy, and as a consequence of that, international trade dramatically dropped. This financial crisis scenario changed the priorities of many stakeholders, which in turn changed their participation, so that a stakeholder who had a high level of interest in a project before the crisis might have a lower level of interest after the crisis.

Integrating the influence of stakeholders to priorities into the available resilience analytics approaches contributes to systems engineering, risk analysis, and stakeholder theory by addressing several kinds of challenges (e.g., environmental, economic, and social) that matter most to all or part of the stakeholders in various application domains. The conception of enterprise resilience analysis supports priorities when they are disrupted by the influences of scenarios and of stakeholders. Priorities can be a set of assets, projects, policies, units, or other entities that matter to stakeholders who are involved in the analysis. Figure 3 shows how this research builds on the previous literature in scenario-based preferences, resilience analysis, and stakeholder theory.

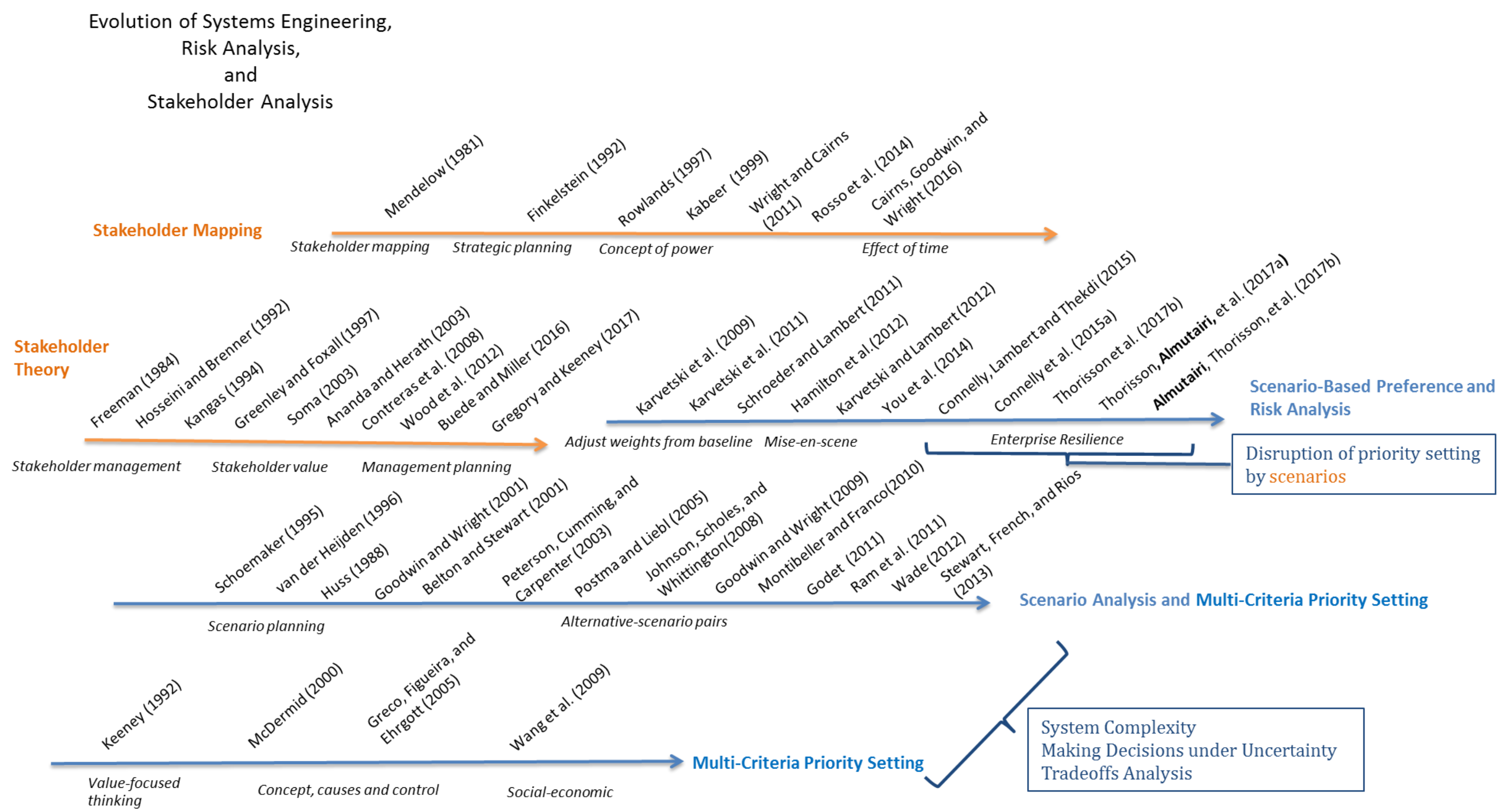


Figure 3 Summary of the literature review in the area of scenario-based preferences, enterprise resilience, and stakeholder theory

2.9 Chapter Summary

This chapter has provided a literature review for risk assessment modeling, especially for scenario-based preferences modeling and stakeholder mapping. The previous literature in strategic planning focuses on the influence of scenarios to priorities; however, it fails to address the influence of stakeholders to priorities across scenarios, a gap that will be addressed in Chapter 3 and demonstrated in Chapter 4, Chapter 5, and Chapter 6.

CHAPTER 3: TECHNICAL APPROACH

3.1 Overview

This chapter describes the integration of stakeholder mapping and scenario-based preferences for a single group of stakeholders and, subsequently, for multiple groups of stakeholders. Section 3.2 briefly introduces the innovation of the enterprise resilience analytics framework that will be presented in this chapter and demonstrated in the next three chapters. Section 3.3 describes the required modeling inputs, which include the set of multiple groups of stakeholders, the set of emergent and future conditions, the set of scenarios, the set of enterprise initiatives, and the set of evaluation criteria for each group of stakeholders. Section 3.4 describes the methodology of constructing a framework that addresses the influence of scenarios to priorities. Section 3.5 describes a methodology that addresses the influences of scenarios and of multiple groups of stakeholders on priorities. Section 3.6 discusses issues related to the implementation of the framework in practice and guidelines for improving the engagement of stakeholders.

3.2 Introduction

Based on the literature review in Chapter 2, the available resilience analytics approaches fail to assess the influence of stakeholders who have different levels of power and interest, which distorts the accuracy of these approaches. Moreover, the influence of stakeholders is not constant across scenarios, since the preferences of the stakeholders are impacted by many emergent and future conditions, including financial crises, natural disasters, terrorist attacks, among others. Therefore, the stakeholders change their priorities, goals, concerns, and objectives to cope with the influence of these conditions to their plans. To address this research gap, this dissertation extends the resilience analytics framework discussed in Chapter 2 to incorporate the influence of stakeholders to priorities. This can be accomplished by integrating the stakeholder mapping approach with scenario-based preferences modeling, as will be shown in this chapter.

3.3 Methods Part 1: Inputs Requirements

3.3.1 Identifying the Multiple Groups of Stakeholders

A facilitated discussion mode was used in this dissertation to describe the scope and the objectives of this research, and to provide the groups of stakeholders involved with guidance on how to insert their preferences. For this mode of discussion, the facilitator(s) need to invite the groups of stakeholders, $L = \{ \ell_1, \dots, \ell_L \}$, that might effect, be affected by or be interested in the decision problem to participate in decision workshops. A group of stakeholders ℓ_L is defined as a group of individuals who share similar interests, beliefs, concerns, and viewpoints when dealing with a specific issue. These groups of stakeholders have various powers, interests, and objectives. As a result of this, conflicts may arise when multiple groups of stakeholders involved in the analysis.

The facilitator(s) guide the groups of stakeholders to create a comprehensive strategic plan that states their long-term and short-terms goals, needs, and interests. This plan will be used to identify all the possible sets of initiatives, criteria, emergent and future conditions, and scenarios.

3.3.2 Identifying the Emergent and Future Conditions Set and the Scenario Set

During the decision workshops, the groups of stakeholders define a set of emergent and future conditions, $S_{ec} = \{ec_1, \ldots, ec_p\}$, in their comprehensive strategic plan. The set reflects the possible future uncertainties and the viewpoints of the groups, and it might include economic, environmental, political, social, and other emergent and future conditions. Almutairi et al. (2017), Thorisson et al. (2017), Connelly (2016), and Karvetski, Lambert, and Linkov (2009) define a scenario as an emergent condition or a combination of emergent conditions. The set of scenarios $S_s = \{s_1, \ldots, s_q\}$ is a subset of the set of emergent and future conditions. Each scenario might change the preferences or the strategies of each group of stakeholders. A disruptive scenario is a scenario that changes the baseline ranking order for an initiative from high to low or from low to high, as described in detail in the next section.

3.3.3 Identifying the Enterprise Initiatives Set and the Evaluation Criteria Set

Three sets $\{Sx, Sc, A\}$ have been defined in this section, where $Sx = \{x_1, x_2, \ldots, x_n\}$ is the set of enterprise initiatives to be prioritized based on the preferences of each group of stakeholders; $Sc = \{c_{\ell_z 1}, \ldots, c_{\ell_z m}\}$ is the set of criteria for each group which will be used for prioritizing the importance of each initiative; $A = \{x_{ij} | \; i = 1, \ldots, n; j = 1, \ldots, m\}$ is a value assessment matrix which shows the score of each initiative in the set of Sx; x_{ij} is a value assessment score which shows how good initiative x_i is in satisfying criterion c_j; and $x_{ij} \in [0,1]$. Moreover, if $x_{kj} > x_{pj}$, then initiative x_k addresses criterion c_j more sufficiently than x_p.

A criteria set will be defined for each group of stakeholders since each group of stakeholders has different objectives, concerns, and interests. Thus, defining one criteria set for all the groups of stakeholders is insufficient since it will not cover all the needs, concerns, and objectives of the groups. Thorisson et al. (2017) states that defining a criteria set for each group is importance when there are possible conflicts of interest among the groups of stakeholders. Thus, using a criteria set for each group will help to highlight where in the analysis there are possible disagreements among the groups.

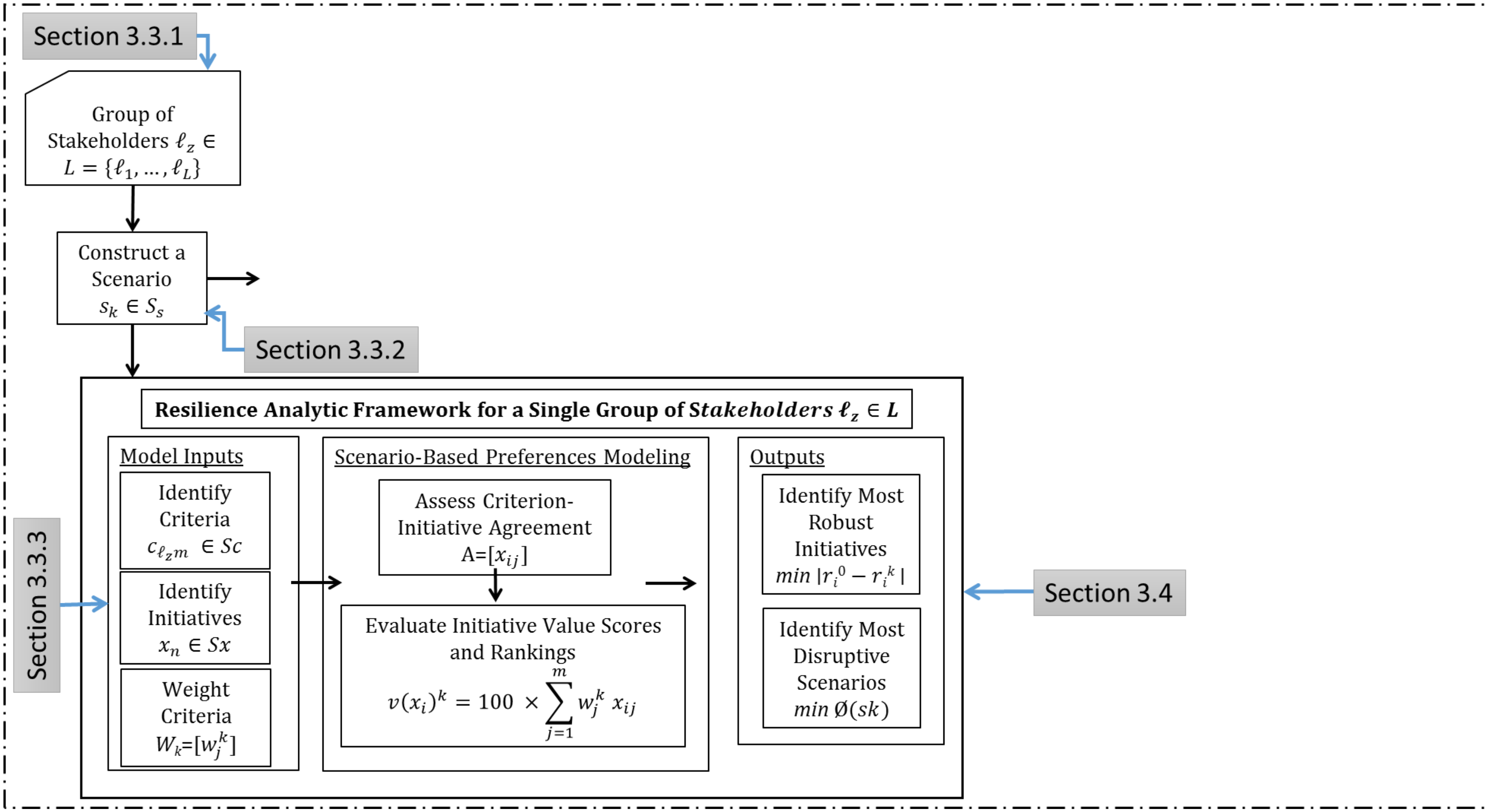


Figure 4. An enterprise resilience analytics framework for each group of stakeholders $\ell_z \in L$ that addresses the influence of scenarios to prioritization of planning initiative

3.4 Methods Part 2: Enterprise Resilience Analytics Framework for a Single Group of Stakeholders $\boldsymbol{\ell_z} \in \boldsymbol{L}$

The purpose of this section is to define the technical approach to the enterprise resilience analytic framework for a single group of stakeholders. Figure 4 shows the technical steps that are needed to develop this framework. The framework builds upon integrating a multi-criteria priority setting analysis with a scenario-based preferences analysis. The multi-criteria priority setting analysis is used to prioritize the initiatives in the baseline (no scenario) and across all the other scenarios.

Stewart (1996) discussed the robustness of multi-criteria priority setting analysis under several practical conditions, even with small errors due to anchoring or dependency between criteria. The additive value function below is used to evaluate the assessment score of each initiative across all the criteria, as follows:

$$v(x_i)^0 = 100 \times \sum_{j=1}^{m} w_j^0 \, x_{ij} \qquad (1)$$

where $\{w_j^0 | \sum_{j=1}^{m} w_j^0 = 1, \; w_j^0 \in [0,1]\}$ is the normalized weight of criterion c_j in the baseline scenario, s_0 (i.e., no scenario) from a single group of stakeholders. The aim of the baseline model is to prioritize the set of initiatives based on the preferences of the single group of stakeholders in the absence of the influence of emergent and future conditions.

The next step is to extend the analysis by introducing the influence of scenarios to the prioritization of initiatives for each group of stakeholders. Combinations of emergent and future conditions are considered as possible scenarios that may influence the baseline value function. The risk analyst will be able to estimate the level of disruptiveness for each scenario by comparing its influences to the priority setting of the initiatives.

For each scenario $s_k \in S_s$, the multi-criteria priority setting analysis will be re-evaluated after introducing the influence of the scenario to the importance of each criterion. Thus, for each scenario, the ranking order of the initiatives might differ from the ranking order in the baseline scenario. A scenario that makes significant changes in the initiatives' ranking order is considered to be a disruptive scenario. A robust initiative is one that has the same or similar ranking orders across all the scenarios. By comparing the ranking orders of initiatives in each scenario with the ranking orders of initiatives in the baseline scenario, the risk analyst will be able to identify the most disruptive scenarios and the least disruptive scenarios, as well as the most robust initiatives and the least robust initiatives.

The normalized weight of each criterion c_j in the baseline scenario, s_0, might change under the influence of each scenario $s_k \in S_s$. A factor multiplier, α_j^k, is used to change the importance of criterion c_j in scenario s_k, where $\alpha_j^k \in \{1/\alpha_1, 1/\alpha_2, \alpha_2, \alpha_1\}$ and $0 < \alpha_2 < \alpha_1$. If the scenario causes a major increase or a major decrease, then α_j^k will be equal to α_1 and $1/\alpha_1$, respectively, while if the scenario causes a minor increase or a minor decrease, then α_j^k will be equal to α_2 and to $1/\alpha_2$, respectively. The mathematical notation for updating the importance weight of each criterion across all the scenarios is shown in the matrix below.

$$W = \begin{bmatrix} w_1^0 & 0 & \cdots & 0 \\ 0 & w_2^0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_m^0 \end{bmatrix} \begin{bmatrix} 1 & \alpha_1^1 & \alpha_1^2 & \cdots & \alpha_1^q \\ 1 & \alpha_2^1 & \alpha_2^2 & \cdots & \alpha_2^q \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & \alpha_m^1 & \alpha_m^2 & \cdots & \alpha_m^q \end{bmatrix} = \begin{bmatrix} w_1^0 & \alpha_1^1 w_1^0 & \alpha_1^2 w_1^0 & \cdots & \alpha_1^q w_1^0 \\ w_2^0 & \alpha_2^1 w_2^0 & \alpha_2^2 w_2^0 & \cdots & \alpha_2^q w_2^0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ w_m^0 & \alpha_m^1 w_m^0 & \alpha_m^2 w_m^0 & \cdots & \alpha_m^q w_m^0 \end{bmatrix}$$

where $\{w_j^k = \alpha_j^k w_j^0 \,|\, \sum_{j=1}^m w_j^k = 1,\ w_j^k \in [0,1]\}$. For each group of stakeholders, the additive value function is used to compute the value score for each initiative in each scenario $s_k \in S_s$, where $v(x_i)^k \in [0,100]$.

$$v(x_i)^k = 100 \times \sum_{j=1}^{m} w_j^k \, x_{ij} \quad (2)$$

The initiatives are ranked based on their value scores in each scenario $s_k \in S_s$. If $v(x_i)^k > v(x_j)^k$ for all $i \neq j$, then initiative x_i is more preferable than initiative x_j in scenario $s_k \in S_s$.

Several measures of robustness for the scenario-based preferences models have been reviewed. These measures will be used to categorize the future scenarios in terms of their disruptiveness to the prioritization of initiatives in the baseline scenario. The most disruptive scenario is the scenario that changes the baseline ranking order for an initiative from high to low or from low to high, and the least disruptive scenario is the scenario that does not significantly change the baseline initiative ranking order. Karvetski (2011) suggested a statistical metric for evaluating the vulnerability of the investigated system to disruptive events, shown in Equation 3:

$$m\left(S_j\right) = \sum_{i} \left(r_i^0 - r_i^j \right)^2 \quad (3)$$

where r_i^0 is the rank of initiatives i at the baseline scenario and r_i^j is the rank of initiatives i at the j^{th} scenario. A high metric score indicates that the j^{th} scenario has a high influence to the baseline priority setting.

You et al. (2014) determined the vulnerability of a system by developing a new metric based on Kendall's tau-b. The metric is a pair-ranked comparison for each two initiatives at the baseline scenario and after they are influenced by a future scenario. The concordant two pairs of ranking are the pairs which have $r_i^0 > r_i^k$ and $r_j^0 > r_j^k$ or both $r_i^0 < r_i^k$ and $r_j^0 < r_j^k$. The tied pairs are the pairs which have $r_i^0 = r_i^k$ or $r_j^0 = r_j^k$. Otherwise, the pairs are discordant.

A Spearman's rank correlation coefficient has been used for comparing two set of ordinal rankings (Kendall and Smith 1939). For multi-criteria methods, the Spearman's rank correlation coefficient is known as a common measure of similarity between ranked projects (Sheskin 2003). It has been used for evaluating the level of disruptiveness for each of the scenario (Almutairi et al. 2017; Thorisson et al. 2017; Connelly and Lambert 2016) as shown in Equation 4, where $\phi(s_k) \in [0,1]$.

$$\phi(s_k) = 1 - \frac{6\sum_{i=1}^{n}\left(r_i^k - r_i^0 \right)^2}{n(n^2-1)} \qquad (4)$$

By using the Spearman rank correlation coefficient, a disruptive scenario is a scenario that has a weak correlation with the baseline scenario (i.e., small $\phi(s_u)$), and a less disruptive scenario is a scenario that has a stronger correlation with the baseline scenario (i.e., large $\phi(s_u)$).

In this dissertation, the Spearman rank correlation coefficient is used for estimating the level of disruptiveness of each scenario.

3.5 Methods Part 3: Resilience Analytics Framework for Multiple Group of Stakeholders *L*

The resilience analytics approach discussed in Section 3.4 addresses only the influence of scenarios to priorities and assumes the influence of the multiple groups of stakeholders to priorities is neglected. The purpose of this section is to address this research gap by integrating the stakeholder mapping approach with the scenario-based preferences modeling. The next two subsections (3.5.1, and 3.5.2) illustrate the technical steps that are needed to formulate the new framework.

3.5.1 A Stakeholder Mapping Approach for Identifying the Behavior of Each Group of Stakeholders across Scenarios

In a real-world problem, the behavior of humans is not constant but rather changes across scenarios. The behavior of humans is sensitive to the influences of various factors (e.g., economic crises, terrorist attacks, natural disasters, etc.) in our surrounding environment. Stakeholder engagement and inputs play a central role in scenario-based preferences modeling (Connelly 2016; Hamilton 2014; You 2013). This has motivated the author of this dissertation to evaluate and incorporate the behavior of each group of stakeholders into the enterprise resilience analytics framework. In stakeholder management theory, the behavior of stakeholders is evaluated by estimating the levels of power and interest of each stakeholder in different scenarios (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981).

Cairns, Goodwin, and Wright (2016) and Rosso et al. (2014) used a 0–10 rating scale for evaluating the power and interest of each group of stakeholders, where 0 means no interest/power and 10 means complete interest/power. The expected levels of power and interest for each group are estimated by interviewing the group during the decision workshops and by reviewing the recent literature on the decision problem. For example, for a port development and expansion program, the facilitator needs to interview the local residents about their participation levels across different scenarios (e.g., traffic congestion, economic slowdown, air pollution). Let $P_{\ell_z}^k$ be the power index for group $\ell_z \in L$ in scenario $s_k \in S_s$, and let $I_{\ell_z}^k$ be the interest index for the same group and in the same scenario, where $P_{\ell_z}^k$ and $I_{\ell_z}^k \in [0, 10]$. Figure 5 shows the technical steps that are needed to estimate the level of power, the level of interest, and the participation level for each group of stakeholders. The participation level for the group $\ell_z \in L$ in scenario $s_k \in S_s$ can be estimated using the following equation:

$$\lambda_{\ell_z}^k = \frac{P_{\ell_z}^k \times I_{\ell_z}^k}{\sum_{i=1}^{\ell_L}(P_{\ell_i}^k \times I_{\ell_i}^k)} \quad (5)$$

where $\{\lambda_{\ell_Z}^k | \sum_{i=1}^{L} \lambda_{\ell_i}^k = 1,\ \lambda_{\ell_z}^k \in [0,1]\}$ is the normalized weight of the expected participation level for group $\ell_z \in L$ in scenario s_k. The expected participation levels for the same group differ across the influence of scenarios, depending on the levels of power and interest of the group in each scenario.

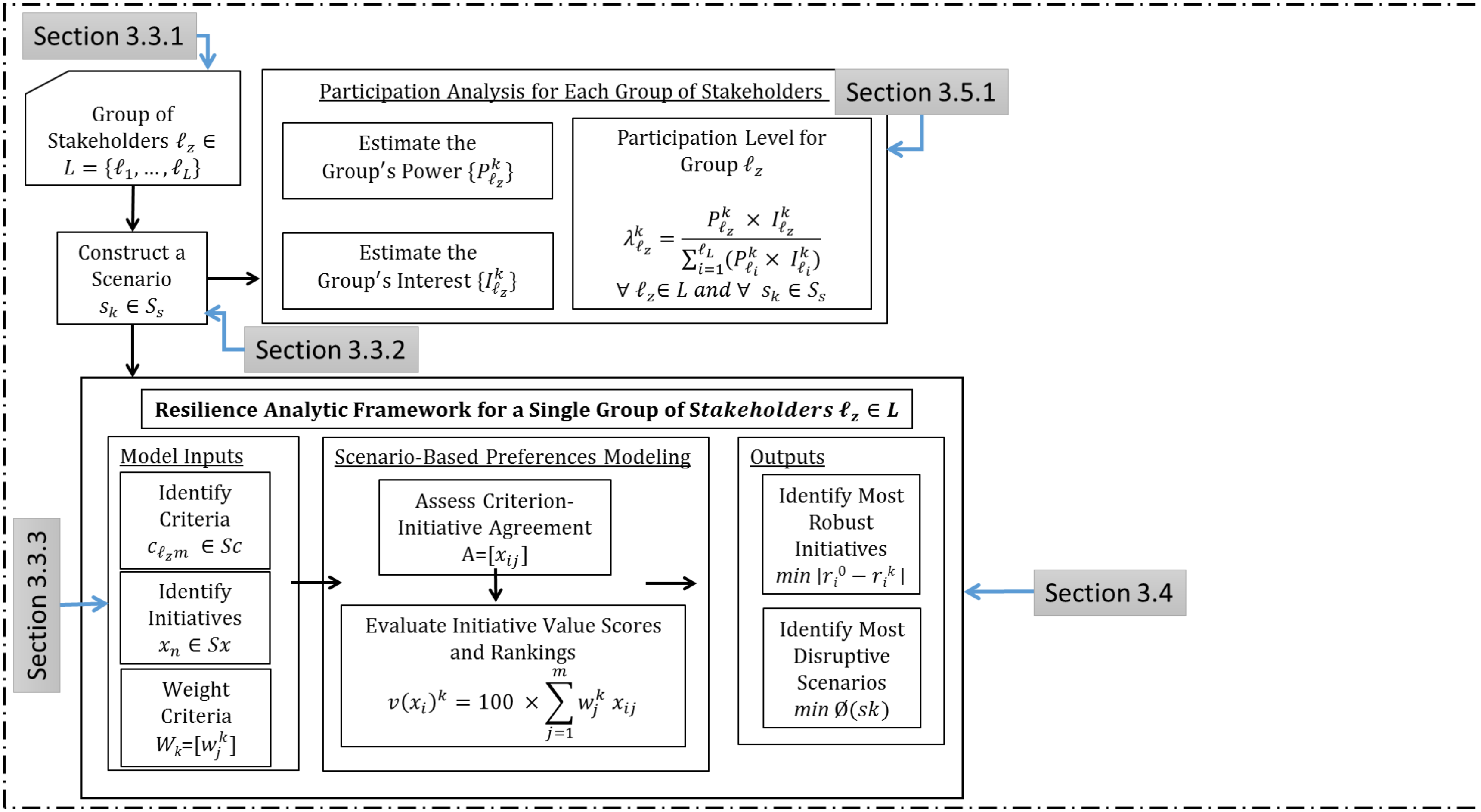


Figure 5. An enterprise resilience analytics framework for each group of stakeholders $\ell_z \in L$ and the stakeholder mapping approach across the infleunce of scenarios

3.5.2 Integrating the Stakeholder Mapping Approach with the Scenario-Based Modeling

The additive value function illustrated in Section 3.4 will be modified to address the influences of both scenarios and multiple groups of stakeholders to the priorities. The new additive value function is adopted from the work of Contreras et al. (2008), Kangas (1994), and Rosso et al. (2014):

$$v(x_i)^k = 100 \sum_{i=1}^{\ell_L} \lambda_{\ell_i}^k \sum_{j=1}^{m} w_j^k \, x_{ij} \quad \forall \, s_k \in S_s \quad (6)$$

Figure 6 shows the whole technical approach for assessing the influences of scenarios and of multiple groups of stakeholder to priorities. This framework takes into account the influence (i.e., the power and the interest) of the participation levels of multiple groups of stakeholders to priority setting across scenarios. Table 1 shows the inputs and expected outcomes of the framework for each group of stakeholders and for multiple groups of stakeholders. The framework outcomes are the most disruptive scenarios, the least disruptive scenarios, the most robust initiatives, the least robust initiatives, the most robust and highly prioritized initiatives, and the least robust and highly prioritized initiatives.

Addressing the influences of scenarios and of multiple groups of stakeholders is more realistic and more appropriate for studying enterprise resilience than other resilience methods. For instance, if scenario s_k is considered to be a disruptive scenario for group $\ell_z \in L$, then perhaps a costly research and development program is needed to avoid this disruptiveness in the future. However, if the participation level for this group is low, then it would be more important to save time and effort by focusing on other important development programs that are of interest to most of the groups or to groups that have high levels of participation.

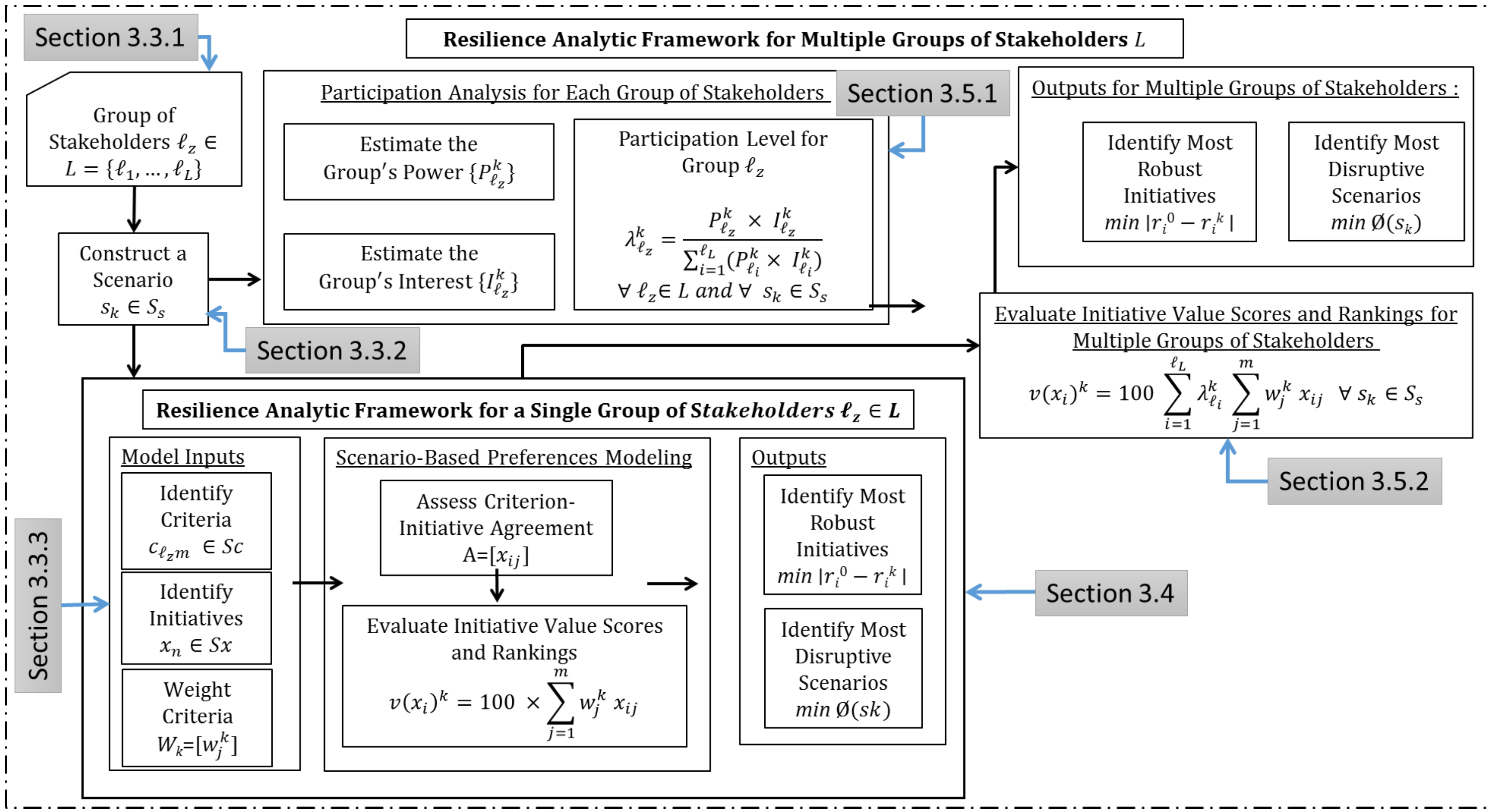


Figure 6. An enterprise resilience analytics framework for the influences of scenarios and multiple groups of stakeholders to prioritization of planning initiatives

Table 1. The inputs and outcomes for the enterprise resilience analytic framework for each group of stakeholders $\ell_z \in L$ and for all the groups L

		Outcomes							
Number of Groups	Inputs	Scenarios		Initiatives					
Single Group of Stakeholders	Set of Initiatives Set of Criteria Set of Scenarios	Most Disruptive	Least Disruptive	Highly Prioritized	Lowest Prioritized	Most Robust	Least Robust	Most Robust & Highly Prioritized	Least Robust & Highly Prioritized
Multiple Groups of stakeholders	Set of Initiatives Set of Criteria for Each Group Set of Scenarios	Most Disruptive	Least Disruptive	Highly Prioritized	Lowest Prioritized	Most Robust	Least Robust	Most Robust & Highly Prioritized	Least Robust & Highly Prioritized

Resilience analytics is defined as a process that identifies the scenarios that are most disruptive to the priorities of the stakeholders (**Almutairi** et al. 2017; Connelly and Lambert 2016; Connelly et al. 2016). The most disruptive scenarios are estimated by minimizing $\phi\ (s_k)$ after incorporating the influence of the participation level into the scenario-based preferences model:

$$\min \phi\ (s_k)\ \forall\ s_k \in\ S_s \quad (7)$$

The disruptive scenarios that are estimated from the above equation will be relatively important to the most influential groups based on their participation level weights. For example, if scenario s_k is found to be a disruptive scenario, then perhaps this scenario changes the priorities of the most influential groups. In other words, a disruptive scenario which affects the priorities for a group that has a low participation level will not be considered to be a disruptive scenario for all the groups.

3.6 Methods Part 4: On the Implementation of the Framework

This section discusses issues on the implementation of the resilience analytics framework and the different strategies are used for improving the implementation process.

3.6.1 Engaging Groups of Stakeholders

The quality of the framework depends heavily on the ability of the stakeholders to provide accurate inputs and tradeoffs during the analysis (**Almutairi** et al. 2017; Connelly 2016; Hamilton 2014; You 2013). The more involved stakeholders are in the analysis, the more accurate the modeling outcomes will be. It is difficult and time consuming, however, to coordinate multiple stakeholders since they normally have different objectives and concerns. During a stakeholders meeting, stakeholders need to update their sets of criteria, initiatives, emergent and future conditions, and scenarios. In addition, they may need guidelines on how to insert their preferences during each meeting. Thus, dealing with large group of stakeholders at the same time is not the most efficient way to improve their engagement in the analysis.

In this dissertation, a *stakeholder clustering analysis* has been used to group the stakeholders in homogenous groups based on the objectives, concerns, interests, and goals that they share (Nguyen and Notteboom 2016). The stakeholder clustering analysis will help to minimize the numbers of participants in the group meetings, which will, in turn improve stakeholder engagement by focusing on the needs and concerns of each group of stakeholders. For instance, in a port development and expansion program, ideally, many external and internal stakeholders will be involved in the analysis, which can negatively impact the stakeholder engagement and the processing time. To avoid these negative impacts, the stakeholders have been grouped in three homogenous groups based on the objectives and concerns that they shared: the terminal users group, the terminal service providers group, and the community group. A criteria set has been defined for each group of stakeholders. Working with only three groups of stakeholders helps to improve the stakeholder engagement, and as a result of that improvement, the quality and accuracy of the model outcomes are improved.

3.6.2 Facilitated Stakeholder Conferences

Belton and Stewart (2002) provide a literature review related to how multi-criteria priority setting analysis can be implemented in practice. They discuss when it is appropriate to implement multi-criteria priority setting analysis in a facilitated and an unfacilitated manner. It can be implemented by one or more expert facilitators or it can be performed without a facilitator. The unfacilitated mode is appropriate when the problem involves a small number of individuals or small homogenous groups, while the guidance of facilitator(s) is the most appropriate mode when there are large groups of stakeholders who are dealing with non-trivial problems. The facilitator(s) mode is used in this dissertation since there are large groups of stakeholders involved.

Phillips (2007) discusses the importance of the decision conferences process and provides guidelines for facilitator(s) on how to resolve importance issues when there are large groups of stakeholders. In addition, reframing the model inputs is crucial to improving the quality of the model outcomes. Normally, the facilitator(s) will start with initial sets of initiatives, criteria, emergent and future conditions, and scenarios for the purpose of launching group discussion. System inputs and boundaries, including sets of initiatives, criteria, emergent and future conditions, scenarios, are subject to change in the light of new information (Hamilton 2014). Updating the system boundaries helps to match the dynamic natural of the group discussions. Thus, the facilitator(s) will keep updating the inputs of the model based on the learning from previous group meetings (Connelly 2016). In this dissertation, the following guidelines have been adopted from the work of Hamilton (2014) and Phillips (2007) and used during the decision workshops with the groups of stakeholders for the purpose of managing the discussion, improving the stakeholder engagement, and reframing the model boundaries:

- Start the initial meeting by describing the scope of the research and objectives.
- Provide a neutral environment for group discussion and encourage the groups of stakeholders to participate
- Define the initial system inputs and boundaries, including initiatives, criteria, emergent and future conditions, and scenarios.
- Describe how the groups of stakeholders can agree or disagree with any of the system inputs and boundaries.
- Provide a user-friendly software workbook to minimize cognitive load and elicitation processes.

- Provide training sessions to illustrate how the groups of stakeholders can use the resilience analytics software to express their preferences, including the importance of criteria, assessment of initiatives at the baseline scenario, and the assessment of initiatives across scenarios.
- Reframe the model inputs and boundaries based on learning from previous group discussions.

The facilitator(s) can reframe the model inputs and boundaries until the groups of stakeholders agree that the model is satisfactory (Hamilton 2014). The steps also can be repeated once a new group of stakeholders becomes involved in the research.

3.7 Chapter Summary

This chapter has discussed the technical approach of the enterprise resilience analytics framework for a single group of stakeholders and for multiple groups of stakeholders. The framework for a single group of stakeholders addresses the influence of scenarios to priority setting for each group, while the framework for multiple groups of stakeholders addresses the influences of both scenarios and multiple groups of stakeholders on priorities. In addition, this chapter has discussed issues related to the implementation of the framework and guidelines for improving the engagement of stakeholders.

CHAPTER 4: DEMONSTRATION: RESILIENCE OF MOBILE SMART GRID SERVICES TO INFLUENCE OF SCENARIOS

4.1 Overview

A coordinated network of bidirectional chargers can help to improve grid stability and resilience and provide revenue to owners/operators of fleets of electric vehicles. This chapter quantifies the resilience of a portfolio of vehicle-to-grid technology investments and milestones when it is subjected to a variety of emergent and future conditions that involve technology, the environment, market prices, regulations, organizations, and others. The chapter demonstrates the technical approach described in Chapter 3. Section 4.2 describes the literature relevant to electric vehicles and smart grids. Section 4.3 describes the elements and the results of the demonstration. Section 4.4 discusses the key findings from the demonstration. Section 4.5 discusses the importance of incorporating the influence of stakeholders to enterprise resilience.

4.2 Backgrounds

This section reviews the literature related to energy mobility and the stability and reliability of smart grids. Electricity distribution systems will be significantly impacted by hybrid electric vehicles and vehicle-to-grid technologies (Tremblay, Dessaint, and Dekkiche 2007), as these new technologies can serve as inexpensive energy resources to bolster the grid at peak energy consumption hours. These technologies will affect a wide range of stakeholders, including utilities, electric vehicle supply equipment (EVSE) manufacturers, and auto manufacturers. The advanced bidirectional charger technology has the potential to promote the use of renewable energy and reduce greenhouse gas emissions (Markel et al. 2015).

How this bidirectional charging concept is used to supplement the power grid has been described by Kempton et al. (2008; 2007; 2005), Tomić and Kempton (2007), and Kempton and Tomić (2005). The requirements for such a technology include "(1) a connection to the grid for electrical energy flow, (2) control or logical connection necessary for communication with the grid operator, and (3) controls and metering on-board the vehicle" (Kempton and Tomić 2005). Kempton and Tomić (2005) observe that to have a near-term proof of concept, these vehicles need to be involved in a power market that takes advantage of the ability of the vehicles' batteries to discharge power quickly, and that power markets need to become amenable to storing power rather than just generating it. The Federal Energy Regulatory Commission (FERC) requires ancillary services, which are services that supplement the grid's power generation. An ancillary service that has been identified as being favorable for the commercialization of vehicle-to-grid technology is frequency regulation (Kempton and Tomić 2005).

Among the regional transmission organizations (RTOs) in United States is the Pennsylvania–New Jersey–Maryland Interconnection (PJM). This RTO establishes the market for electricity in New Jersey, Delaware, the District of Columbia, a large portion of Pennsylvania and Maryland, and a small portion of Virginia (Gravener and Nwankpa 1999). The PJM offers the ancillary services of the Demand Response Market and Frequency Regulation. The decisions of the RTO, which is supervised by the FERC, affect the regulatory climate for ancillary services (Blumsack 2017).

The policies of the electricity markets create significant challenges to the successful commercialization of electric vehicles (Shepard and Gartner 2013), and the impact of the frequency regulation service on the batteries of electric vehicles is unclear. This potential impact can be viewed as a cost, but this impact has not yet been empirically tested (Han and Han 2013; Kempton and Tomić 2005). A previous study (Merrill et al. 2015) addressed some of these challenges through an economic feasibility model, but the potential challenges need to be assessed by establishing different risk assessment methods for advanced bidirectional chargers.

The enterprise resilience analytics framework that is presented in this chapter assesses the influence of scenarios to the priorities for multiple groups of stakeholders. The innovative aspect of this framework is that it can be used to help users/managers/clients employ their limited research and development funding and resources more efficiently by focusing their efforts on the most highly ranked and robust enterprise initiatives. In regard to advanced bidirectional charger technology, risk analysts are seeking to minimize the risk of not providing ancillary services to the power grid by implementing robust initiatives. The technical modeling aspects were discussed in detail in Chapter 3.

4.3 Demonstration of Methods

Figure 6 in Chapter 3 presents the technical approach to the resilience analytics framework for a single group of stakeholders and for multiple groups of stakeholders. The present chapter demonstrates the framework for only a single group of stakeholders. In other words, the framework evaluates only the influence of scenarios to priorities without considering the influence of the participation levels of multiple groups of stakeholders, which will be demonstrated in Chapter 5 and Chapter 6.

4.3.1 Problem Statement

The advanced bidirectional charger technology will promote grid stabilization, reduce dependence on oil, lower the cost of electric vehicle ownership, and support renewable energy. Figure 7 shows electric vehicles plugged into advanced bidirectional fast chargers at a charging station. This case study will demonstrate the effectiveness of the resilience analytics framework at prioritizing large numbers of advanced bidirectional charger initiatives across the influence of different emergent and future conditions. The most important factors in assessing the risks of adapting electric vehicle fleets to the particular needs of the power grid are the initiatives, the criteria, and the scenarios. The goal of this analysis is to rank initiatives, which are necessary for the creation of successful resource mobility technology, across the influence of different emergent and future conditions.

Figure 7. Advanced bidirectional fast charger to reduce utility costs with vehicle-to-grid (V2G) and demand charge management integrated into logistics systems (Source: Fermata LLC 2017)

4.3.2 Identification of Enterprise Initiatives

The enterprise resilience analytics framework has been implemented using the facilitator mode which was discussed in detail in Chapter 3 (see section 3.5.2 Decision Conferencing). The facilitator (the author of this dissertation) guided the stakeholders through the creation of a comprehensive plan for the mobile smart grid technology problem. It is essential to improve the engagement of stakeholders at this stage of the analysis since they are in charge of defining the modeling inputs, including the planning initiatives, criteria, and emergent and future conditions. Improving the engagement of stakeholders is necessary for performing a widespread economic analysis to define the most important initiatives. The comprehensive plan addresses all the important opportunities, requirements, and outputs for each industrial sector, which will help to improve the engagement of the stakeholders.

A set of initiatives has been defined based on the information from the group meetings and other published sources. The purpose of each initiative will vary based on the objectives, resources, and requirements of each project. Such initiatives cannot be fully comprehensive, but the list should be determined through a collaborative study across the important sectors of several agencies. The set should be selected so as to cover the perspectives of most of the stakeholders, including the energy market, the industry market, the mobility market, auto manufacturers, electric vehicle owners, systems control, cyber security and communication, device controls, home/building, and neighborhoods. The initiatives demonstrate the requirements and tasks needed to address the concerns of multiple stakeholders who are interested in energy mobility integration. Table 2 shows the list of the planning initiatives that are included in this analysis. The set of initiatives are published by the National Renewable Energy Laboratory (Markel et al., 2015); this is not a complete set but was identified by several public and private energy agencies, such as the U.S. Department of Energy.

Assessment was done on a total of 35 initiatives $Sx = \{x_1, \ldots, x_{35}\}$, ranging from running the necessary market simulations to evaluating the impacts of engaging in ancillary services on the batteries of vehicles. Some of the initiatives involve Department of Energy analysis tools. In conducting the analysis, the initiatives are considered in the light of fleet logistics, even though the report is an assessment of general vehicle-to-grid integration. The defined initiatives derive from the perspective of multiple physical and communication layers, regions of service, and the stakeholders. These views are combined to create a more holistic inventory of the initiatives needed to create an environment where the technology can thrive. A report from the National Renewable Energy Laboratory lists those initiatives from different perspectives, including electric vehicle markets, cyber security and communications, system control, and others. These initiatives give an outline of possible future strategies that are recommended to improve the integration of the grid system with the energy mobility technology from different regions, including neighborhoods, ISO territories, and other physical perspectives.

In addition, the initiatives outline future strategies to overcome problems facing the aggregators, EVSE manufacturers, and others (Markel et al. 2015). Also considered in the report are issues related to building codes, utilities, and other policy perspectives (Markel et al. 2015). Although policy is crucial to the success of the technology, the needs outlined arise from the perspective of each specific organization, which is beyond the scope of a private enterprise engaging in research and development.

Table 2. List of mobile smart grid initiatives included in the analysis taken directly from the NREL study, "Multi-Lab EV Smart Grid Integration Requirements Study" (Markel et al. 2015)

Initiative	Description	Perspective
x_1	Run simulation of market variability	Market
x_2	Access wholesale markets	Market
x_3	Conduct regional resource planning	Market
x_4	Control methods from PEVs to utilities	System Controls
x_5	Determine grid value role	Cyber Security and Communication
x_6	Develop standards of encryption	Cyber Security and Communication
x_7	Establish sensors and communications	Cyber Security and Communication
x_8	Develop communications standards	Cyber Security and Communication
x_9	Test features for aggregator control	Device Controls
x_{10}	Develop power electronics and energy storage components	Components and Devices
x_{11}	Develop charge controllers	Components and Devices
x_{12}	Improve understanding of load cycles	Home/Building
x_{13}	Identify requirements for energy performance	Home/Building
x_{14}	Provide solution to enhance energy performance	Home/Building
x_{15}	Mitigate transformer issues	Neighborhood
x_{16}	Investigate results of technology adoption	Neighborhood
x_{17}	Verify projected results of technology adoption	Neighborhood
x_{18}	Perform resource planning	Balancing Authority Area

Initiative	Description	Perspective
x_{19}	Model plug-in electric vehicle (PEV) penetration at independent systems operator (ISO) level	ISO Territory
x_{20}	Establish standards for PEV owners	PEV Owner
x_{21}	Analyze effects on battery	
x_{22}	Create tool for displaying technology's benefits	Building Owner
x_{23}	Create interoperability standards	EVSE Manufacturer/ Owner
x_{24}	Identify advantages of technology for PEV adoption	
x_{25}	Analyze potential aggregator operations	Aggregator
x_{26}	Identify PEV requirements for aggregation markets	
x_{27}	Identify at-risk components	Distribution Grid Operator
x_{28}	Test at-risk components	
x_{29}	Develop distribution monitoring for local PEV load sharing	
x_{30}	Determine connection requirements for invertor	
x_{31}	Analyze distribution system impacts of PEV adoption	Utility/Generator
x_{32}	Verify distribution system impacts	
x_{33}	Collaborate with OEMs	Auto Manufacturer
x_{34}	Analyze time-of-use rates	
x_{35}	Test new PEV and charging infrastructure	

4.3.3 Identification of Evaluation Criteria

A set of m criteria $Sc = \{c_1, \dots, c_m\}$ will be defined by the stakeholders for the purpose of evaluating and prioritizing how each initiative satisfies the requirements of each criterion. For instance, the Department of Energy's mission is "to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions" (U.S. Department of Energy 2014). This mission aligns with electric-vehicle-to-power-grid integration as the bidirectional advanced charger technology has the potential to be transformative in both its energy-related and environmental aspects. The relative importance of each criterion among the other criteria will be assessed by the stakeholders while considering the influences of different scenarios.

The criteria set is defined and adapted from several energy sources so as to ensure the criteria set is sufficient to address the sustainability of the power grid system. Therefore, to define the criteria set, the needs of several energy and transportation organizations, such as the U.S. Department of Energy (DOE), the U.S. DOE National Renewable Energy Laboratory (NREL), the U.S. Energy Information Administration, Fermata, LLC, Nissan North America, and other local agents, are investigated. The Department of Energy's Sustainability Performance Plan (U.S. Department of Energy 2014) was reviewed in order to study the factors and attributes that might support or impact the sustainability of the Department of Energy's practices. Other criteria were solicited from a local enterprise engaged in the research and development of electric vehicle and energy mobility technologies.

The criteria included in this case study are described in Table 3 and are as follows. The first criterion, c_1, *Fleet Management*, is an engineering management measure used to evaluate the effectiveness of fleet vehicles in satisfying the electric grid demands at peak energy consumption hours. The second criterion, c_2, *Renewable Energy*, measures the reliability of the bidirectional advanced chargers technology as a dynamic energy supplement source for the future. The third and the fourth criteria, *Economic Cost* (c_3) and *Economic Revenue* (c_4), are economic measures used to evaluate the effectiveness of future energy initiatives in meeting the stakeholders' economic concerns. The fifth criterion, c_5, *Market Standards*, measures the effectiveness of future planning initiatives in meeting the needs of the power and industry markets.

The criteria were relatively weighted in a baseline assessment, with *economic cost*, *economic revenue*, and *market standards* as the most important criteria. If these basic metrics are not met, the technology will not be feasible for commercialization. In this initial analysis, a local enterprise's criteria for launching the technology are viewed as the first and most important step toward meeting overarching needs. The least important criteria for the commercialization of the advanced bidirectional charger technology are *renewable energy* and *fleet management*. Although these criteria are important for the future, they are not important to the immediate success of the technology's commercialization but rather reflect larger goals for U.S. energy consumption.

Table 3. The evaluation criteria included in the analysis to prioritize mobile smart grid initiatives

	Criteria	Description
c_1	*Fleet Management*	The bidirectional advanced charger technology will support fleet management goals, specifically, promoting the use of alternative fuel fleet vehicles and reducing petroleum dependence.
c_2	*Renewable Energy*	The bidirectional advanced charger technology will enable renewable energy usage more than the alternative of not using the device. This criterion is combined with the goal of decreasing greenhouse gas emissions, since both support a similar goal for the technology's usage.
c_3	*Economic Cost*	The overall cost of the technology will be manageable for the technology's generation of revenue.
c_4	*Economic Revenue*	The overall revenue of the technology will sustain an efficient and viable industry.
c_5	*Market Standards*	The standards of the market in which the technology participates will support a viable industry, and these include the power market and general industry standards.

4.3.4 Identification of the Emergent and Future Conditions Set and the Scenarios Set

The identification of a set of possible emergent conditions is the first step in defining future scenarios. Let $S_{ec} = \{ec_1, \dots, ec_p\}$ be the set of p emergent conditions. The set should cover several possible future changes/disruptions that might affect the planning initiatives. The future emergent conditions list covers several possible disruption changes, including but not limited to the following: economic changes, electricity shifts, an increase/decrease in battery costs, an increase/decrease in electricity prices, and security changes. Let $S_s = \{s_1, \dots, s_q\}$ be the set of q scenarios. A scenario is an emergent condition or a combination of emergent conditions (Karvetski et al., 2009). For instance, s_3 could be a scenario in which public education and awareness and support of fleet procurement are relevant conditions.

Emergent conditions cover a wide range of possible future changes that could affect the initiatives outlined. Local and federal government renewable energy programs have many positive effects on the energy mobility industry. Such support could lower the cost of batteries, which is a major market barrier for the technology and could also lead to more available EVSE equipment, leading to more widespread consumer adoption (International Energy Agency 2013). The Annual Energy Outlook Report (2015) provides information about the shift in the electricity market. Table 4 describes 15 emergent conditions which are grouped into four future scenarios by taking into consideration different perspectives arising from the interests of multiple stakeholders. These emergent conditions are derived from the 2013 International Energy Agency's EV Outlook Report and the 2015 Annual Energy Outlook Report.

Table 4. Mobile smart grid emergent and future conditions list and the scenarios list

Emergent Conditions		Scenario	Description of the Scenario
ec_1	Fuel economy standards are developed	s_1. Public support	This scenario, a combination of these emergent conditions, represents a change in the public industry which affects the electric vehicle initiative.
ec_2	Infrastructure development is optimized		
ec_3	Battery costs fall	s_3. Private and public support	This scenario, a combination of these emergent conditions, represents a change in both the private and the public industries which affects the electric vehicle initiative.
ec_4	Electric vehicle performance improves		
ec_5	Public education and awareness increase		
ec_6	Fleet procurement is supported		
ec_7	Standards are harmonized		

Emergent Conditions		Scenario	Description of the Scenario
ec_8	Vehicle financing markets develop	s_2. Private support	This scenario, a combination of these emergent conditions, represents a change in the private industry which affects the electric vehicle initiative.
ec_9	Sustainable electric vehicle supply equipment business models are developed		
ec_{10}	Electric vehicle model diversity increases		
ec_{11}	Retail electricity prices increase	s_4. Electricity market shift	This scenario, a combination of these emergent conditions, represents a change in the electricity market which affects the technology.
ec_{12}	Power grid reliability increases		
ec_{13}	Smart grids increase		
ec_{14}	Electricity usage increases		
ec_{15}	Renewable energy generation and dependence increase		

Since a scenario is an emergent condition or a combination of emergent conditions, the stakeholders should make sure that the scenarios they define result from realistic combinations of emergent conditions. For instance, emergent conditions, such as ec_5, *Public education and awareness increase*, and ec_6, *Fleet procurement is supported*, capture the possibility that public education programs to educate individuals and organizations about the importance of reducing fleet emissions could shift preferences from using petroleum fleets to using EV fleets, creating support for the bidirectional advanced charger technology. Other emergent conditions that would increase the economic value of the advanced charger technology, such as ec_3, *Battery costs fall*, ec_4, *Electric vehicle performance improves*, and ec_6, *Standards are harmonized*, capture the possibility of private industry's supporting this technology by improving EVs' performance and reducing their cost, making them more attractive to customers. Hence, the combination of emergent conditions listed in this paragraph forms the public and private support scenarios.

4.3.5 Prioritization of Initiatives across Scenarios

The next step in the framework is to prioritize the initiatives across the influences of all the scenarios. The goal is not to recommend one initiative or a set of initiatives to the stakeholders, but rather to understand the influence of the emergent conditions to priority setting. Thus, the risk analyst will be able to identify a set of the most robust initiatives and to rank the scenarios based on their level of disruptiveness to the priority setting.

To prioritize the planning initiatives across the influence of various possible scenarios, a scenario-based preferences analysis is conducted. First, the stakeholders evaluate how each initiative satisfies the requirement of each criterion. Table 5 shows the 5 $\times$35 assessments of how well each initiative works in satisfying the requirement of each criterion. The rows show the impact of all initiatives on each criterion, while the columns show the impact of each initiative on all the criteria. For example, x_3, *Conduct regional resource planning*, strongly addresses two criteria (c_1 and c_5) and somewhat addresses two other criteria (c_2 and c_3). The assessment is based on interviewing the stakeholders during regular decision workshops with them.

The relative importance of each criterion can be altered across the influence of different scenarios by multiplying the weight of the criterion by constants: for example, $\alpha_1 = 9$ and $\alpha_2 = 3$, where α_1 is used for a major increase and $1/\alpha_1$ for a major decrease, and α_2 is used for a minor increase and $1/\alpha_2$ for a minor decrease. Table 6 shows the influence of the four scenarios to the importance of criteria based on the stakeholders' elicitation. For instance, the s_1 *Public Support* scenario causes a minor increase in the importance of the c_1 *Fleet Management* criterion.

Table 5. Impact of enterprise initiatives across criteria, with ● indicating initiatives that strongly address the criterion, ◗ indicating initiatives that somewhat address the criterion, ○ indicating initiatives that marginally address the criterion, and an empty cell indicating initiatives that do not address the criterion

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	
c_1			●				○		◗	◗	○				◗	◗	◗	
c_2		◗	◗	○		○		○				○	○	○				
c_3	◗	◗	◗	○								○	○	○				
c_4	◗											○	○	○				
c_5	◗	●	●		○				◗	◗							◗	
	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
c_1		●		○								◗						
c_2	○	◗			○		◗			◗	◗	◗						○
c_3	○	◗			◗		○	○	○					○	○	○		
c_4	○	◗			◗		○							○	○	○		
c_5		○	○			◗						◗	○			○	○	○

Table 6. The influence of scenarios to the importance of the mobile smart grid criteria

	s_1	s_2	s_3	s_4
c_1	Increases Somewhat	Decreases	-	-
c_2	-	Increases Somewhat	Increases Somewhat	Increases
c_3	-	Increases	Increases Somewhat	Increases Somewhat
c_4	-	Increases Somewhat	Increases Somewhat	Increases Somewhat
c_5	Increases Somewhat	-	Increases Somewhat	Increases

To examine the level of disruptiveness of each scenario to the initiatives, the changes in the rank order of the initiatives across the influence of scenarios are analyzed, as these rank orders represent the relative prioritization across the different scenarios. Table 7 summarizes the prioritization for all the initiatives in the baseline scenario (s_o) and in the other scenarios. Figure 8 gives a visual representation of the analysis shown in Table 7. The diamonds in Figure 8 represent the ranking of each initiative in the baseline scenario. In the baseline scenario, the highest ranked initiative is x_3, *Conduct regional resource planning*. Initiatives such as x_6, x_7, x_8, x_{11}, and x_{21} are the lowest ranked initiatives in the baseline scenario.

The vertical bar associated with each initiative in Figure 8 displays the range of the ranking order for each initiative across the influence of scenarios. These vertical bars indicate the robustness of each initiative to the impact of scenarios. For example, x_{35} , *Test new PEV and charging infrastructure*, is sensitive to the impact of scenarios as the range of ranks (lower rank = 2 , upper rank = 17) is relatively large compared to other initiatives. The least robust initiatives are x_1, x_{34}, and x_{35}, and the most robust initiative is x_3, *Conduct regional resource planning* , as its rank varies the least across the scenarios. Thus, investing in x_3 may be important regardless of the realizations of possible emergent conditions, whereas investing in x_{35} is less important, as the initiative's priority rank is not stable across the influence of different scenarios.

Table 7. Ranking of mobile smart grid initiatives across the influences of all scenarios

	$\boldsymbol{x_1}$	$\boldsymbol{x_2}$	$\boldsymbol{x_3}$	$\boldsymbol{x_4}$	$\boldsymbol{x_5}$	$\boldsymbol{x_6}$	$\boldsymbol{x_7}$	$\boldsymbol{x_8}$	$\boldsymbol{x_9}$	$\boldsymbol{x_{10}}$	$\boldsymbol{x_{11}}$	$\boldsymbol{x_{12}}$	$\boldsymbol{x_{13}}$	$\boldsymbol{x_{14}}$	$\boldsymbol{x_{15}}$	$\boldsymbol{x_{16}}$	$\boldsymbol{x_{17}}$
s_0	3	5	1	21	22	31	31	31	20	12	31	12	12	12	27	27	10
s_1	2	8	1	26	14	34	29	34	12	9	29	18	18	18	24	24	7
s_2	16	12	3	13	26	29	33	29	25	21	33	6	6	6	31	31	20
s_3	4	6	1	20	22	29	33	29	21	16	33	11	11	11	31	31	15
s_4	4	6	1	24	15	29	33	29	14	9	33	18	18	18	31	31	8

	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
s_0	12	2	22	31	4	17	10	22	22	27	27	7	22	17	17	7	7	5
s_1	18	5	14	29	13	10	17	27	27	32	32	6	14	22	22	11	4	3
s_2	6	2	26	33	1	22	4	14	14	23	23	18	26	10	10	5	19	17
s_3	11	2	22	33	3	17	10	22	22	27	27	9	22	17	17	7	7	5
s_4	18	5	15	33	12	10	13	27	27	25	25	7	15	22	22	11	3	2

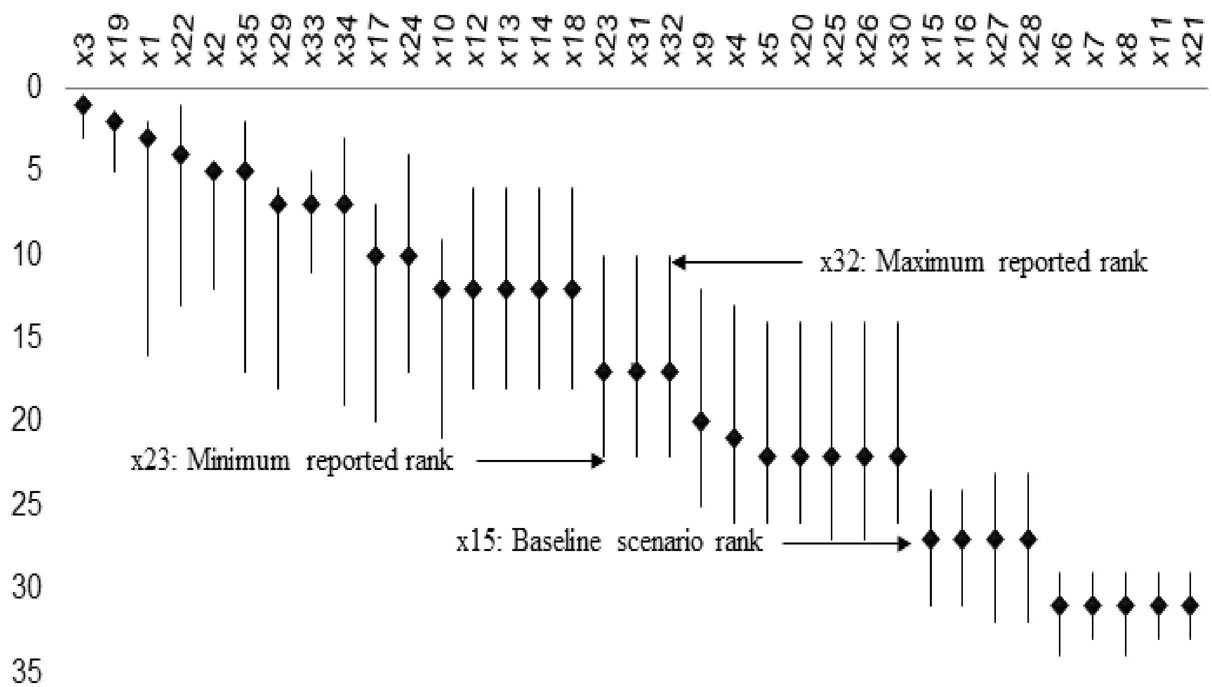


Figure 8. Ranking of mobile smart grid initiatives across the influences of all scenarios

Table 8 shows the level of disruptiveness of each scenario as measured by the Spearman rank correlation coefficient. Scenarios s_3 and s_4 have high Spearman rank correlation coefficients, meaning that those scenarios correlate strongly with the baseline scenario, whereas s_2 has the lowest Spearman rank correlation coefficient, meaning that this scenario correlates weakly with the baseline scenario. Thus, s_2, *Private support*, is the scenario that is most disruptive to the mobile smart grid technology.

The private industry support scenarios include supporting vehicle financing markets, identifying sustainable energy mobility equipment, and increasing the diversity of electric vehicles (International Energy Agency 2013). It appears that an increase in private industry support would cause more disruption to the rankings of the initiatives. In addition, the support of private industry also made the most significant change in priority setting compared to the other scenarios, whereas the public and private scenario seems not to be disruptive to the initiatives.

Table 8. Disruptiveness of the four scenarios to the priority setting of the mobile smart grid stakeholders by Spearman Rank Correlation Coefficient

Scenario	Spearman Rank Correlation Coefficient
s_1	0.88
s_2	0.79
s_3	0.98
s_4	0.90

An analysis of the initial comparison of various initiatives that met selected criteria under certain perceived emergent and future conditions yielded the following results. The most critical initiatives based on ranking were x_3, *Conduct regional resource planning*, and x_{19}, *Model plug-in electric vehicle (PEV) penetration at the independent systems operator (ISO) level*. These initiatives address the need for more consistency in assessing the differences in the development of technology in different electric grid regions. They touch on the uncertainty both about policies surrounding the technology and about how to operate within requirements of the various electricity markets. For example, the demand response market is particularly sensitive to power policy changes (Tweed 2014), and the FERC 745 ruling leaves energy mobility technology in the demand response market in a highly uncertain state. It is notable that, in addition to x_3 and x_{19} being highly ranked initiatives, they are also robust. This robustness to change is shown in Table 7 and in Figure. 8, since their rank order only changes from 1 to 3 for x_3 and from 2 to 5 for x_{19} across the influences of all the scenarios.

4.4 Discussion

This chapter has discussed the ability of plug-in electric vehicles to support the stability and reliability of the electrical grid system across the influences of different disruptive events. It has demonstrated an enterprise resilience analytics framework to evaluate the influences of scenarios to integrating the electric vehicles into the electric grid system. The approach assesses the interests and preferences of multiple stakeholders and translates them into a mathematical model that prioritizes a large set of future enterprise initiatives across the influences of various scenarios.

The resilience analytics framework is used to inform risk analysts about which initiatives are most robust and least robust to the influences of various scenarios, thus allowing them to assess the risk associated with implementing each initiative across the influences of scenarios. The results identify critical initiatives where additional investigation, including risk analysis, might be needed to improve the confidence in and acceptance of an evolving technology roadmap. Thus, the framework guides risk analysts to identify the initiatives that are most crucial to the mobile smart grid technology.

The approach recognizes that priorities are defining characteristics of many systems and organizations. Priorities can be established across assets, projects, units, policies, geographic entities, and time horizons. An update of priorities, however, can disrupt an organization or system and an update of priorities that results in an entity moving from high to low or low to high in priority is particularly disruptive. For entities to stay at the same or a similar priority rank is a type of robustness, understood as the stability of an entity's relative priority when subjected to the influences of emergent and future conditions. No agreed-upon numerical threshold defines what degree change of priority implies robustness, and thus this dissertation describes entities as being more or less robust in regard to a set of given emergent and future conditions—an approach which is common in the field of risk analysis (Thorisson et al. 2017; Connelly et al. 2016; Hamilton, Lambert, and Valverde Jr 2015).

Systems engineering management integrates systems engineering, system implementation, and systems management in order to manage research and development projects at the enterprise level in a wide range of engineering operations (SEBoK 2017). The framework described in this chapter overlaps with the concept of systems engineering management because it focuses on the implementation of energy mobility research and development initiatives at the operational and the enterprise level. Moreover, ranking initiatives on the basis of their level of robustness to the influence of scenarios and ranking the scenarios on the basis of their level of disruptiveness to priorities of stakeholders is an engineering management approach that shares a context with the systems engineering management approach. For example, this approach emphasizes that, among the 35 planning initiatives, initiative x_3, *Conduct regional resource planning*, is the most robust and highly ranked initiative across the influence of future scenarios. It also emphasizes that scenario s_2, *Private industry support*, is the most disruptive scenario when compared to all the other scenarios, as described in detail in the case study section.

In this methodology, stakeholder elicitation is used to preserve differences among stakeholders rather than to aggregate preferences of stakeholders. A scenario represents the perspective of a group of like-minded stakeholders. A typical interpretation is that an expert(s) on natural disasters is represented by a scenario that includes particular natural disasters, while an expert on behaviors is represented by a scenario that includes particular individual, population, and/or workforce behaviors. To address more stakeholders and/or the evolving views of current stakeholders, the methodology encourages iteration with new sets of criteria, initiatives, and emergent/future conditions.

The initial and updated priorities are elicited in decision workshops that are followed by the presentation of the methodology and an initial set of results. In a process aimed at uncovering singular and minority viewpoints across the stakeholders, the members of the group are encouraged to question inputs, assumptions, and results. Based on the stakeholders' feedback from the initial or the previous elicitation process, the stakeholders refines the set of initiatives, the set of criteria, and the set of emergent conditions. If the preferences of stakeholders are aggregated, valuable information will be lost. In this methodology, all the preferences of stakeholders are included when defining the set of initiatives, of criteria, and of emergent conditions.

4.5 How Might the Participation Level Postpone the Desired Outcomes?

The framework assumes that the stakeholders have equal impacts on enterprise initiatives. This assumption, however, introduces systematically biased judgments for two reasons that have been discussed in great detail in Chapters 1, 2, and 3. First, the participation levels of the stakeholders cannot be equal under any problematic circumstances, since the stakeholders have different goals, objectives, power, interest, budgets, and other factors that significantly impact their ability to participate in any decision-making problem. Second, the participation level of each stakeholder is not constant across all the scenarios. It is expected that a stakeholder will have a high participation level if a scenario directly impacts social, environmental, economic, or other aspects that are important to the stakeholder. For instance, in the baseline scenario, the grid operators, as a stakeholder group, showed a high interest in the advanced bidirectional charger technology since it supports the reliability and the stability of the grid system; however, this interest might decrease if a more reliable and less expensive technology emerges that would improve the stability of the grid.

Chapter 5 and Chapter 6 present and demonstrate a resilience analytics framework that addresses the influences both of scenarios and of multiple groups of stakeholders to the priority setting of the stakeholders.

4.6 Chapter Summary

Table 9 provides a summary of key results for the mobile smart grid demonstration. A total of 35 planning initiatives addressing different perspectives, such as marketing, systems control, cyber security, and communications, were assessed. A resilience analytics framework was used to prioritize the set of planning initiatives across the influences of scenarios. A total of 15 emergent and future conditions used in this study were published by the International Energy Agency (2013) and the U.S. Energy Information Administration (2015). Four future scenarios were defined using combinations of these 15 emergent conditions. Initiative, x_3, *Conduct regional resource planning*, was considered to be the most highly ranked and robust initiative. The lowest ranked initiatives across the influence of the scenarios were x_6, x_7, x_8, x_{11}, and x_{21}. The private industry support scenario, s_2, was shown to be the most disruptive scenario since it had a significant impact on the economic cost of and the economic revenue from the advanced bidirectional chargers technology. The stakeholder group discussions indicated that the stakeholders had different levels of power and interest across scenarios. Chapters 5 and 6 demonstrate the resilience analytics framework when the influences both of scenarios and of the participation levels of stakeholders are taken into consideration in the analysis.

Table 9. Summary of key results from the analysis of the mobile smart grid initiatives

Type of results	Description
Five criteria	Criteria are defined by the stakeholders for the purpose of evaluating and prioritizing how each initiative satisfies the requirement of each criterion.
Thirty-five initiatives	The 35 planning initiatives are determined by a collaborative study across several enterprise important sectors.
Most robust initiative	x_3: Conduct regional resource planning
Highest ranked initiative	x_3: Conduct regional resource planning
Lowest ranked initiatives	x_6: Establish standards of encryption x_7: Establish sensors and communications x_8: Develop communications standards x_{11}: Develop charge controllers x_{21}: Analyze effects on battery
Most disruptive scenario	s_2: Private Support Increases
Least disruptive scenario	s_3: Private and Public Support Increases

CHAPTER 5: DEMONSTRATION: RESILIENCE OF SMART GRID SERVICES TO INFLUENCES OF SCENARIOS AND OF GROUPS OF STAKEHOLDERS

5.1 Overview

The future of energy mobility will involve networks of users, operators, organizations, vehicles, charging stations, communications, materials, transportation corridors, and points of service, among other entities. Integrating smart grids with plug-in electric vehicle technologies will have societal and commercial advantages such as improving grid stability, minimizing dependence on nonrenewable fuels, reducing vehicle emissions, and lowering the cost of electric vehicle ownership. This chapter demonstrates the enterprise resilience analytics framework in the deployment of smart grid technologies to address the influences both of scenarios and of groups of stakeholders on priorities. Section 5.2 provides an introduction to energy mobility technologies, reviews the literature relevant to demand charge management and risk analysis, and gives the purpose and scope of the study. Section 5.3 describes the main findings from the analysis for each group of stakeholders and for all the groups. Section 5.4 discusses the key findings from the demonstration.

5.2 Introduction

5.2.1 Motivating

Energy mobility networks consist of interdependent and interconnected networks, including social networks, cyber networks, and physical networks. Investigating the interdependency and interconnectedness of these networks from different perspectives is essential when analyzing the risks associated with the complexity of these networks (Barker et al. 2017; Andrijcic and Haimes 2016). Because of environmental, economic, and security concerns, the number of plug-in electric vehicles (PEVs) in the world is dramatically increasing (Fernandez et al. 2011). The increase in the additional load on the power grid network is a result of the increase in the number of PEVs being deployed (Akhavan-Rezai et al. 2016; Rezaei, Frolik, and Hines 2014; Ma, Callaway, and Hiskens 2013). The benefits to and impacts on the grid system of a high deployment of PEVs have been investigated by several scholars (Hines et al. 2014; Denholm and Short 2006). Despite numerous studies describing the technical details, the impacts, and the benefits of energy mobility networks, the ability of these networks to withstand future disruptions needs further study. These networks' high interdependency and interconnectedness make them more vulnerable and less resilient to the influence of disruption events (Barker et al. 2017). Moreover, Ayyub (2014) has pointed out that developing systems' resilience is required in order to address the three pillars of sustainability: social, environmental, and economic sustainability.

Demand charge management is a concept where the electricity stored in the chargers of electric vehicles is used for load leveling. Load leveling reduces the energy demand on power grid networks during peak periods by supplying the grid network with electricity stored in advance chargers and increasing the peak-off demand for recharging the advance chargers and preparing for the next high-demand event (Damiano et al. 2014). New smart grid resources, such as advanced bidirectional chargers, can feed the grid system at peak energy consumption hours. Masoum et al. (2011) propose a smart load management approach that supports grid security, reliability, and stability by employing peak demand shaving and minimizing power losses. Demand charges are additional charges for electricity based on the highest capacity, that is, when the transmission system has failed to accommodate all the power demand flow (Markel et al. 2015).

5.2.2 Background

The energy stored in advanced bidirectional chargers is used for supplying electricity to the power grid networks during peak hours. The economic value of this technology is proved because of the quick response of the advanced bidirectional chargers (Kempton and Tomić 2005). Frequency regulation services are attractive services for commercializing advanced bidirectional charger technology (Kempton and Tomić 2005). The Federal Energy Regulatory Commission (FERC) requires ancillary services for supplementing power to the grid. “Regulation services fine-tune the balance between power generation and demand. This is also called frequency regulation or automatic generation control, and it is priced separately from power generation and procured as an ancillary service” (Markel et al. 2015, 4).

Energy mobility technologies generate opportunities and threats to several groups of stakeholders (Bakker, Maat, and van Wee 2014). A group that participates in the development of these technologies will receive benefits from those opportunities and also help to mitigate the threats; thus, the cooperation of groups in the development of energy mobility networks is vital to developing electric vehicles, the electricity market, and the recharging infrastructure.

Recent developments in risk analysis and systems engineering have addressed the topic of system resilience for a wide range of application fields by focusing on the influence of scenarios to priorities for systems that involve multiple stakeholders, multiple objectives, and uncertainties in several fields of application (**Almutairi** et al. 2017; Thorisson et al. 2017; Connelly et al. 2016; Hamilton et al. 2016; You et al. 2014; Lambert 2012). To manage risk as an influence of scenarios (compriseing emergent and future conditions) to priorities, researchers have applied a scenario-based preferences model to various energy topics (**Almutairi** et al. 2017; Thorisson et al. 2017; Connelly et al. 2015; Karvetski and Lambert 2012; Karvetski, Lambert, and Linkov 2011). Research is lacking, however, that addresses the changing behavior of stakeholders in different scenarios (Cairns, Goodwin, and Wright 2016). The available scenario-based modeling approaches have given little consideration to the influences of groups of stakeholders to priorities. Conflicts between stakeholders and unbalanced outcomes might result from failing to incorporate the preferences of stakeholders into the analysis (Talantsev 2017). Environmental, political, economic, technical, and social concerns, among others, need to be considered when investigating the development of the energy market (Talantsev 2017; Wang et al. 2009).

5.2.3 Purpose and Scope

This chapter considers how enterprise resilience analysis can address the influences of scenarios and of multiple groups of stakeholders on priorities. The framework integrates two existing approaches: (i) *stakeholder mapping* (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981), and (ii) *scenario-based preferences in risk analysis* (**Almutairi** et al. 2017; Thorisson et al. 2017; Connelly et al. 2016; Hamilton et al. 2016; You et al. 2014; Lambert 2012). Subsequently, the framework is demonstrated in the context of the mobile smart grid by deploying the demand charge management technology to support grid operation and lower dependence on nonrenewable fuels, while accounting for the influences of scenarios and of multiple groups of stakeholders to priorities.

5.3 Demonstration of Methods

5.3.1 Problem Statement

The increasing sophistication of the power grid networks, requiring an understanding of the reliability, security, efficiency, and sustainability of the grid systems, highlights the importance of developing new technologies that support grid operation (Moslehi and Kumar 2010). Moreover, the impact of the additional load generated by charging plug-in electric vehicles (PEVs) requires investigation (Hines et al. 2014). Demand charge management is a new concept that supports grid stability and reliability while ameliorating other grid demand problems. The concept is to use the electricity stored in advanced bidirectional chargers for load leveling during peak load periods. Hence, "smart energy" enables PEV owners to generate profit by providing ancillary services to the grid system, such as frequency regulation, load leveling, and reserve (Damiano et al. 2014). Figure 9 illustrates how electric vehicles that are providing demand charge management services perform load leveling and decrease peak demand for a smart grid.

This demonstration in this chapter will emphasize the influences of scenarios and of multiple groups of stakeholders on priorities. This demonstration prioritizes smart grid initiatives toward deploying advanced technologies (e.g., demand charge management) along with the influences of scenarios (e.g., electricity market shift) and of groups of stakeholders (e.g., public agencies, vehicle manufacturers, PEV owners). A stakeholder group is defined as people who share the same viewpoint when considering a specific problem; they could be system owners, users, customers, business vendors, scientists, or others.

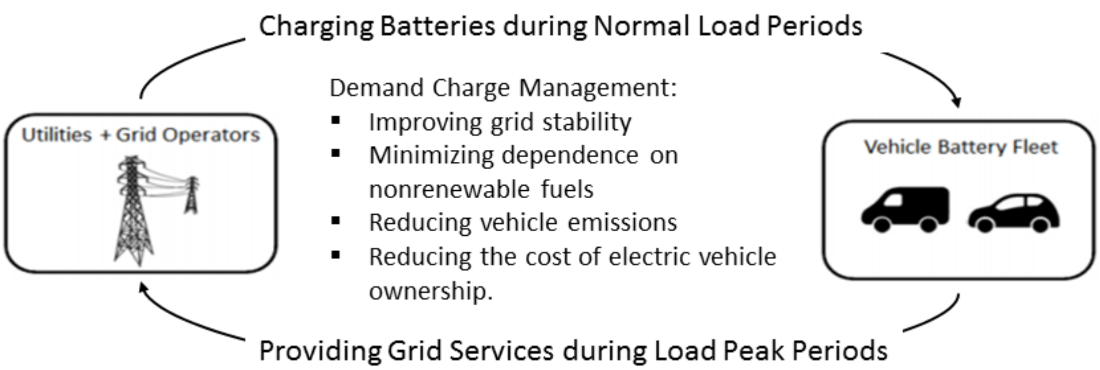


Figure 9. Demonstration of the resilience analytics of an enterprise for a smart energy mobility network that provides demand charge management services

5.3.2 Identifying Groups of Stakeholders with the Corresponding Evaluation Criteria

The facilitated workshop discussion mode that discussed in Chapter 3 is used in this case study. The facilitator is responsible for inviting the groups of stakeholders who can affect or be affected by the deployment of the smart grid planning initiatives. Several concerns need to be taken into consideration when identifying the groups of stakeholders, the criteria set, and the smart grid initiatives, including environmental, political, economic, technical, and social concerns, among others. Seven energy mobility stakeholders have expressed their interests, expectations, and strategies for the development of electric vehicles (Bakker, Maat, and van Wee 2014): the national government, the local government, car manufacturers, electricity producers, electricity grid operators, oil companies, and charging equipment developers. This case study assigns the above-mentioned stakeholders to *groups* based on their interests, goals, and concerns, as shown in Table 10. The criteria sets are adapted from several sources (Yavuz et al. 2015; Bakker, Maat, and van Wee 2014; U.S. Department of Energy 2014). Each criteria set is used to evaluate and prioritize the smart grid initiatives for the associated group. The purpose of creating a specific criteria set for each group is to clarify where potential conflicts or agreements among the groups may arise (Thorisson et al. 2017).

Table 10. Groups of stakeholders with the corresponding criteria sets used to evaluate smart grid initiatives

Group of Stakeholders	Criteria Set
ℓ_P : Public agencies	• c_{P1}: Reducing carbon emissions • c_{P2}: Reducing dependence on oil fuel • c_{P3}: Economic growth
ℓ_G : Grid operators	• c_{G1}: Grid stability • c_{G2}: Market expansion • c_{G3}: Low cost of operation
ℓ_V : Vehicle manufacturers	• c_{V1}: Feasibility of business • c_{V2}: Reducing carbon emissions • c_{V3}: Safety and reliability of PEVs and their equipment
ℓ_O : PEV owners	• c_{O1}: Reducing ownership cost • c_{O2}: Reducing carbon emissions • c_{O3}: Vehicle reliability (charging time, driving range)

5.3.3 Identification of Enterprise Initiatives

The smart grid planning initiatives should be defined so as to satisfy the requirements of each evaluation criterion. Table 11 shows a total of 35 initiatives resulting from a comprehensive collaborative study published by the National Renewable Energy Laboratory (Markel et al. 2015). These initiatives stem from different perspectives, such as marketing, system controls, security, communication, device control, home building, distribution grid operators, and others (Markel et al. 2015). It should be noted that groups of stakeholders may have some overlapping interests. For example, the groups $\ell_{V,}$ *vehicle manufacturers*, and $\ell_{G,}$ *grid operators*, are both interested in the system control perspective. In addition, addressing different perspectives that are important to all or some of the groups will ensure that the initiatives include technologies that are most important for stabilizing the grid system and commercializing the demand charge management concept.

Table 11. Smart grid initiatives of the U.S. National Renewable Energy Laboratory's *Multi-Lab EV Smart Grid Integration Requirements Study* (Markel et al. 2015)

Initiative	Description
x_1	Simulate V2G scenarios for market variability
x_2	Ensure resource access to wholesale markets
x_3	Establish a regional resource planning simulation
x_4	Collaborate with utilities to enable PEVs to satisfy utility goals
x_5	Determine the grid value role
x_6	Establish energy standards of known encryption
x_7	Establish sensors and communications
x_8	Provide accepted communication values
x_9	Test aggregator control structures to ensure robust operation
x_{10}	Support grid performance by developing electric duty cycle
x_{11}	Improve charge controllers
x_{12}	Balance load cycles by knowing influential factors
x_{13}	Enhance energy performance by identifying PEV requirements
x_{14}	Identify strategies to enhance energy performance
x_{15}	Identify charging management levels that mitigate transformer problems
x_{16}	Explore various PEV penetration levels
x_{17}	Verify V2G simulation results using available PEV data
x_{18}	Provide PEV resource planning analysis using a V2G simulation model
x_{19}	Expand the distribution scale size of the PEV penetration model to explore various PEVs' operation levels
x_{20}	Provide energy standards for different organizations and PEV owners
x_{21}	Study the impact of PEV batteries on V2G technology

Initiative	Description
x_{22}	Establish a tool for emphasizing the technology's benefits
x_{23}	Collaborate on creating interoperability standards
x_{24}	Identify the capability of V2G technology to reduce PEV ownership cost
x_{25}	Provide aggregator operations analysis
x_{26}	Identify the need for aggregation markets
x_{27}	Develop risk analysis procedures to test the system components
x_{28}	Provide system component information
x_{29}	Develop distribution monitoring to improve local PEV penetration analysis
x_{30}	Support bidirectional inverter connection requirements
x_{31}	Explore the impacts of distribution systems for various PEV penetration levels
x_{32}	Verify the impacts of the distribution system for various PEV penetration levels
x_{33}	Collaborate with OEMs
x_{34}	Perform a study analyzing the battery time-of-use rate
x_{35}	Study the production of PEVs and charging locations

5.3.4 Identification of Emergent Conditions and Scenarios

A total of 15 emergent and future conditions that could impact the stability of the smart grids are listed in Table 12. The emergent conditions are from the 2013 International Energy Agency's EV Outlook Report and the 2015 Annual Energy Outlook Report (U.S. Energy Information Administration 2015; International Energy Agency 2013) and consist of the threats and opportunities to energy mobility technology, finance, markets, and policymakers that could affect future improvement strategies.

Table 12 shows four scenarios that are constructed by combining one or more emergent conditions. The *Public support* scenario captures a situation where the public sector, including public agencies and organizations, support energy mobility technology by providing sufficient charging stations and predictable fuel prices. The second scenario is the *Private support* scenario, which captures a situation where private industry supports electric vehicle financing markets and sustainable electric vehicle equipment. The third scenario is the *Private and public support* scenario, in which both the public and the private sectors work together to reduce battery cost, enhance performance of electric vehicles, support fleet procurement, educate the public about the importance of supporting electric vehicle technology, and generalize electric vehicle standards. The fourth scenario is an *Electricity market shift* scenario, in which the technology is supported by an increase in retail electricity prices, in the reliability of the power grid, in electricity consumption, and in the importance of renewable energy.

Table 12. Scenarios comprising emergent and future conditions

Scenario		Emergent and Future Conditions
s_1.*Public support*	ec_1	Change in fuel economy standards
	ec_2	Development of energy infrastructure system
s_2.*Private support*	ec_3	Growth in electric vehicle financing markets
	ec_4	Identification of sustainable electric vehicle equipment
	ec_5	Increase in the number of electric vehicle models
s_3.*Private and public support*	ec_6	Reduction in battery costs
	ec_7	Improvement in electric vehicle performance
	ec_8	Increase in public interest in the benefits of renewable energy
	ec_9	Support of fleet production and use
	ec_{10}	Development of consistent standards
s_4. *Electricity market shift*	ec_{11}	Increase in retail electricity prices
	ec_{12}	Improvement in the reliability of the power grid system
	ec_{13}	Development of more smart grid features
	ec_{14}	Increase in electricity consumption
	ec_{15}	Development of renewable energy generation

5.3.5 Enterprise resilience for each group of stakeholders $\boldsymbol{\ell_z} \in \boldsymbol{L}$

This section will demonstrate a framework for evaluating the influence of scenarios to priorities for each of the four groups of stakeholders: $\ell_{\mathrm{P},}$ *Public agencies*; ℓ_{G}, *grid operators*; $\ell_{\mathrm{V},}$ *vehicle manufacturers*; and ℓ_{O}, *PEV owners*. A detailed analysis will be performed for the group $\ell_{\mathrm{O},}$ *PEV* owners, and the analysis results for the other three groups will be given at the end of this section.

For the group $\ell_{\mathrm{O},}$ *PEV owners*, the criteria were relatively weighted in the baseline scenario s_0, with c_{W1} , *Reducing ownership cost*, as the most important criterion, c_{W3} , *Vehicle* reliability, as the second most important criterion, and c_{W2} , *Reducing carbon emissions*, as the least important criterion. Table 13 describes an assessment evaluating how each initiative satisfies the requirements of each criterion. Each row in the table shows how well each initiative satisfies the requirements of each criterion, while each column shows how well each initiative satisfies the requirements of all the criteria. For example, x_{20}, *Providing energy standards for different organizations and PEV owners*, strongly addresses c_{W1}, *Reducing ownership cost*, somewhat addresses c_{W2}, *Reduce carbon emissions*, and moderately addresses c_{W3}, *Vehicle reliability*. The numerical values for the initiatives' assessment are shown in Table 14.

Table 13. For the group $\boldsymbol{\ell_{0}}$, *PEV owners*, assessments of initiatives across the criteria, with ● indicating initiatives that strongly address the criterion, ◗ indicating initiatives that address the criterion, ○ indicating initiatives that somewhat address the criterion, and a no symbol cell indicating initiatives that do not address the criterion

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}
c_{W1}		○	○							○		○					
c_{W2}	○			○	○	○	○	○	○				○	○	○	◗	○
c_{W3}	○	○	○	◗	○	○	○	○	○	◗	○	○	◗	◗	○	○	○

	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
c_{W1}		○	●	◗	○	○				○	○	○		○	○	○	○	○
c_{W2}	○		○	◗	○		○	○	○			◗	○					
c_{W3}	◗	◗	◗	●		◗	○	○	○	○	○		○	◗	◗			○

Table 14. Numerical values for the degree to which each initiative addresses each criterion

Qualitative Assessment	Symbol	Quantitative Value
Does not address	[no symbol]	0
Somewhat addresses	○	0.33
Moderately addresses	◗	0.67
Strongly addresses	●	1

The baseline relative importance weight for each criterion c_j changes based on the influence of the scenario $s_k \in S_s$: $w_j^k = \alpha_j^k w_j^0$, where α_j^k is equal to 9 for a *major increase* and to 1/9 for a *major decrease* in the importance weight of each criterion, and the α_j^k is equal to 3 for a *minor increase* and to 1/3 for a *minor decrease* in the relative importance weight of each criterion. The constants are drawn from an analytical hierarchy process analysis (Saaty 2008). Re-weighting the relative importance of criteria weights in each scenario results in the 3×5 matrix W, in which the first column shows the relative importance weight for each criterion in the baseline scenario s_0, while the other columns show the relative importance weights for each criterion in scenarios s_1, s_2, s_3, and s_4, respectively.

$$W = \begin{bmatrix} 57\% & 71\% & 16\% & 31\% & 21\% \\ 14\% & 18\% & 12\% & 23\% & 47\% \\ 29\% & 12\% & 72\% & 46\% & 32\% \end{bmatrix}$$

The additive value function, as shown in Equation 2 in Chapter 3, is used for determining the overall rank for each initiative in each scenario. The overall ranking scores for each initiative in the baseline scenario and across the four scenarios are shown in Table 15. Each column describes the range of the ranking order for each initiative across the scenarios, where a small ranking range means that the initiative is robust to the influences of the scenarios, while a large ranking range means that the initiative is less robust to the influence of the scenarios. For instance, x_{20}, *Provide energy standards for different organizations and PEV owners*, is considered a highly ranked and robust initiative since its ranking order range is small— $v(x_{20}) \in [1,2]$ — across all the scenarios, whereas x_{22}, *Establish a tool for emphasizing the technology's benefits*, is considered a less robust initiative since its ranking order range is large— $v(x_{22}) \in [8,33]$ — across all the scenarios.

Table 15. Smart grid initiative priorities for the group ℓ_0, *PEV owners*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}
s_0	23	8	8	15	23	23	23	23	23	3	35	8	15	15	23	22	23
s_1	23	11	11	19	23	23	23	23	23	4	35	11	19	19	23	18	23
s_2	20	13	13	7	20	20	20	20	20	3	32	13	7	7	20	12	20
s_3	20	13	13	7	20	20	20	20	20	3	35	13	7	7	20	12	20
s_4	13	28	28	4	13	13	13	13	13	9	35	28	4	4	13	3	13

	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
s_0	15	3	1	2	15	3	23	23	23	8	8	15	23	3	8	15	7	8
s_1	19	4	1	2	8	4	23	23	23	11	11	8	23	4	11	8	3	11
s_2	7	3	2	1	33	3	20	20	20	13	13	33	20	3	13	33	11	13
s_3	7	3	2	1	32	3	20	20	20	13	13	32	20	3	13	32	11	13
s_4	4	9	2	1	25	9	13	13	13	28	28	25	13	9	28	25	8	28

Figure 10 gives a visualization of the range of rankings for each initiative, as shown in Table 15. In Figure 10, the diamonds represent the ranking order for each initiative $x_i \in S_x$ in the baseline scenario. Initiative x_{20}, *Provide energy standards for different organizations and PEV owners*, has the highest ranking order in the baseline scenario s_0, while initiative, x_{11}, *Improve Charge controllers*, has the lowest ranking order in the baseline scenario s_0. The vertical bars in Figure 10 indicate the level of robustness for each initiative across all the scenarios. For example, the least robust initiatives to the influences of the scenarios are x_{22}, x_{29}, and x_{33}, as their rankings vary the most across all the rankings of the other initiatives, while x_{20} is both the highest priority and the most robust initiative, as it has the highest rank and the shortest vertical bar.

Table 16 shows the level of disruptiveness for the four scenarios to the priority setting for the group $\ell_{O,}$ *PEV owners*, using the Spearman rank correlation coefficient. Scenario $s_1, Public\ support,$ is the least disruptive scenario, since it has the highest Spearman rank correlation coefficient, and thus is significantly correlated to the baseline scenario. Scenario s_4, $Electricity\ market\ shifts,$ is the most disruptive scenario, since it has the lowest Spearman rank correlation coefficients, and thus is less correlated to the baseline scenario.

The framework was applied to each of the other three groups (public agencies, grid operators, and vehicle manufacturers), and the results are given below in Tables 17, 18, 19, 20, 21, and 22 and Figures 11, 12, and 13.

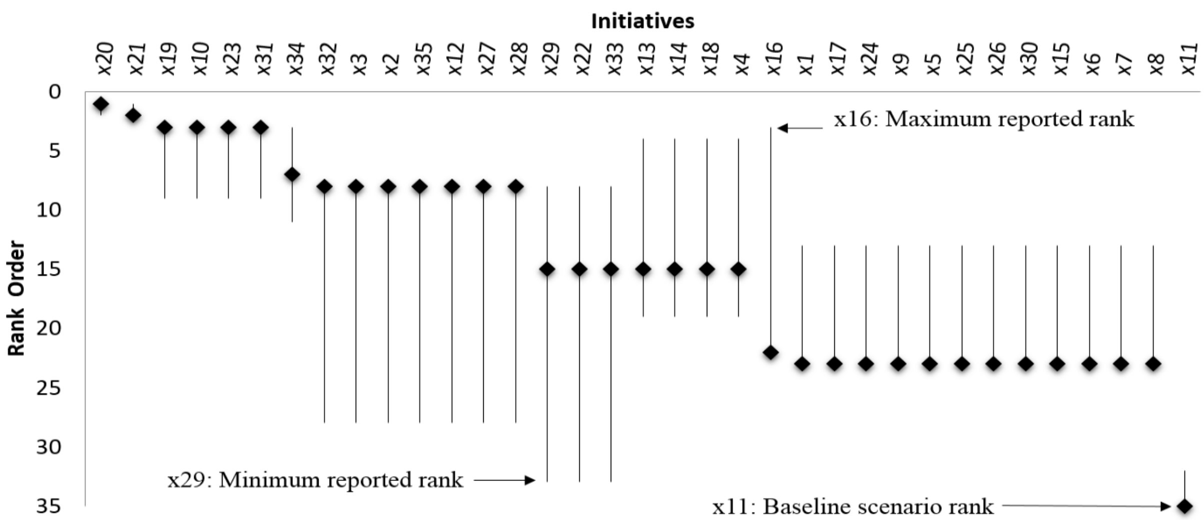


Figure 10. Initiative priorities for the group ℓ_0, *PEV owners* across the influences of all scenarios (diamond represents the baseline scenario; vertical bar represents influence of other scenarios)

Table 16. Disruptiveness of scenarios for the group $\ell_{0,}$ *PEV owners*, using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.95	4
s_2	0.77	2
s_3	0.79	3
s_4	0.25	1

Table 17. Smart grid initiative priorities for the group l_V, *Vehicle manufacturers*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}
s_0	17	17	10	17	17	17	34	17	32	33	10	17	17	17	17	17	17
s_1	21	21	12	21	21	21	18	21	17	11	12	21	21	21	21	21	21
s_2	17	17	10	17	17	17	34	17	32	33	10	17	17	17	17	17	17
s_3	19	19	11	19	19	19	34	19	18	16	11	19	19	19	19	19	19
s_4	18	18	10	18	18	18	34	18	17	33	12	18	18	18	18	18	18

	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
s_0	4	3	6	5	10	9	15	10	10	15	17	6	34	17	17	1	1	6
s_1	6	3	8	6	12	4	5	12	12	20	21	8	18	21	21	1	1	8
s_2	5	3	6	4	10	9	16	10	10	15	17	6	34	17	17	1	1	6
s_3	4	3	7	5	11	6	10	11	11	16	19	7	34	19	19	1	1	7
s_4	4	3	7	5	12	6	11	12	12	16	18	7	34	18	18	1	1	7

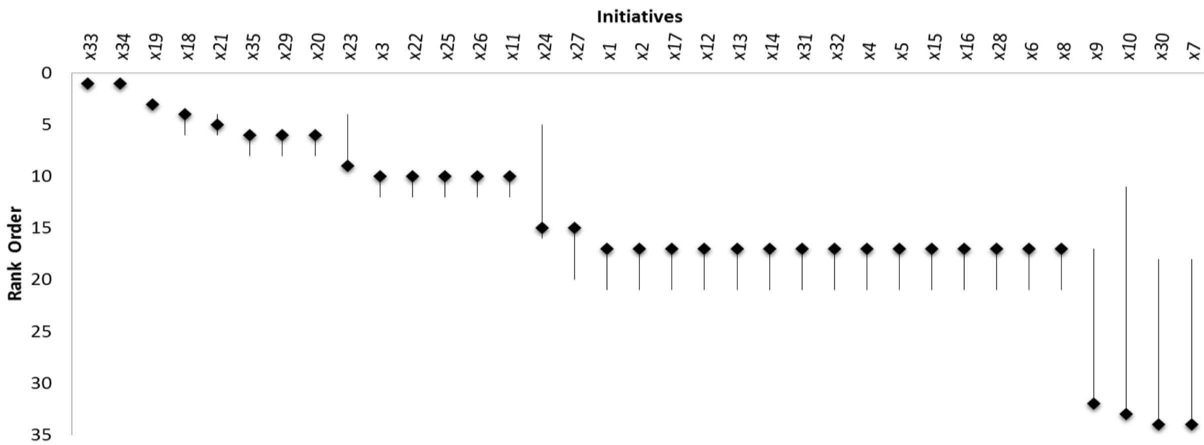


Figure 11. Initiative priorities for the group $\ell_{V,}$ *Vehicle manufacturers* across the influences of all scenarios

Table 18. Disruptiveness of scenarios for the group $\ell_{V,}$ *Vehicle manufacturers*, using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.77	1
s_2	0.99	4
s_3	0.91	2
s_4	0.96	3

Table 19. Smart grid initiative priorities for the group $\ell_{P,}$ *Public agencies*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	
s_0	11	12	3	24	16	16	28	28	28	5	24	8	5	1	24	28	28	
s_1	12	15	5	13	19	19	28	28	28	3	13	9	3	1	27	28	28	
s_2	7	13	5	34	27	27	18	18	18	11	34	2	11	8	9	18	18	
s_3	10	12	3	34	19	19	26	26	26	7	34	5	7	2	16	26	26	
s_4	12	15	5	13	19	19	28	28	28	3	13	9	3	1	27	28	28	
	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
s_0	8	2	28	12	12	12	16	16	16	3	8	16	28	27	28	5	16	16
s_1	9	2	28	15	15	15	19	19	19	5	8	25	28	26	28	7	11	19
s_2	2	1	18	13	13	13	27	27	27	5	26	4	18	17	18	10	27	27
s_3	5	1	26	12	12	12	19	19	19	3	17	11	26	18	26	7	19	19
s_4	9	2	28	15	15	15	19	19	19	5	8	25	28	26	28	7	11	19

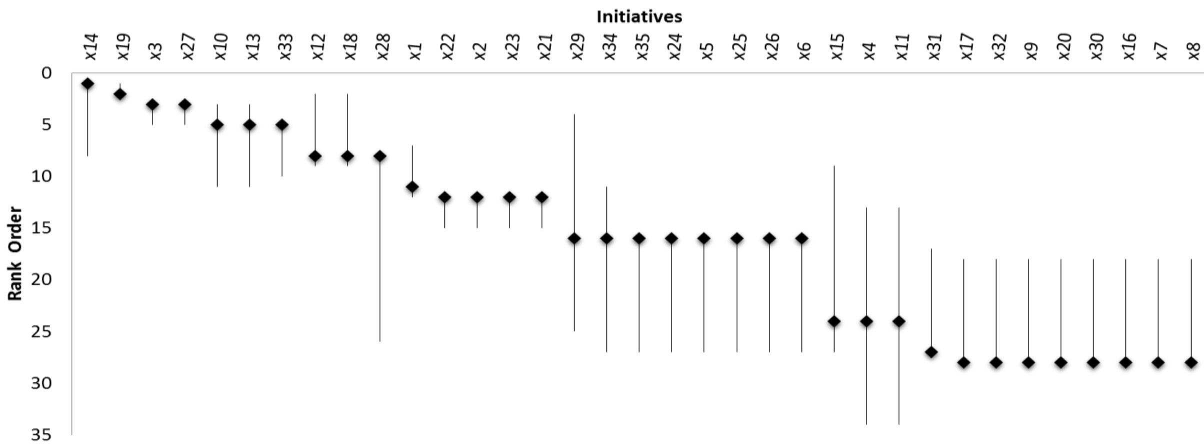


Figure 12. Initiative priorities for the group $\ell_{P,}$ *Public agencies* across the influences of all scenarios

Table 20. Disruptiveness of scenarios for the group ℓ_P, *Public agencies*, using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.93	3
s_2	0.59	1
s_3	0.91	2
s_4	0.93	3

Table 21. **Smart grid initiative priorities for the group ℓ_G,** ***Grid operators***

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}
s_0	18	29	3	18	7	18	29	29	18	18	18	16	7	5	3	5	7
s_1	25	32	4	18	5	18	29	29	18	18	18	16	10	8	3	8	10
s_2	18	32	4	18	7	18	28	28	18	18	18	16	7	5	3	5	7
s_3	25	32	4	18	5	18	29	29	18	18	18	16	10	8	3	8	10
s_4	17	31	5	24	13	24	20	20	24	24	24	23	6	3	12	3	6

	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
s_0	7	16	33	18	33	33	18	12	12	1	12	12	18	2	29	18	18	7
s_1	5	17	33	25	33	33	25	12	12	1	12	12	18	2	29	25	18	5
s_2	7	16	33	31	33	33	18	12	12	1	12	12	18	2	28	18	18	7
s_3	5	17	33	25	33	33	25	12	12	1	12	12	18	2	29	25	18	5
s_4	13	16	33	32	33	33	17	8	8	1	8	8	24	2	20	17	24	13

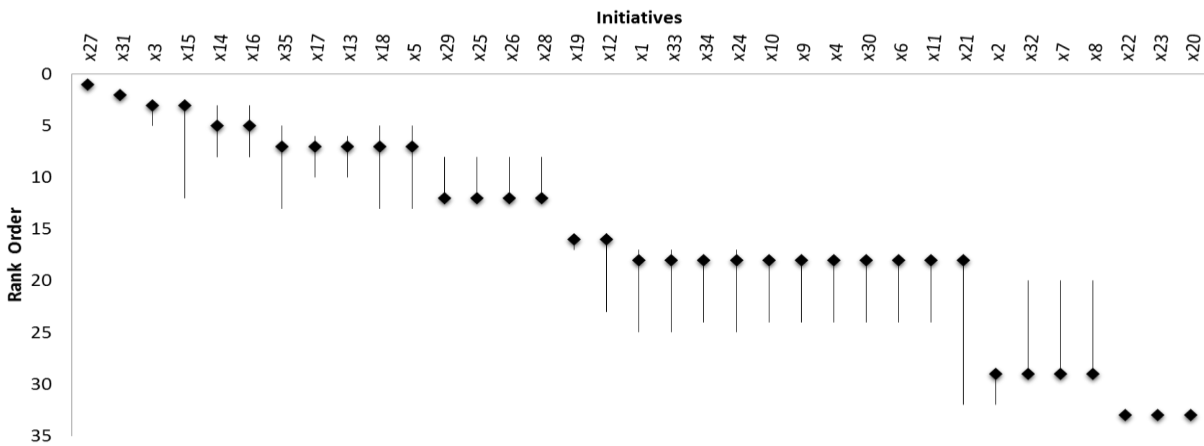


Figure 13. Initiative priorities for the group ℓ_G, *Grid operators* across the influences of all scenarios

Table 22. Disruptiveness of scenarios for the group $\ell_{G,}$ *Grid operators*, using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.96	2
s_2	0.97	3
s_3	0.96	2
s_4	0.85	1

5.3.6 Enterprise resilience for groups of stakeholders *L*

The groups of stakeholders have different levels of power and interest in different scenarios—in fact, their levels of power and interest change across scenarios. Intuitively, for instance the level of power and interest of the group $\ell_{V,}$ *Vehicle manufacturers*, should increase in the *Private support* scenario, because they would receive private subsidies and gain profit from growth in the electric vehicle financing markets. In sum, groups have different levels of impact on each other, and these levels of impact change across scenarios.

The *Multi-Lab EV Smart Grid Integration Requirements Study* (2015), the *Pathways to Decarbonization: Natural Gas and Renewable Energy* report (2015), and the *Mobilizing Public Markets to Finance Renewable Energy Projects: Insights from Expert Stakeholders* report (2012) set forth various aspects of energy mobility, including needs, interests, and strategies. To determine the levels of power and interest for each of the four groups across the scenarios, the present framework used a published power–interest matrix (Muttoni 2015), which shows the levels of power and interest for each group, together with information in the reports above and information from regular group meetings with a local energy mobility company (Fermata Energy LLC), as shown in Table 23. Equation 5 in Chapter 3 is used to determine the participation level of each group $\ell_z \in L$. For example, the group $\ell_{\mathrm{V},}$ *Vehicle manufacturers*, have the highest participation level ($\lambda_A^0 = 0.38$) in the baseline scenario, while the group $\ell_{\mathrm{O},}$ *PEV owners*, have the lowest participation level ($\lambda_W^0 = 0.11$) in that scenario. Thus, the group $\ell_{\mathrm{V},}$ *Vehicle manufacturers*, has the highest influence to priorities in the baseline scenario.

Table 23. Power–interest analysis to evaluate the participation levels of the four groups of stakeholders across all the scenarios

	s_0			s_1			s_2			s_3			s_4		
	$P^0_{\ell_z}$	$I^0_{\ell_z}$	$\lambda^0_{\ell_z}$	$P^1_{\ell_z}$	$I^1_{\ell_z}$	$\lambda^1_{\ell_z}$	$P^2_{\ell_z}$	$I^2_{\ell_z}$	$\lambda^2_{\ell_z}$	$P^3_{\ell_z}$	$I^3_{\ell_z}$	$\lambda^3_{\ell_z}$	$P^4_{\ell_z}$	$I^4_{\ell_z}$	$\lambda^4_{\ell_z}$
ℓ_P Public agencies	4	4	**0.18**	5	5	**0.19**	4	5	**0.15**	5	5	**0.17**	4	5	**0.13**
ℓ_G Grid operators	6	5	**0.33**	6	6	**0.28**	6	5	**0.22**	6	6	**0.25**	7	7	**0.32**
ℓ_V Vehicle manufacturers	5	7	**0.38**	7	8	**0.43**	8	8	**0.47**	8	8	**0.44**	8	9	**0.46**
ℓ_O PEV owners	2	5	**0.11**	2	6	**0.09**	3	7	**0.16**	3	7	**0.14**	2	7	**0.09**

The influences of the two modes of disruptions (multiple groups of stakeholders and scenarios) is determined using Equation 6 in Chapter 3. Figure 14 shows the rank scores and the level of robustness for each initiative $x_i \in S_x$ across the influences of scenarios and groups of stakeholders. For instance, initiative x_{34}, *Perform a study for analyzing the battery time-of-use rate*, has the highest rank among the initiatives, meaning that developing a study which shows how the time-of-use rate can impact the feasibility of the demand charge management technology is of interest to multiple groups of stakeholders. Initiative x_{19}, *Expand the distribution scale size of the PEV penetration model to explore various PEV operation levels*, is a high-priority and robust initiative because it is ranked third in the baseline scenario and the range of its rankings (vertical bar) is short. Thus, investigating various levels of PEV penetration is highly recommended when deploying the demand charge management technology since it has less sensitivity to disruptive scenarios and is important to almost all stakeholder groups.

Table 24 shows the level of disruptiveness of the four scenarios and groups to priorities using the Spearman rank correlation coefficient. After incorporating the influence of multiple groups, scenario s_1, *Public support*, is the most disruptive scenario, since it has the lowest Spearman rank correlation coefficient, meaning it is less correlated to the baseline scenario—that is, the *Public support* scenario causes more disruption to the rankings of the initiatives that matter to multiple groups of stakeholders.

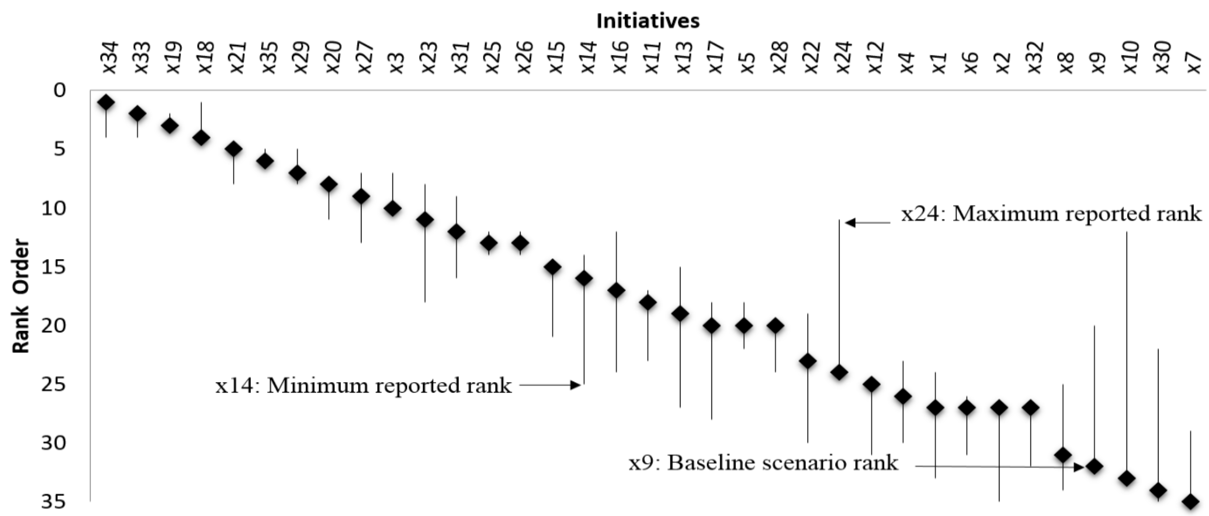


Figure 14. Priorities for smart grid initiatives with the influences of scenarios and of multiple groups of stakeholders

Table 24. Disruptiveness of scenarios with multiple groups of stakeholders using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.79	1
s_2	0.96	4
s_3	0.93	2
s_4	0.95	3

5.4 Discussion

This newly developed framework for enterprise resilience has been shown to be able to quantify the influences both of scenarios and of multiple groups of stakeholders to priorities. Expert elicitation for the demand charge management concept was used to prioritize smart grid initiatives and to estimate the participation levels of each group of stakeholders across all the scenarios. In this elicitation process, information was used that derived from interviewing experts from a local energy mobility company (Fermata Energy LLC) during decision workshops and other information from energy mobility sources (Markel et al. 2015; Muttoni 2015; Pless et al. 2015; Schwabe et al. 2012). The analysis of a single group of stakeholders (Figure 10 and Table 16) and the analysis of the multiple groups of stakeholders (Figure 14 and Table 24) show that there are significant variations in the level of disruptiveness of each scenario and in the prioritization of initiatives. These variations indicate that the interests, strategies, and goals of each group of stakeholders have significant effects on the analysis, and because of this, the level of disruptiveness for each of the scenarios varies across the four groups. It was this fact which motivated the author of the present study to investigate the influence of multiple groups of stakeholders on priorities across the scenarios.

It should be noted that in this approach there are no thresholds for the robustness of an initiative or the disruptiveness of a scenario. The general rule is that the robustness of an initiative is defined by its having the same or similar priority rank across scenarios. A disruptive scenario is one that changes the rank order of an initiative from high to low or low to high—something that is measured numerically using the Spearman rank correlation coefficient

Table 25. Disruptiveness of scenarios to priorities *for each group of stakeholders* $\ell_z \in L$ and for *multiple groups of stakeholders* L using the Spearman Rank Correlation Coefficient with corresponding ranking (in parentheses)

	$\phi(s_1)$	$\phi(s_2)$	$\phi(s_3)$	$\phi(s_4)$	A*	B*	C*	D*	E*	F*	G*	H*
ℓ_P : Public agencies	0.93 (7)	0.59 (2)	0.91 (6)	0.93 (7)	x_{14}, x_{19}	$x_7, x_8, x_9, x_{16}, x_{17}, x_{20}, x_{30}, x_{32}$	x_{19}	x_4, x_{11}, x_{29}	x_{19}	x_{14}	s_2	s_1, s_4
ℓ_G : Grid operators	0.96 (9)	0.97 (10)	0.96 (9)	0.85 (5)	x_{27}	x_{20}, x_{22}, x_{23}	$x_{20}, x_{22}, x_{23}, x_{27}, x_{31}$	x_{21}	x_{27}	x_{15}	s_4	s_2
ℓ_V : Vehicle manufacturers	0.77 (3)	0.99 (11)	0.91 (6)	0.96 (9)	x_{33}, x_{34}	x_7, x_{30}	x_{19}, x_{33}, x_{34}	x_{10}	x_{33}	x_{23}	s_1	s_2
ℓ_O : PEV owners	0.95 (8)	0.77 (3)	0.79 (4)	0.25 (1)	x_{20}	x_{11}	x_{20}	x_{22}, x_{29}, x_{33}	x_{20}	x_{19}	s_4	s_1
Multiple Groups of stakeholders	0.79 (4)	0.96 (9)	0.93 (7)	0.95 (8)	x_{34}	x_7	x_{25}, x_{26}	x_{10}	x_{19}	x_{23}	s_1	s_2

A = Highest Prioritized Initiative, B = Lowest Prioritized Initiative, C = Most Robust Initiative, D = Least Robust Initiative, E = Most Robust & Highly Prioritized, F = Least Robust & Highly Prioritized, G = Most Disruptive Scenario, and H = Least Disruptive Scenario

Table 25 provides the main findings when considering only the influence of *scenarios to priorities* and also when considering *both* the influences of *scenarios* and of *multiple groups of stakeholders to priorities*. It shows the highest prioritized initiatives and the lowest prioritized initiatives for each group and for multiple groups of stakeholders. For instance, for the group $\ell_{P,}$ *Public agencies*, initiative x_{14}, *Identify strategies to enhance energy performance*, is the highest prioritized initiative in the baseline scenario s_0, whereas x_{34}, *Perform a study analyzing the battery time-of-use rate,* is the highest prioritized initiative when considering the influence of the multiple groups of stakeholders. In addition, Table 25 shows the most robust initiatives and the least robust initiatives across all the scenarios for each group and for all the groups.

The first four columns in Table 25 indicate the level of disruptiveness of each scenario to the priorities of each group and to the multiple groups of stakeholders. The overall rank orders of Spearman rank correlation coefficients for all the groups are shown in parentheses (smaller rank indicates higher disruptiveness). For instance, *Private support*, s_2, is considered to be the most disruptive scenario for the group ℓ_P, *Public agencies*, and the least disruptive scenario for the group ℓ_V, *Vehicle manufacturers*. Despite being highly disruptive to the group ℓ_P, *Public agencies*, scenario s_2 is considered the least disruptive scenario after incorporating the influence of the multiple groups of stakeholders, since the participation level of the group ℓ_V,*Vehicle manufacturers*, is greater than the participation level for the public agencies (see Table 23), λ_A^2 = 0.47, λ_P^2 = 0.15, respectively. Thus, the risk analyst can avoid spending time and effort to study the impact of this scenario since the other scenarios have more impact on the priorities of groups of stakeholders that have higher participation levels.

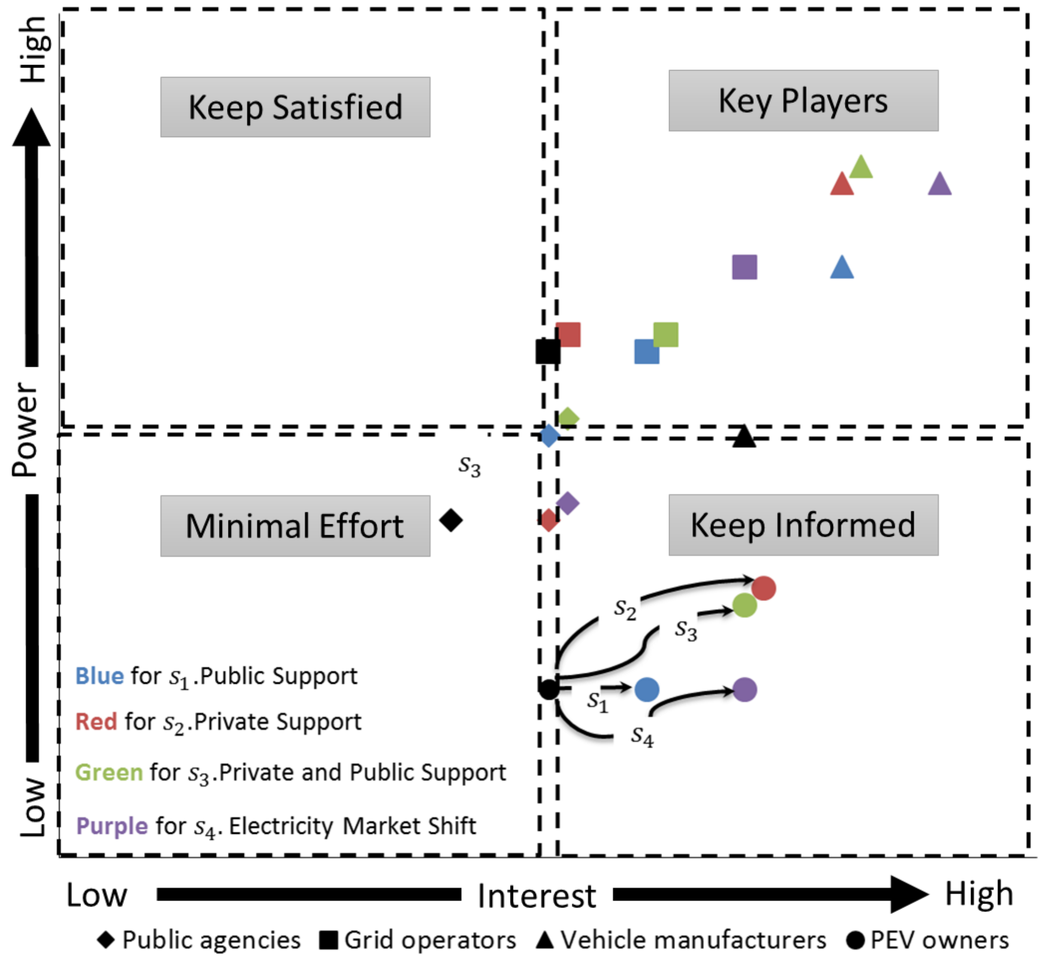


Figure 15. Stakeholder mapping for three groups of stakeholders across all the scenarios for a smart energy mobility network; shapes represent groups of stakeholders and colors represent scenarios

The role of each group is unlikely to be constant across all the scenarios, as shown in Figure 15. In other words, a group of stakeholders located in the *Minimal effort* quadrant (low power and low interest) at the baseline scenario s_0 might be located in another quadrant, such as the *Keep satisfied*, *Key players*, or *Keep informed* quadrant in scenario $s_k \in S_s$. For example, the group ℓ_P, *Public agencies*, is in the *Minimal effort* quadrant at the baseline scenario s_0 , but in scenario s_3, *Private and public support*, this group is in the *Key players* quadrant. Thus, the risk analyst should plan to satisfy the needs of this group since the *Key players* group has a direct impact on smart grid initiatives as a result of their high participation level (i.e., high levels of power–interest). The group $\ell_{O,}$ *PEV owners*, is in the *Minimal effort* quadrant at the baseline scenario s_0 and in the *Keep informed* quadrant across all the other scenarios. Figure 15 shows the changes in the roles of the other groups of stakeholders across all the scenarios.

Table 26 gives a summary of the key results that includes the most disruptive scenarios and the most and least robust initiatives for each group of stakeholders and for the multiple groups of stakeholders.

Table 26. Key demonstration results for the influences of scenarios and of multiple stakeholders on enterprise resilience for a smart energy mobility network

Groups of Stakeholders	Key results
ℓ_P : Public agencies	• Most robust and highly prioritized initiative: x_{19}, *Expand the distribution scale size of the PEV penetration model to explore various PEV operation levels* • Least robust and highly prioritized initiative: x_{14}, *Identify strategies to enhance energy performance* • Most disruptive scenario: s_2, *Private support* • Least disruptive scenario: s_1, *Public support*, and s_4, *Electricity market shifts*
ℓ_G : Grid operators	• Most robust and highly prioritized initiative: x_{27}, *Develop risk analysis procedures to test the system components* • Least robust and highly prioritized initiative: x_{15}, *Identification of charging management levels for mitigating transformer problems* • Most disruptive scenario: s_4, *Electricity market shifts* • Least disruptive scenario: s_2, *Private support*
ℓ_V : Vehicle manufacturers	• Most robust and highly prioritized initiative: x_{33}, *Collaborate with OEMs* • Least robust and highly prioritized initiative: x_{23}, *Collaboration for creating interoperability standards* • Most disruptive scenario: s_1, *Public support* • Least disruptive scenario: s_2, *Private support*

Groups of Stakeholders	Key results
ℓ_O : PEV owners	• Most robust and highly prioritized initiative: x_{20}, *Provide energy standards for different organizations and PEV owners* • Least robust and highly prioritized initiative: x_{19}, *Expand the distribution scale size of the PEV penetration model to explore various PEV operation levels* • Most disruptive scenario: s_4, *Electricity market shifts* • Least disruptive scenario: s_1, *Public support*
Multiple groups of stakeholders	• Most robust and highly prioritized initiative: x_{19}, *Expand the distribution scale size of the PEV penetration model to explore various PEV operation levels* • Least robust and highly prioritized initiative: x_{23}, *Collaboration for creating interoperability standards* • Most disruptive scenario: s_1, *Public support* • Least disruptive scenario: s_2, *Private support*

5.5 Conclusion

This chapter has introduced a framework for quantifying the influences of *scenarios* and of *multiple groups* of stakeholders on priorities. The demonstration has included 35 smart grid initiatives, four groups of stakeholders, four associated criteria sets, and 15 emergent and future conditions. The four scenarios were defined as combinations of emergent and future conditions published by the International Energy Agency (2013) and the U.S. Energy Information Administration (2015). The analysis showed that performing further improvement strategies for public infrastructure are essential for the deployment of the demand charge management technology, since the *Public support* scenario, s_1, was the most disruptive scenario after incorporating the influences of the two modes of disruption. Initiative x_{19}, *Expand the distribution scale size of the PEV penetration model to explore various PEVs operation levels*, is a high ranked and robust initiative across the influences of the two modes of disruption, which suggests that grid operators should consider spending more resources to investigate various PEV penetration methods.

CHAPTER 6: DEMONSTRATION: RESILIENCE OF LARGE-SCALE MARITIME CONTAINER PORT DEVELOPMENT PROJECTS

6.1 Overview

Port infrastructures and port operations are highly impacted by disruptive scenarios that stem from several different types of causes, including adverse weather events, economic crises, traffic congestion, and spikes in demand, among others. This chapter demonstrates the resilience analytics framework, which was described in Chapter 3, in order to address the influences of scenarios and of groups of stakeholders to priorities. Section 6.2 provides an introduction to port strategic planning, reviews the relevant literature on seaport strategic planning, and describes the purpose and scope of this study. Section 6.3 describes the elements and the results of the demonstration. Section 6.4 discusses the key findings from the demonstration.

6.2 Introduction

6.2.1 Motivating

Port sustainability has been defined as "business strategies and activities that meet the current and future needs of the enterprise and its stakeholders, while protecting and sustaining human and natural resources" (AAPA 2007, 25). Dooms and Macharis (2003) note that using multidisciplinary strategic planning approaches comprising multiple factors—including technological, economic, social, and political factors—helps in addressing the complexity and the uncertainty of the many challenges that face port authorities. Several economic, social, and environmental factors directly affect port sustainability. Although the social factors of the sustainability of systems are an important research topic, scholars have not yet investigated in detail the social responsibility and ethical behavior of stakeholders and how these factors impact port sustainability (Denktas-Sakar and Karatas-Cetin 2012). Based on a survey published by the European Sea Ports Organization, only 17% of stakeholders and local communities are involved in port development plans (Brooke 2002). If the participation of a particular stakeholder is delayed or neglected, the desired outcomes of these development plans could be disrupted.

Allen (2012) observes that future opportunities and challenges which might affect the operational and financial status of an organization—including the vision, mission, and principles of each organization—should be included in port strategic planning. The author notes that early stakeholder involvement helps to address concerns and needs that are crucial to the port business process. As a result of the increase in port sophistication, port strategic planning is a recent research topic that assesses the risks and the opportunities that port authorities may face during their development plans (Dooms and Macharis 2003). The port authorities may play two roles: either that of a "comprehensive port," where the port authority performs almost all the services inside the port, or that of a “landlord port,” where the port authority is only responsible for planning and private companies operate the other activities (Goss 1990).

Depending on the enterprise and business process time horizon, port strategic planning can include three types of planning: short-term, medium-term, and long-term planning (Coeck, Haezendonck, and Notteboom 1999). In order to satisfy the needs of port sustainability and development, it is essential to involve more stakeholders and to address multiple perspectives (Dooms and Macharis 2003). A variety of external and internal stakeholders who have diverse interests and objectives participate in port systems (Henesey, Notteboom, and Davidsson 2003). Conflicts and disagreements among stakeholders often arise in projects that involve multiple stakeholders who share diverse objectives and interests. These contexts are described as coordination failures defined as a lack of consensus related with the tradeoffs and opportunities associated to the use of a certain propriety (Palma-Oliveira et al. 2017). De Langen (2006) describes major port conflicts of interests that can be predicted as including environmental protection, urban development, labor conditions, residents’ interests, and overall economics. One of the greatest engineering management challenges today is solving and managing stakeholder conflicts.

6.2.2 Background

A stakeholder is “an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project” (Freeman 1984, 5). A port stakeholder is “any individual or group having interest or being affected by the port” (Henesey, Notteboom, and Davidsson 2003, 3). Rose (2013) observes that stakeholders may or may not support the development of seaport, depending on their various objectives, interests, and expectations and highlights the importance of stakeholder management as a technique for managing, understanding, and solving conflicts that might arise from the diverse needs and objectives of the stakeholders. Complex systems cannot be analyzed by assessing needs from a single perspective (Barker et al. 2017; Cairns, Goodwin, and Wright 2016; Haimes 2015, 2012; Rogerson and Lambert 2012). Methods based on negotiation and argumentation verified to be sufficient in minimizing the complexity of issues that involve multiple stakeholders (Marashi and Davis 2006).

Mansouri, Sauser, and Boardman (2009) note that studying the resilience of maritime container port to the influence of future disruptive events is essential, since ports transfer goods between many national and international locations, and a disruption of operations may cause serious financial losses. They describe four kinds of disruptive events—natural, organizational, technological, and those involving other human factors. Haimes (2009, 498) defines system *resilience* as "the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risks." Berle, Asbjørnslett, and Rice (2011) study the resilience of the maritime supply system to resist the influence of disruptive events and to maintain normal operations. Gharehgozli et al. (2017) have developed a port resilience framework that depends on the collaboration of stakeholders to mitigate the impacts of disruptive events. The authors conclude that the availability of resources and stakeholder management are essential for successful resilience strategies. To improve port resilience, it is important for the risk analyst to understand how the multiple stakeholders interact with each other (Shaw, Grainger, and Achuthan 2017).

Researchers have addressed the concept of system resilience across a wide range of application domains. Recent system resilience approaches have addressed the influence of scenarios to priorities for systems that involve high uncertainties, multiple stakeholders, and multiple objectives in several fields. Such applications include the prioritization of enterprise initiatives in the energy mobility domain (**Almutairi** et al. 2017), energy security domain (Thorisson et al. 2017; Hamilton et al. 2012; Karvetski, Lambert, and Linkov 2011; Martinez, Lambert, and Karvetski 2011), the biofuel industry domain (Collier et al. 2017a; Collier et al. 2016; Connelly et al. 2015), the climate change domain (Hamilton, Lambert, and Valverde 2015; You et al. 2014; Lambert et al. 2012), the infrastructure systems domain (Lambert et al. 2011), and the risk and safety organization domain (Teng, Thekdi, and Lambert 2012). These approaches define priorities as the improvement or development characteristics of a variety of systems and organizations. A priority set can be a set of assets, policies, projects, entities, and so on. These resilience analytics approaches focus on the influence of scenarios to priorities but fail to address the influence of multiple groups of stakeholders to priorities in various development projects, especially when those groups have conflicting interests, strategies, and objectives. In port operation and development programs, a wide range of conflicting economic, environmental, social, national, local, and regional interests arise (Hiranandani 2014; Grigalunas, Luo, and Chang 2001). Port resilience depends on environmental, economic, social, and political factors, among others (Gharehgozli et al. 2017). Incorporating the influence of multiple groups of stakeholders to priorities into the available resilience analytics approaches makes a contribution to the risk analysis field by addressing several kinds of challenges (e.g., environmental, economic, and social challenges) that matter most to all or part of the stakeholder groups in various application domains.

6.2.3 Purpose and Scope

This chapter demonstrates an enterprise resilience analytics framework that addresses the influences of scenarios and of multiple groups of stakeholders to priorities. The framework integrates and extends two existing published approaches: (1) *participant mapping* (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981), and (2) *scenario-based preferences in risk analysis* (**Almutairi** et al. 2017; Collier et al. 2017a; Thorisson et al. 2017; Collier et al. 2016; Hamilton et al. 2016; Connelly et al. 2015; Lambert et al. 2011).

6.3 Demonstration of Methods

6.3.1 Problem Statement

Container ports are facing challenging operational and financial problems, leading them to search for innovative methods to support infrastructure, maximize land use, and reduce operational risk through the diversification of cargo types. The Port of Virginia has published a port strategic plan that covers large-scale development projects with the aim of expanding the capacity of the container area, enhancing levels of services and operations, improving the resilience of container ports to the influence of disruptions, and improving the sustainability of its operations (Port of Virginia 2015). To address potential conflicting stakeholder needs, stakeholder management is required for these large-scale projects (Mok, Shen, and Yang 2015). Several disruptions will be included in the following case study, including those that are environmental, economic, social, and political. These possible disruptions have significant impacts on the development projects. The need for resilience analytics approaches to maritime infrastructure systems has been discussed in recent studies (Mansouri, Nilchiani, and Mostashari 2009). The following Port of Virginia case study will apply the enterprise resilience analytics framework to address the influences of scenarios and of groups of stakeholders to port operational and development priorities.

Chapter 3 discussed the technical aspects of the framework. In this framework, a group of stakeholders is defined as any group of individuals who have similar viewpoints when considering a specific topic. Figure 6 in Chapter 3 summarizes the technical components of this framework.

6.3.2 Identification of Groups of Stakeholders with the Corresponding Evaluation Criteria

The initial step is to initiate a decision conferencing that involves the groups of stakeholders who might affect or be affected by the operational and development projects. The facilitated discussion mode discussed in further detail in Chapter 3 is used in this case study. The facilitator invites and guides the groups during the decision workshops. Several perspectives should be discussed in these, including environmental, economic, social, and political perspectives. Taking multiple perspectives into consideration ensures that the multiple objectives, interests, and needs of the groups are covered.

A stakeholder classification approach clusters stakeholders of a port based on their interests and their influences to port services, policies, projects, and programs (De Langen 2006). Such stakeholders include transport firms, port workers, local industries, end users, environmental groups, local residents, local and regional governments, and the national government. The present case study uses an approach for clustering stakeholders in three homogenous groups based on the objectives and concerns that they share, as described by Nguyen and Notteboom (2016) . The first group is the terminal users group—shipping companies, logistics companies, service provider companies, transport companies, and freight forwarders—who have homogenous interests which center on logistics concerns. The second group is the terminal service providers group—investors, operators, and the port authority—whose interests center on port development strategies and the financial feasibility of port operations. The third group is the community group—local residents, local government, road users, and business vendors—who share similar interests, such as job creation opportunities, regional economic impact, and regional environmental impact.

Selecting evaluation criteria that accurately reflect stakeholder values is critical for this analysis. Belton and Stewart (2002) emphasize that good criteria are non-redundant (avoid double counting) and reflective of stakeholder values. In complex decision environments, stakeholders may find it difficult to separate criteria from strongly held positions on specific initiatives. Thus, it may be beneficial to use a skilled facilitator to elicit criteria from a stakeholder group. Several studies have sought to define the criteria set for each group of stakeholders (Nguyen and Notteboom 2016; Yang and Chen 2016; Bentaleb, Mabrouki, and Semma 2015; Gallego-Ayala and Juízo 2014; Louis and Magpili 2007; Peris-Mora et al. 2005). Table 27 shows each group with its associated set of criteria. The purpose of defining a criteria set for each group is that they are important for prioritizing the priority setting for each group when there are potential conflicting interests between them (Thorisson et al. 2017).

Table 27. Groups of stakeholders with the corresponding evaluation criteria sets

Groups of Stakeholders	**Criteria Set**
ℓ_U : *Terminal users group*	c_{U1}: Transportation time and cost c_{U2}: Accessibility of road, railway, and waterway infrastructures c_{U3}: Range of services
ℓ_S : *Terminal service providers group*	c_{S1}: Safety and security c_{S2}: Market expansion c_{S3}: Operational cost
ℓ_C : *Community group*	c_{C1}: Pollution impact (air, water, and noise) c_{C2}: Job creation c_{C3}: Road congestion c_{C4}: Regional economic development

6.3.3 Identification of Enterprise Initiatives

The set of initiatives is defined to address the needs, requirements, and objectives of the three groups. A total of 29 development and port expansion initiatives, as described in a consulting engineering report (Moffatt & Nichol 2016), are shown in Table 28. Various development and operational projects for five marine terminals (Norfolk International Terminals (NIT), Virginia International Gateway (VIG), Portsmouth Marine Terminal (PMT), Newport News Marine Terminal (NNMT), and Richmond Marine Terminal (RMT)) and one inland terminal (Virginia Inland Port (VIP)) are included in the set of initiatives. The list covers a variety of perspectives, including security, economic, environmental, marketing, and communication perspectives. The growth in cargo demand necessitates such port development projects (Moffatt & Nichol 2016). The interests of each of the three groups differ for each of the initiatives based on the needs and objectives of each group. Interests of groups may or may not overlap. For example, the three groups of stakeholders may have overlapping interests in x_1, *NIT north container yard expansion*, since services will be accelerated (an interest of the terminal users group), more profits generated (an interest of the terminal providers group), and more jobs created (an interest of the community group).

Table 28. Port development and expansion initiatives published in a consulting engineering report (Moffatt & Nichol 2016)

Initiative	Description
x_1	NIT north container yard expansion
x_2	NIT central rail yard construction
x_3	NIT channel depth extension to 50 ft
x_4	NIT acquisition of attached rail yard
x_5	NIT upgrading the main gate
x_6	NIT upgrading rail portals
x_7	NIT upgrading south straddle carriers to automated cranes
x_8	NIT increasing the number of north terminal gates
x_9	NIT demolition of old warehouses
x_{10}	NIT infrastructure and equipment maintenance
x_{11}	NIT maintenance dredging
x_{12}	NIT increasing the number of ship-to-shore cranes
x_{13}	VIG container yard expansion
x_{14}	VIG intermodal yard expansion
x_{15}	VIG gate expansion
x_{16}	VIG container wharf expansion
x_{17}	VIG infrastructure and equipment maintenance
x_{18}	Constructing the CIMT marine terminal
x_{19}	PMT wharf repair

Initiative	Description
x_{20}	PMT infrastructure and equipment maintenance
x_{21}	PMT maintenance dredging
x_{22}	NNIT maintenance dredging
x_{23}	NNIT maintenance of warehouses
x_{24}	NNIT crane repairs
x_{25}	VIP upgrading intermodal yard
x_{26}	RMT improvements to gates
x_{27}	RMT maintenance dredging
x_{28}	RMT facility renovation (e.g., pavement replacement, rail improvement, structure repairs, etc.)
x_{29}	All terminals: other improvements and maintenance projects (e.g., communication systems, security systems, data collections, data analysis, etc.)

6.3.4 Identification of Emergent Conditions and Scenarios

The next step is to identify a list of emergent and future conditions that can affect the enterprise initiatives. Table 29 gives a list of 81 emergent and future conditions and four scenarios that are published in a port strategic scenario-based preference model (Collier et al. 2017b). These conditions were identified after reviewing trends and factors that could disrupt the operation of ports and conditions that represent a threat or an opening for a disruption that might affect the port system. A variety of sources of threats and opportunities that might impact the port system—such as finance, marketing, social issues, transportation, technology—are included on the list. For example, ec_3, *Midtown tunnel construction delayed*, is a threat that might affect the number of trucks that serve the port system, and as a result, the overall port throughputs could be impacted.

Table 29. Port development and expansion initiatives published in a consulting engineering report (Moffatt & Nichol 2016)

Emergent Condition	Description
ec_{01}	Other countries leave EU following "Brexit"
ec_{02}	Shipping line goes out of business
ec_{03}	Midtown tunnel construction delayed
ec_{04}	Average Virginia resident's per capita income falls
ec_{05}	Growth in Virginia's healthcare industry
ec_{06}	Federal government strengthens/centralizes
ec_{07}	Federal government weakens/decentralizes
ec_{08}	Procurement of military goods increases
ec_{09}	Manufacturing continues to shift to southern states
ec_{10}	Rapid GDP growth
ec_{11}	Stagnant GDP growth
ec_{12}	Federal Reserve raises interest rates
ec_{13}	Cargo diverted from West Coast ports
ec_{14}	Slow transition to larger vessels at Port
ec_{15}	Asian market share increases due to Panama Canal
ec_{16}	Nicaraguan Canal opens
ec_{17}	Imports from India via Suez Canal increase
ec_{18}	Demand for US manufactured goods increases
ec_{19}	Greater utilization of Heartland Corridor
ec_{20}	Greater utilization of National Gateway
ec_{21}	Financial crisis similar to 2008/2009
ec_{22}	I-664 is widened
ec_{23}	Continued development of distribution centers
ec_{24}	High inflation/consumer price index
ec_{25}	Shipping lines form alliances
ec_{26}	Security expenses rise
ec_{27}	Stevedoring expenses rise
ec_{28}	Monthly container storage revenue falls
ec_{29}	Fixed/variable operating expenses rise
ec_{30}	Container volume shifts to VIG
ec_{31}	Container volume at NIT handled by RMGs
ec_{32}	Maintenance expenses rise
ec_{33}	SG&A expenses rise

Emergent Condition	Description
ec_{34}	Population growth in urban areas
ec_{35}	Manufacturers and distribution attracted to rural areas
ec_{36}	Diminished capacity of rail service
ec_{37}	Diminished capacity of highway network
ec_{38}	Diminished capacity of intermodal barge service
ec_{39}	Service disruption and congestion at other ports
ec_{40}	Competing ports ready for post-Panamax ships
ec_{41}	More large ships diverted to Virginia
ec_{42}	Channel deepening and widening delayed
ec_{43}	Vessel size constraints relaxed
ec_{44}	Traffic congestion and checkpoints on major roadways
ec_{45}	Grants awarded to improve key Virginia roadways
ec_{46}	More double-stack trains
ec_{47}	Hurricane Sandy-like disruption
ec_{48}	Long term sea level rise
ec_{49}	Increased and more severe flooding
ec_{50}	Sequestration-related spending cuts
ec_{51}	Trade growth with India and Asia
ec_{52}	Strong US Dollar
ec_{53}	Weak US Dollar
ec_{54}	Slowed import demand
ec_{55}	Exports grow faster than imports
ec_{56}	Trans-Pacific Partnership enacted
ec_{57}	Housing market weakens
ec_{58}	Base case demand
ec_{59}	Low overall demand
ec_{60}	High overall demand
ec_{61}	Costs increase for inland rail transport
ec_{62}	Higher demand for rail container transport
ec_{63}	Non-containerized cargo demand growth
ec_{64}	Ro/Ro demand growth
ec_{65}	Dry grain bulk cargo demand growth
ec_{66}	Incentive programs to attract new business to VA
ec_{67}	Neighboring ports capture larger market share
ec_{68}	Lack of federal funding contributions
ec_{69}	Lack of state funding contributions
ec_{70}	Ship lines press for lower rates
ec_{71}	Labor unions press for higher wages

Emergent Condition	**Description**
ec_{72}	Disruptive changes in container handling technology
ec_{73}	Disruptive changes in underlying information networks
ec_{74}	Driverless car technology
ec_{75}	3D printing technology
ec_{76}	Additional environmental mitigation/project modifications
ec_{77}	Disruptions from technology transitions
ec_{78}	Natural disasters
ec_{79}	Customer expectations higher
ec_{80}	Supply chain disruptions
ec_{81}	Armed conflicts

Table 30 shows four scenarios that one or more emergent or future conditions create. The first scenario s_1, *Traffic Congestion*, which captures the impact of the surrounding transportation networks on the port throughputs. The time and the cost of travel are increased as a result of traffic congestion. This bad performance decreases the reliability of shipment delivery time (Moffatt & Nichol 2016). The second scenario is s_2, *Economic Slowdown*, which captures the impact of regional and global economic crisis on the port throughputs. A decrease in the number of shipment transactions would be expected under the influence of this scenario. The third scenario is s_3, *High Operation Cost*, which captures the impact of increases in the costs for material, fuel, maintenance, labor, shipping, and so forth on the port throughputs. The fourth scenario is s_4, *Environmental Mitigation*, which captures how environmental mitigation projects can improve the port systems by lowering air, water, and noise pollution and by increasing the system's resilience to the impact of natural disasters.

Table 30. Scenarios comprising emergent and future conditions

Scenario		Emergent and Future Conditions
s_1. Traffic Congestion	ec_{03}	Midtown tunnel construction delayed
	ec_{44}	Traffic congestion and checkpoints on major roadways
	ec_{47}	Hurricane Sandy-like disruption
s_2. Economic Slowdown	ec_{01}	Other countries leave EU following "Brexit"
	ec_{04}	Average Virginia resident's per capita income falls
	ec_{21}	Financial crisis similar to 2008–2009
	ec_{54}	Slowed import demand
	ec_{59}	Low overall demand
s_3. High Operation Cost	ec_{26}	Security expenses rise
	ec_{27}	Stevedoring expenses rise
	ec_{28}	Monthly container storage revenue falls
	ec_{29}	Fixed/variable operating expenses rise
	ec_{32}	Maintenance expenses rise
s_4. Environmental Mitigation	ec_{74}	Driverless car technology
	ec_{76}	Additional environmental mitigation/project modifications

6.3.5 Enterprise resilience for each group of stakeholders $\boldsymbol{\ell_z} \in \boldsymbol{L}$

This section evaluates the influence of scenarios to the priorities of each group of stakeholders. A detailed analysis for ℓ_S , *Terminal service providers group*, is shown in this section, and the key findings for the other two groups are given at the end of this section.

The importance criteria weights for the ℓ_S ,*Terminal service providers group*, in the baseline scenario s_0 were weighted by interviewing Port of Virginia representatives during decision workshops. It was founded that c_{S2} , *Market expansion*, and c_{S3}, *Operational cost*, were the most important criteria and had the same weight, while c_{S1}, *Safety and security*, has the less relative important weight. Assessment of the impact of initiatives on the criteria of the ℓ_S ,*Terminal service providers group*, in the baseline scenario s_0 is shown in Table 31. Table 32 describes the quantitative scores for the assessment shown in Table 32.

Table 31. Assessment of criteria in the baseline scenario s_0 for ℓ_S ,*Terminal service providers group*; ● indicates that an initiative strongly addresses the criterion, ◗ that an initiative addresses the criterion, ○ that an initiative somewhat addresses the criterion, and a no symbol cell that an initiative does not address the criterion

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
c_{W1}					●	◗	○	○	○	◗					○
c_{W2}	◗	○	○	○							◗	○	○	◗	
c_{W3}							◗			◗		○			

	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}
c_{W1}	○	◗		●	◗			○	◗		●		◗	●
c_{W2}			●			◗	◗			○		◗		○
c_{W3}		◗	○		◗				○				○	●

Table 32. Numerical Scores for the criteria assessment shown in Table 31

Qualitative Assessment	Symbol	Quantitative Value
Does not address	[no symbol]	0
Somewhat addresses	○	0.33
Moderately addresses	◗	0.67
Strongly addresses	●	1

The criteria relative importance weight at the baseline scenario s_0 could change across scenarios, and thus the relative importance weight for criterion c_j in scenario $s_k \in S_s$ is $w_j^k = \alpha_j^k w_j^0$. The factor multiplier α_j^k, adopted from Saaty (2008), is used to change the relative importance weight for criterion c_j under scenario s_k, with α_j^k equal to 9 for a *major increase*, to 3 for a *minor increase*, to 1 for *no change*, to 1/3 for a *minor decrease*, and to 1/9 for a *major decrease*. Matrix W gives the relative importance weight for ℓ_S ,*Terminal service providers group*, across all the scenarios; the first column shows the relative importance weight for each criterion in the baseline scenario, and the other columns shows the relative importance weights for each criterion under scenarios s_1, s_2, s_3, and s_4, respectively.

$$W = \begin{bmatrix} 11\% & 36\% & 2\% & 2\% & 28\% \\ 44\% & 16\% & 74\% & 88\% & 36\% \\ 44\% & 48\% & 24\% & 10\% & 36\% \end{bmatrix}$$

Table 33 shows the overall ranking scores for all the initiatives across all the scenarios. Each row gives the ranking score for each initiative in each scenario, and each column gives the ranking score for each initiative across the scenarios. For instance, in the baseline scenario x_{29}, *All terminals: Other improvements and maintenance projects,* has the highest ranking score, and the 9th ranking score in s_3, *High Operation Cost*. In the baseline scenario, x_8, x_9, x_{15}, x_{16}, and x_{23} have the lowest ranking scores, indicating that the ℓ_S , *Terminal service providers group*, care less about those initiatives in the baseline scenario s_0.

Table 33. Port planning initiative ranking scores for ℓ_S ,*Terminal service providers group*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
s_0	8	17	3	17	21	24	7	25	25	4	8	8	17	8	25
s_1	20	26	14	26	8	12	5	15	15	2	20	13	26	20	15
s_2	4	11	2	11	21	24	18	25	25	15	4	10	11	4	25
s_3	3	11	2	11	21	24	18	25	25	15	3	10	11	3	25
s_4	13	21	6	21	10	20	7	25	25	3	13	13	21	13	25

	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}
s_0	25	4	2	21	4	8	8	25	15	17	21	8	15	1
s_1	15	2	11	8	2	20	20	15	6	26	8	20	6	1
s_2	25	15	1	21	15	4	4	25	19	11	21	4	19	3
s_3	25	15	1	21	15	3	3	25	19	11	21	3	19	9
s_4	25	3	2	10	3	13	13	25	8	21	10	13	8	1

Figure 16 provides a visualization of the initiatives' ranking assessment shown in Table 33. The robustness of an initiative to disruptions is a measure of how large the difference is between the maximum ranking score and the minimum ranking score for each initiative across scenarios. The diamond represents the initiatives' ranking scores in the baseline scenario, and the vertical bar represents the ranking scores of each initiative across all the scenarios. The most robust initiative is x_{12}, *NIT increasing the number of ship-to-shore cranes*, since its ranking scores have the smallest changes across the influences of all scenarios: $v(x_{12}) \in [8,13]$, whereas x_1, x_{11}, x_{14}, x_{21}, x_{22}, and x_{27} are the least robust initiatives, since their ranking scores have the largest changes across the influences of all scenarios: $v(x_1) = v(x_{11}) = v(x_{14}) = v(x_{21}) = v(x_{22}) = v(x_{27}) \in [3,20]$.

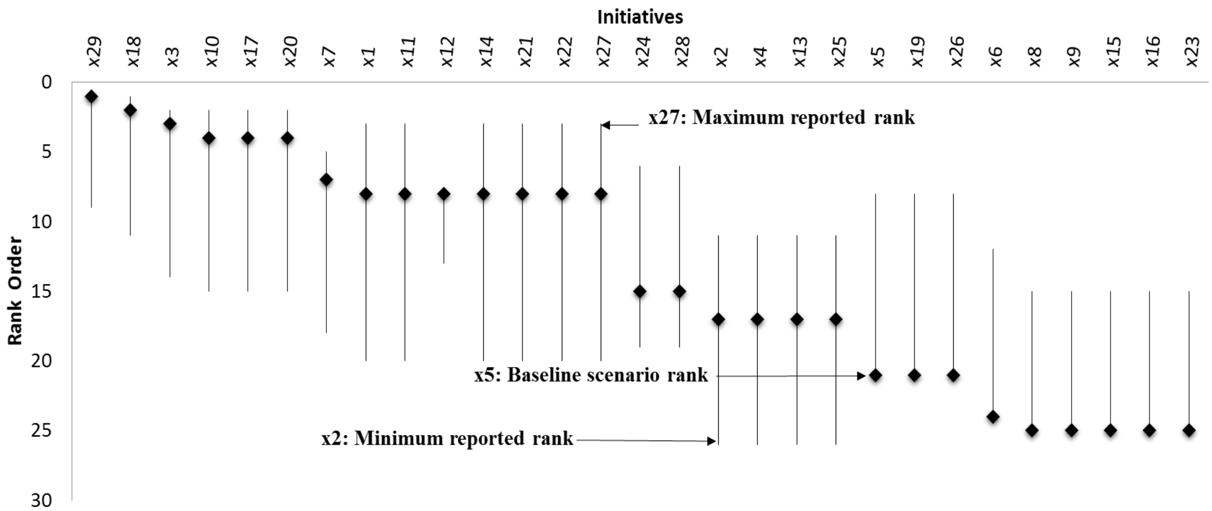


Figure 16. Initiative priorities for ℓ_S, *Terminal service providers group* across all the scenarios (a diamond represents the ranking score of each initiative in the baseline scenario; a vertical bar represents the ranking scores of each initiative across all the scenarios)

The level of disruptiveness for each of the four scenarios is measured by Spearman rank correlation coefficient. The correlation coefficient values for each of the scenarios with the corresponding disruptiveness ranking orders are shown in Table 34. The most disruptive scenario is s_1, *Traffic Congestion*, since it is least correlated to the baseline scenario, indicating that this scenario significantly changes most of the baseline initiatives' priority ranks. The least disruptive scenarios are s_2, *Economic Slowdown*, and s_4, *Environmental Mitigation*, since they have the highest correlation coefficient values, indicating that those two scenarios are highly correlated to the baseline scenario. In other words, those two scenarios only change the baseline initiatives' priorities ranks slightly.

This analysis has been replicated for the other two groups (ℓ_U, *Terminal users group*, and ℓ_C , *Community group*), and the results are given below in Tables 35, 36, 37, and 38 and Figures 17 and 18.

Table 34. Disruptiveness of scenarios for ℓ_S , *Terminal service providers group*, using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.32	1
s_2	0.82	3
s_3	0.78	2
s_4	0.82	3

Table 35. Container port enterprise initiative ranking scores for ℓ_U *Terminal users group*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
s_0	16	2	11	5	8	14	23	11	28	23	19	16	16	5	8
s_1	16	2	10	4	7	12	24	10	23	24	19	16	16	4	7
s_2	16	2	11	4	7	14	23	11	28	23	19	16	16	4	7
s_3	25	9	14	11	16	19	4	14	28	4	21	25	25	11	16
s_4	21	3	12	6	9	14	16	12	28	16	24	21	21	6	9
	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	
s_0	2	23	1	14	23	19	19	29	23	5	8	19	11	2	
s_1	2	24	1	12	24	19	19	29	24	4	7	19	15	14	
s_2	2	23	1	14	23	19	19	29	23	4	7	19	11	10	
s_3	9	4	2	19	4	21	21	29	4	11	16	21	3	1	
s_4	3	16	2	14	16	24	24	29	16	6	9	24	3	1	

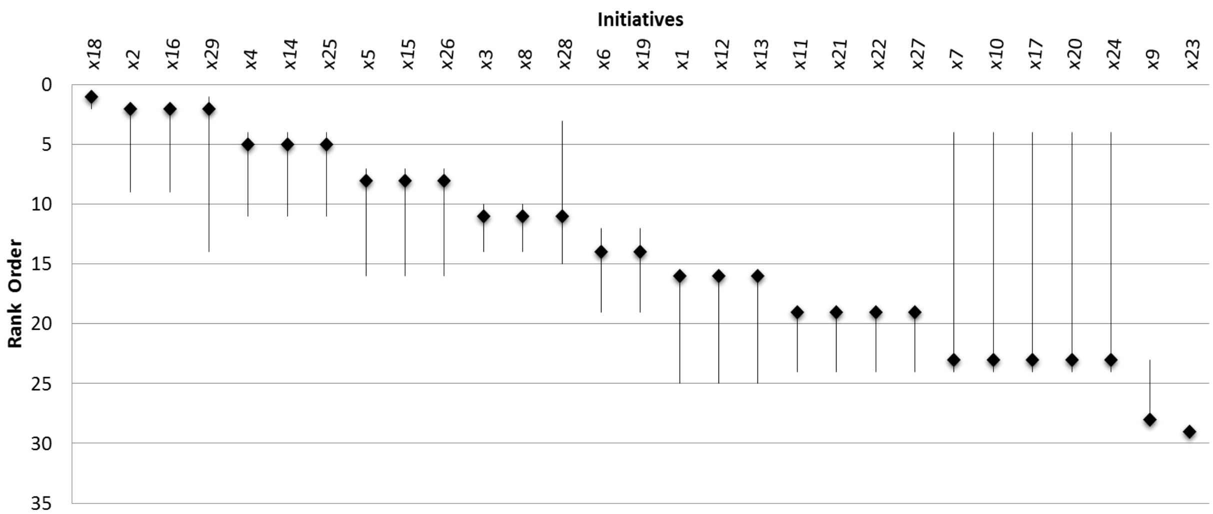


Figure 17. Initiative priorities for ℓ_U *Terminal users group* across all the scenarios

Table 36. Disruptiveness of scenarios for ℓ_U *Terminal users group* using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.95	3
s_2	0.98	4
s_3	0.36	1
s_4	0.87	2

Table 37. Container port enterprise initiative ranking scores for ℓ_C *Community group*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
s_0	7	3	1	3	12	7	21	21	28	21	12	21	7	7	12
s_1	10	7	5	7	2	10	18	6	28	18	24	18	10	10	2
s_2	7	3	1	3	16	7	21	21	28	21	12	21	7	7	16
s_3	7	3	1	3	16	7	21	21	28	21	12	21	7	7	16
s_4	19	16	7	16	2	19	9	9	28	9	24	9	19	19	2

	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}
s_0	12	21	2	12	21	12	12	28	21	7	12	12	3	6
s_1	15	18	4	15	18	24	24	28	18	10	15	24	7	1
s_2	16	21	2	16	21	12	12	28	21	7	16	12	3	6
s_3	16	21	2	16	21	12	12	28	21	7	16	12	3	6
s_4	2	9	8	2	9	24	24	28	9	19	2	24	16	1

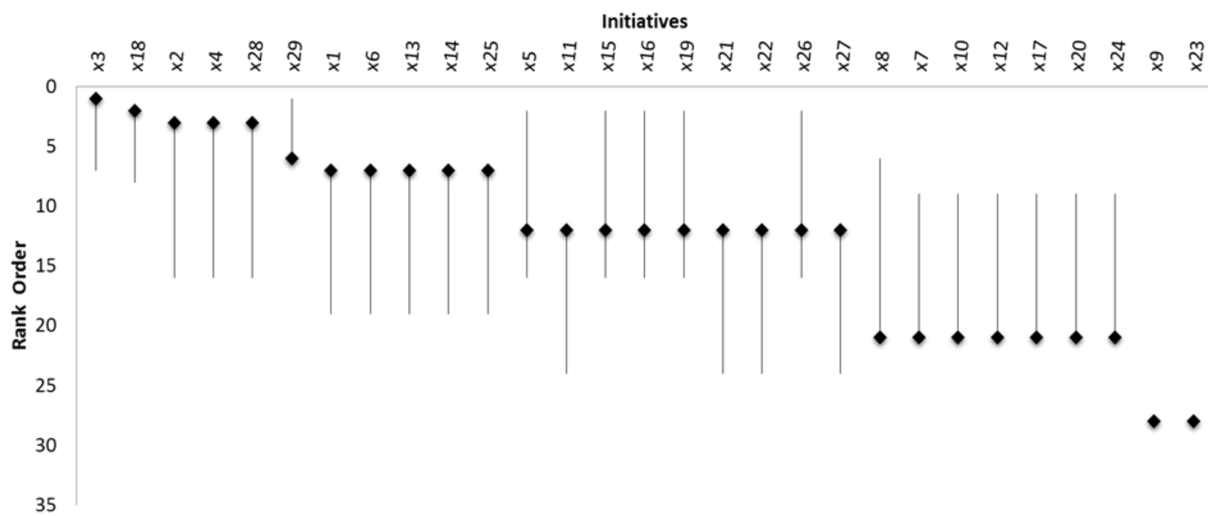


Figure 18. Initiative priorities for ℓ_C *Community group* across all the scenarios

Table 38. Disruptiveness of scenarios for ℓ_C *Community group* using the Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.69	2
s_2	0.98	3
s_3	0.98	3
s_4	0.16	1

6.3.6 Enterprise resilience for multiple groups of stakeholders *L*

The influences both of scenarios and of multiple groups of stakeholders to priorities will be determined in this section. The three groups of stakeholders—the terminal service providers, the terminal users, and the community groups—have varied participation levels across the influences of scenarios—that is, their levels of power and interest change across the influences of scenarios. De Langen (2006) described port clusters that include a variety of stakeholders who have various levels of interest and influence in the port, and noted that these levels of power and interest change over time. For the present study, several port stakeholder mapping approaches (Mok, Shen, and Yang 2015; Nijdam and Romochkina 2012; Pomeroy and Douvere 2008; De Langen 2006) were reviewed and combined with information gathered from monthly decision workshops with Port of Virginia representatives in order to determine the expected levels of power and interest for each of the three groups. The levels of power and interest and the participation level for each group across all the scenarios are shown in Table 39. For example, the ℓ_U, *Terminal users group*, has the highest level of participation ($\lambda_U^0 = 0.54$) at the baseline scenario, and the ℓ_C , *Community group*, has the lowest level of participation ($\lambda_C^0 = 0.13$) at the baseline scenario. The ℓ_S, *Terminal service providers group*, has the highest level of participation under the influence of s_3, *High Operation Cost*. Thus, this group has the highest influence to the port development and expansion initiatives when the port operational costs increase since they have high levels of interest in and power over the financial feasibility of the initiatives and of port operations.

These expected (not absolute) values of the levels of power and interest are based on information collected from published studies and from group meetings with Port of Virginia representatives as described above. Hence, the goal of this case study is to demonstrate the advantages of using the resilience analytics framework in evaluating the influences of scenarios and groups of stakeholders, rather than to validate the accuracy of these expected values.

The next step is to determine the influences of the two modes of disruptions: scenarios and multiple groups of stakeholders. Equation 6 in Chapter 3 is used to evaluate the influences of these disruptions to priorities of the multiple groups of stakeholders. Figure 19 gives the ranking scores of the initiatives across the influences of scenarios and groups. It shows that, in the baseline scenario, x_{18} , *Constructing the CIMT marine terminal*, has the highest ranking score and x_{23} , *NNIT maintenance of warehouses*, has the lowest ranking score. The initiatives most robust to the influences of scenarios and groups are x_9 , *NIT demolition of old warehouses*, and x_{23} , *NNIT maintenance of warehouses*, since their ranking scores are the same across all the scenarios, as shown in Figure 19, but those two initiatives are not important to most stakeholders, as they have the lowest ranking scores across the scenarios. Initiative x_{18} , *Constructing the CIMT marine terminal*, is a high ranked and robust initiative, meaning that constructing the CIMT marine terminal is an important initiative to most of the groups based on their levels of participation across scenarios and is less affected by the influences of the disruptive scenarios. It should be noted that the results of this analysis differ from the results of the analysis in the previous section (section 6.3.5), since these results matter relatively to most of the groups, based on their levels of participation across scenarios.

Table 39. Power–interest analysis for the three groups of stakeholders across all the scenarios

	s_0			s_1			s_2			s_3			s_4		
	$P_{\ell_z}^0$	$I_{\ell_z}^0$	$\lambda_{\ell_z}^0$	$P_{\ell_z}^1$	$I_{\ell_z}^1$	$\lambda_{\ell_z}^1$	$P_{\ell_z}^2$	$I_{\ell_z}^2$	$\lambda_{\ell_z}^2$	$P_{\ell_z}^3$	$I_{\ell_z}^3$	$\lambda_{\ell_z}^3$	$P_{\ell_z}^4$	$I_{\ell_z}^4$	$\lambda_{\ell_z}^4$
ℓ_U *Terminal users group*	7	7	0.54	7	7	0.45	5	5	0.50	6	5	0.28	8	5	0.40
ℓ_S *Terminal service providers group*	5	6	0.33	7	6	0.39	4	4	0.32	8	8	0.60	7	4	0.28
ℓ_C *Community group*	3	4	0.13	3	6	0.17	3	3	0.18	3	4	0.11	4	8	0.32

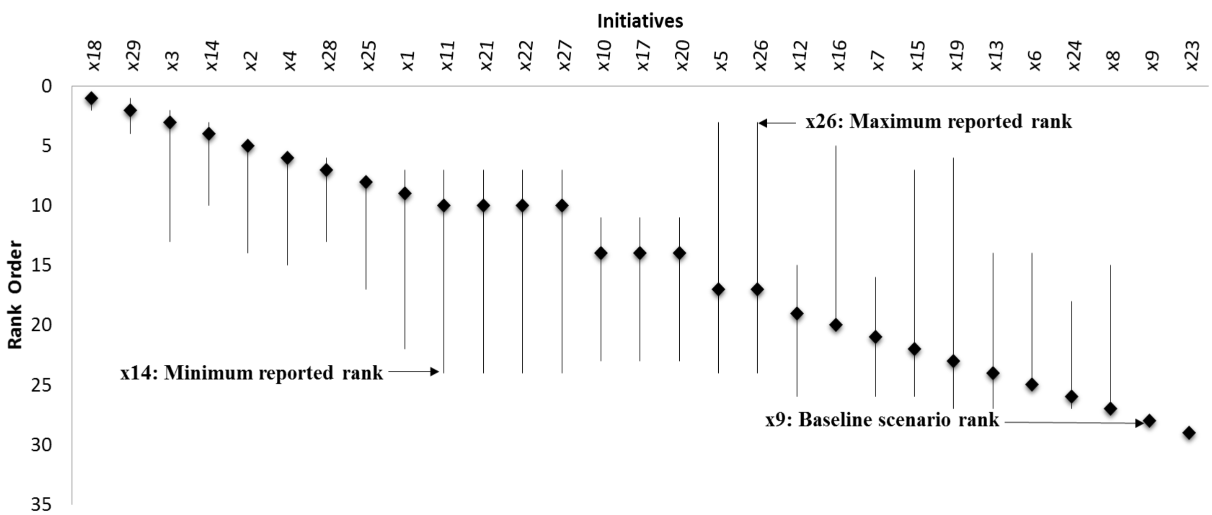


Figure 19. Priorities for the container port initiatives with the influences of scenarios and of multiple groups of stakeholders

The level of disruptiveness for each scenario after incorporating the influence of multiple groups of stakeholders into the analysis is measured by the Spearman rank correlation coefficient and shown in Table 40. The most disruptive scenario is s_1, *Traffic Congestion*, followed by s_4, *Environmental Mitigation*, since they are less correlated to the baseline scenario, meaning that those two scenarios cause major disruptions to the priority setting of the initiatives that matter most to multiple groups of stakeholders.

Table 40. Disruptiveness of scenarios with multiple groups of stakeholders measured by Spearman rank correlation coefficient

Scenario	Spearman Rank Correlation Coefficient $\phi(s_k)$	Disruptiveness Ranking
s_1	0.38	1
s_2	0.87	3
s_3	0.91	4
s_4	0.46	2

6.4 Discussion

The dynamic role of stakeholder participation across scenarios has a significant impact on the modeling outcomes. As the case study shows, a group with a low participation level (i.e., low levels of power and interest) in the baseline scenario might have a high participation level in other scenarios. For example, ℓ_S , *Terminal service providers group*, has a low participation level in the baseline scenario ($\lambda_S^0 = 0.33$), but the same group has the highest level of participation in scenario s_3, *High Operation Cost* ($\lambda_S^3 = 0.6$). Thus, a management strategy ought to address the needs and concerns (e.g., implement or take action on high ranked initiatives, take action to mitigate the influences of disruptive scenarios, etc.) of groups when their level of participation is high. Table 41 shows the key results of the demonstration, taking into consideration the influence of scenarios to priorities for each group of stakeholders and the influences both of scenarios and of multiple groups of stakeholders to priorities. For each group and for multiple groups, the key results include the most and least disruptive scenarios; the most and least robust initiatives; and the most robust and highly prioritized initiatives and the least robust and highly prioritized initiatives; these and other results are shown in Table 41. The information in this table can be used as a guideline for how risk analysts can determine the expected disruptive scenarios, and the most and the least robust initiatives to the disruptiveness of scenarios for each group of stakeholders and for all the groups. Table 41 also shows the overall ranking order of the level of disruptiveness of all the scenarios using the Spearman rank correlation coefficient for each group and for all the groups (lower rank indicates higher disruptiveness).

Table 41. Disruptiveness of scenarios to priorities for *each group of stakeholders* $\ell_z \in L$ and for *all the groups* L using Spearman rank correlation coefficient with corresponding ranking (in parentheses)

	$\phi(s_1)$	$\phi(s_2)$	$\phi(s_3)$	$\phi(s_4)$	**A***	**B***	**C***	**D***	**E***	**F***	**G***	**H***
ℓ_U *Terminal users group*	0.95 (11)	0.98 (12)	0.36 (3)	0.87 (9)	x_{18}	x_{23}	x_{23}	$x_7, x_{10}, x_{17}, x_{20}, x_{24}$	x_{19}	x_{18}	s_3	s_2
ℓ_S *Terminal service providers group*	0.32 (2)	0.82 (8)	0.78 (7)	0.82 (8)	x_{29}	$x_8, x_9, x_{15}, x_{16}, x_{23}$	x_{12}	$x_1, x_{11}, x_{14}, x_{21}, x_{22}, x_{27}$	x_{12}	x_{29}	s_1	s_2, s_4
ℓ_C *Community group*	0.69 (6)	0.98 (12)	0.98 (12)	0.16 (1)	x_3	x_9, x_{23}	x_9, x_{23}	x_8	x_3	x_2, x_4, x_{28}	s_4	s_2, s_3
Multiple Groups of stakeholders	0.38 (4)	0.87 (9)	0.91 (10)	0.46 (5)	x_{18}	x_{23}	x_9, x_{23}	x_5, x_{19}, x_{26}	x_{18}	x_3	s_1	s_3

A = Highest Prioritized Initiative, B = Lowest Prioritized Initiative, C = Most Robust Initiative, D = Least Robust Initiative, E = Most Robust & Highly Prioritized, F = Least Robust & Highly Prioritized, G = Most Disruptive Scenario, and H = Least Disruptive Scenario

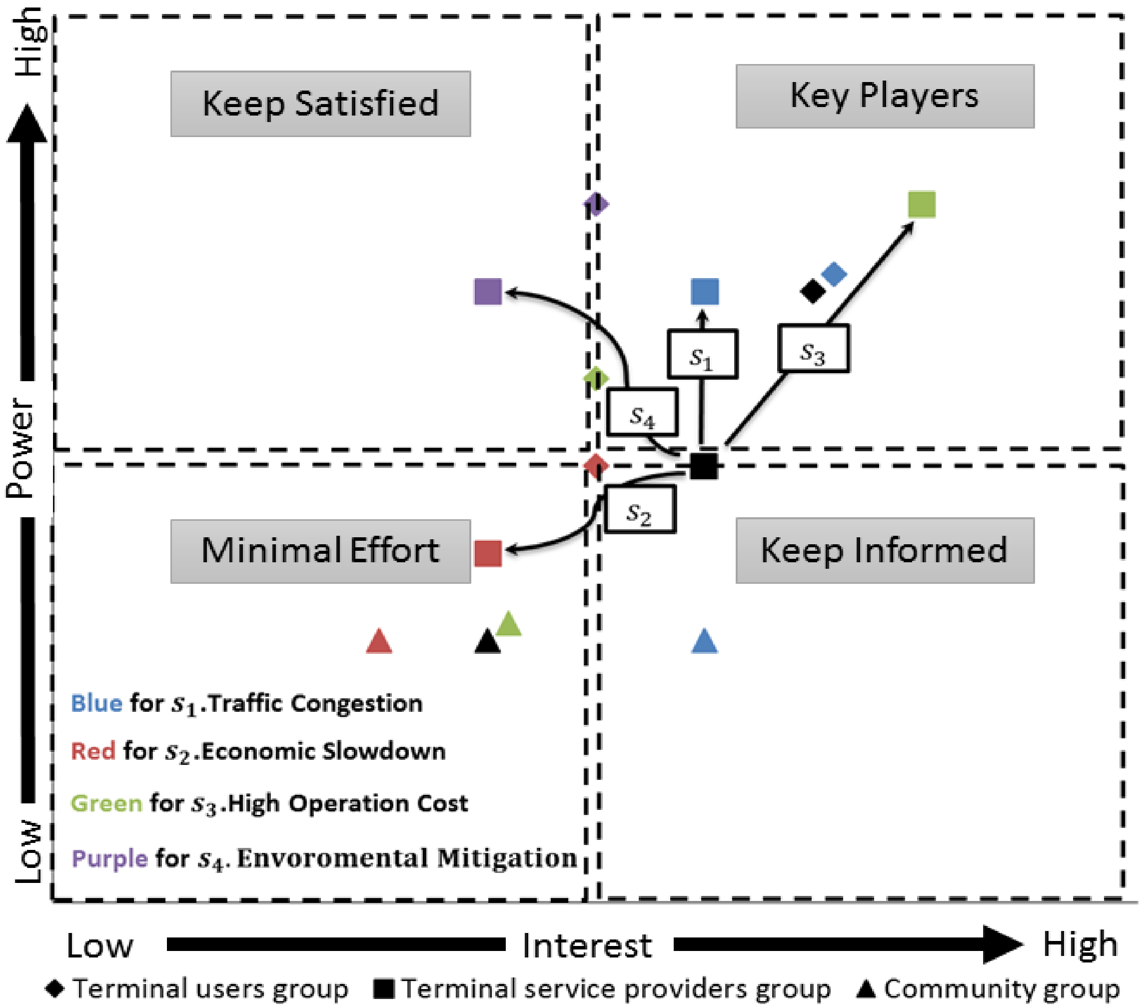


Figure 20. Stakeholder mapping for four groups of stakeholders across all the scenarios for maritime container ports projects; shapes represent groups of stakeholders and colors represent scenarios

Figure 20 gives a visualization of how the participation level of each group changes across the scenarios. For instance, ℓ_S, *Terminal service providers group*, is located in the *Keep Informed* quadrant since it has a high level of interest and a low level of power at the baseline scenario, but the same group is located in the *Key Players* quadrant under the influence of s_3, *High Operation Cost*. Updating the participation level of each group across the scenarios is crucial, since the groups with high levels of power and interest (i.e., *Key Players*) have direct and significant impacts on their surrounding environment. In contrast, ignoring the influences of groups (i.e., their participation level: levels of power and interest) postpones the desired outcomes. Investing efforts and resources to mitigate the influence of a scenario that is disruptive for a group with low levels of power and interest is not as advantageous as investing the same efforts to mitigate the influence of a scenario that is disruptive for a group with high levels of power and interest. Thus, taking into consideration and updating the level of participation of each group is a beneficial strategy for mitigating risks in an efficient way.

Table 42 gives a summary of the key results for demonstrating the resilience analytics framework in the Port of Virginia development and planning program to evaluate the influences of scenarios to priorities of each group and for all the groups. It shows the most robust and highly prioritized initiatives, the least robust and highly prioritized initiatives, the most disruptive scenarios, and least disruptive scenarios for each group and for all groups.

Table 42. Highlights of key results from the resilience analytics framework that addresses the influences of *scenarios* and of *multiple stakeholders* to the prioritization of seaport planning initiatives

Groups of Stakeholders	Key Results
ℓ_U *Terminal users group*	• Most robust and highly prioritized initiative: x_{19}, *PMT wharf repair* • Least robust and highly prioritized initiative: x_{18}, *Constructing the CIMT marine terminal* • Most disruptive scenario: s_3, *High Operation Cost* • Least disruptive scenario: s_2, *Economic Slowdown*
ℓ_S *Terminal service providers group*	• Most robust and highly prioritized initiative: x_{12}, *NIT increasing the number of ship-to-shore cranes* • Least robust and highly prioritized initiative: x_{29}, *All terminals: other improvements and maintenance projects* • Most disruptive scenario: s_1, *Traffic Congestion* • Least disruptive scenario: s_2, *Economic Slowdown*, s_4, *Environmental Mitigation*
ℓ_C *Community group*	• Most robust and highly prioritized initiative: x_3, *NIT channel depth extension to 50 ft* • Least robust and highly prioritized initiative: x_2, *NIT central rail yard construction*, x_4, *NIT acquisition of attached rail yard*, x_{28}, *RMT facility renovation (e.g., pavement replacement, rail improvement, structure repairs, etc.)*

Groups of Stakeholders	Key Results
	• Most disruptive scenario: s_4, *Environmental Mitigation* • Least disruptive scenario: s_2, *Economic Slowdown*, s_3, *High Operation Cost*
Multiple groups of stakeholders	• Most robust and highly prioritized initiative: x_{18}, *Constructing the CIMT marine terminal* • Least robust and highly prioritized initiative: x_3, *NIT channel depth extension to 50 ft* • Most disruptive scenario: s_1, *Traffic Congestion* • Least disruptive scenario: s_3, *High Operation Cost*

6.5 Conclusion

This chapter has presented a framework that addresses the influences of two modes of disruptions, the influences of *scenarios* and of *multiple groups of stakeholders*, to priorities. The framework integrates two existing approaches—a stakeholder analysis approach called *stakeholders mapping* (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981), and a risk analysis approach called *scenario-based preferences modeling* (Collier et al. 2017a; Thorisson et al. 2017; Collier et al. 2016; Hamilton et al. 2016; Connelly et al. 2015). The innovation of this framework is that it takes into consideration the influence of the participation levels of multiple groups of stakeholders across all the scenarios. The analysis showed that the most disruptive scenario is s_1, *Traffic Congestion*, followed by s_4, *Environmental Mitigation*. The high-ranked and most robust initiative is x_{18}, *Constructing the CIMT marine terminal*. Designing and building the CIMT marine terminal is an important initiative to most of the groups and is less affected by the influences of the disruptive scenarios. The analysis also showed the significant impact of the dynamic role of stakeholder participation on priorities.

CHAPTER 7: VALIDATION OF METHODS AND ISSUES AND LIMITATIONS

7.1 Overview

This chapter reviews rational decision-making validation methods, provides a detailed validation method for the enterprise resilience analytics framework developed and demonstrated in this dissertation, and discusses the issues and the limitations of the resilience analytics framework. Section 7.2 reviews the literature on validating rational decision models. Section 7.3 describes how the framework has been validated using five validation criteria developed by French and Insua (2000) for validating a decision process. Section 7.4 describes a supplementary simulation analysis that has been used to improve stakeholder engagement, the feasibility of the framework, and the validation analysis. Section 7.5 discusses issues and limitations of the discussed framework, including bias associated with stakeholder engagement, bias associated with the availability of scenarios, and bias associated with anchoring.

7.2 Validation Methods

There is an old and ongoing debate in the scholarly literature about the possibility of validating rational decision models that build on the preferences of human beings. Although a wide range of research deals with assessing the preferences of stakeholders, it is still difficult to find a complete validation procedure in this literature (Neslo and Cooke 2011). Systems that have limited resources, multiple constraints, and multiple stakeholders with conflicting objectives are often considered as complex systems. In risk analysis and decision making, rational decision models, such as multi-criteria decision analysis, are used to prioritize the preferences of multiple stakeholders while minimizing stakeholders' responsibilities for making difficult judgements (Belton and Stewart 2002). Qureshi, Harrison, and Wegener (1999) state that a system model can be seen as a scientific theory which needs to be validated to ensure that the model accurately represents the real system, and they have noted that multi-criteria models are difficult to be validate since there are many parameters and inputs which are based on the preferences of stakeholders.

A model has been defined as "a simplified version of a part of reality, not a one-to-one copy" (Qureshi, Harrison, and Wegener 1999, 105). Although modeling is useful for representing real systems, it is still difficult to make a simplified model that represents a comprehensive description of the real system. Schilling, Oeser, and Schaub (2007) describe three metrics for evaluating the effectiveness of decision models: process effectiveness, output effectiveness, and outcome effectiveness. *Process effectiveness* is a metric used for assessing the quality of the decision process, *output effectiveness* is a metric used for assessing the quality of model results, and *outcome effectiveness* is a metric used for assessing the significance of a model in the long term.

Using the outcome preferences metric for evaluating the quality of outcomes of the enterprise resilience analytic framework is inappropriate for two reasons. First, the metric is used for evaluating the quality of the outcomes of each scenario; however, it is impossible to predict all the scenarios. Thus, the outcomes that are used in this validation step may be biased by risk analysts' anchoring on the known scenarios and ignoring the possible impacts of unknown scenarios (Goodwin and Wright 2010). This is because a scenario could be an emergent condition or a combination of emergent conditions, and it is not practicable to assess the model outcomes for massive numbers of emergent condition combinations. Second, the framework has been developed for assessing the influences of scenarios and of multiple stakeholders on priorities in a long-term plan; it is impossible, however, to forecast the long-term outcomes of the framework since all the model parameters change over time, including the preferences of stakeholders, emergent conditions, initiatives, and so forth. There are other challenging questions that also make it impossible to use the outcome effectiveness metric to validate the presented resilience framework for a long-term plan, including, among many others, the following: Are all the possible outcomes known? How could all the outcomes be known in the absence of some scenarios? How could insufficient assessment through anchoring on the known scenarios affect the outcomes? Is there a threshold for better and worse outcomes, and if so, how does this threshold change across known and unknown scenarios?

The output effectiveness metric is used to capture the quality of the immediate output of the enterprise resilience analytic framework. This validation step can be accomplished by collecting feedback from the stakeholders through distributing satisfaction surveys (Finlay and Forghani 1998; Timmermans and Vlek 1996). Appendix A shows a sample of a survey that was distributed to groups of stakeholders and the groups' responses. The survey asked the groups about their satisfaction with the key findings of the analysis, since the effectiveness of the key findings depends heavily on the inputs and the engagement that stakeholders have contributed during the analysis.

You (2013) suggests that, despite a lack of research proof or reasoning about which evaluation metric to select for validating rational decisions, it is more effective and efficient to use the process evaluation metric to evaluate the quality of a decision model in representing a real-world problem. It has been recommended that rational decision models be validated based on an evaluation of the decision process (Dean and Sharfman 1993; Von Winterfeldt and Edwards 1986), since it is difficult to validate them by evaluating the decision outcomes. Thus, the enterprise resilience analytic framework will be validated using the process effectiveness metric and the output effectiveness metric.

7.3 Validation Implementation

The enterprise resilience analytic framework builds on the preferences of stakeholders. French and Insua (2000) developed five criteria for validating a decision process—axiomatic basis, feasibility, robustness, transparency, and compatibility with the decision context—and observed that a satisfactory model should meet those five criteria. An assessment has been performed to ensure that the resilience analytic framework meets those criteria, as shown below.

Axiomatic basis: In a rational decision model, courses of action should be selected in a such a way as to maximize the utility function (Goodwin and Wright 2010), and this can be attained if the stakeholders conform to the axioms, including the complete ordering axiom, the transitivity axiom, the continuity axiom, and others. In three case studies, the stakeholders conformed to the complete ordering axiom and the transitivity axiom. Validation of these axioms was carried out during monthly decision workshops with Mr. Daniel Hendrickson, the Director of Business

Intelligence at the Port of Virginia, for the container port development and expansion case study, and with Professor David L. Slutzky, the President and CEO of Fermata Energy, LLC, for the mobile smart grid case study.

Axiom 1: The complete ordering axiom

In order to satisfy this axiom, the stakeholders should be able to rank all the initiatives in order based on how well each initiative addresses each criterion. In Chapter 3, the complete ordering axiom was addressed by constructing an n by m decision matrix A which records how well each initiative $x_1 \in Sx$, where Sx is a set of n initiatives, addresses each criterion $c_j \in Sc$, where Sc is a set of m criteria. Thus, the stakeholders were able to express their preferences for ordering the initiatives in each scenario either by saying $x_i > x_j$, $x_i < x_j$, or that they had no preference between them.

- Axiom 2: The transitivity axiom

The transitivity axiom is satisfied if a stakeholder prefers option *A* to *B* and *B* to *C*, in which case the stakeholder should prefer *A* to *C* (Goodwin and Wright 2010). The transitivity axiom is satisfied, since the additive value function ranks the initiatives in each scenario starting with the initiative that has the highest value score and ending with the initiative that has the lowest. Thus, if $x_i > x_j$, $x_j > x_k$, then it must be true that $x_i > x_k$.

Feasibility: A user-friendly software workbook was created to minimize the cognitive load and to make the elicitation techniques more practical. The figures below show how the model is designed to improve the usability of the elicitation process. Figure 21 shows how easy it is to include or exclude any criterion from the analysis by clicking on the corresponding cell. Figure 22 shows how the model minimizes the cognitive load by enabling the stakeholders to express the importance of criteria by choosing from a drop-down list. The list categorizes the importance as high, medium, or low. Figure 23 shows the usability of the model for including and excluding any initiative from the analysis by clicking on the corresponding cell. Figure 24 displays a sample of a prioritization assessment matrix which is used for including how well each initiative addresses each criterion. The user needs only to select from a drop-down list that is shown in each cell to input his or her thinking about how each initiative addresses each criterion. The list includes four assessment choices: does not address, somewhat addresses, moderately addresses, and strongly addresses.

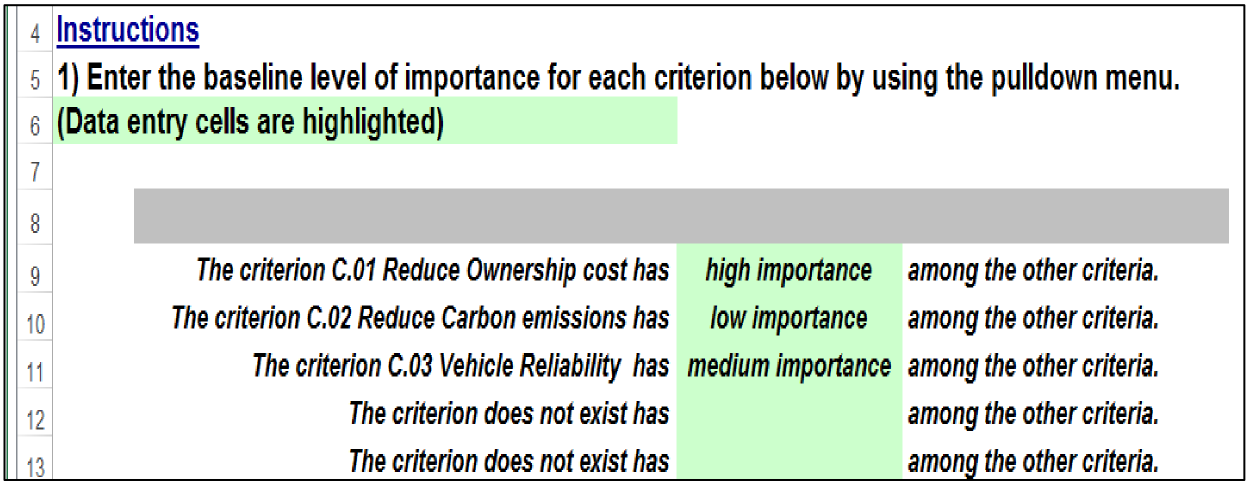
Instructions

1) Enter each criterion and corresponding description (if necessary).

2) Check box for inclusion in analysis.

Criteria	Descriptions	Include?
C.01 Reduce Ownership cost	Maximize the revenue made by selling electricity to the grid	☑
C.02 Reduce Carbon emissions	The advance charger technology reduces the environmental since it reduces the dependence on oil use, and reduces greenhouse gas emissions	☑
C.03 Vehicle Reliability	Safety and reliability of the technology is very important issue. The technology should minimize the risk of battery failures, increasing battery degradation rate, fire, etc.	☑

Figure 21. Set of criteria used for prioritizing enterprise initiatives



Instructions

1) Enter the baseline level of importance for each criterion below by using the pulldown menu.

(Data entry cells are highlighted)

The criterion C.01 Reduce Ownership cost has	*high importance*	*among the other criteria.*
The criterion C.02 Reduce Carbon emissions has	*low importance*	*among the other criteria.*
The criterion C.03 Vehicle Reliability has	*medium importance*	*among the other criteria.*
The criterion does not exist has		*among the other criteria.*
The criterion does not exist has		*among the other criteria.*

Figure 22. Evaluating the importance of each criterion in the baseline scenario

Instructions
1) List initiatives for Port of Virginia.
2) Check box for inclusion in analysis.

Initiative	Description		Notes
x1	Simulation for Market Variability	☑	
x2	Access to Wholesale Markets	☑	
x3	Regional resource planning	☑	
x4	Control methods from PEVs to utilities	☑	
x5	Grid value role	☑	
x6	Standards of encryption	☑	
x7	Establish sensors and communications	☑	
x8	Communications Standards	☑	
x9	Testing features for aggregator control	☑	
x10	Develop power electronics and energy storage components	☑	

Figure 23. Sample of enterprise initiatives used in the mobile smart grid case studies

Instructions

1) Using the pulldown menu, enter how

A blank cell indicates that the alternative c

(Data entry cells are highlighted)

Criteria	x15 Mitigate transformer issues	x16 Investigate results of technology adoption	x17 Verify projected results of technology adoption	x18 Resource planning	x19 Model Plug-in Electric Vehicle (PEV) penetration at Independent Systems Operator (ISO) level	x20 Establishing standards for PEV owners	x21 Analysis of effects on battery	x22 Tool for displaying technology's benefits	x23 Create interoperability standards	x24 Identify advantages of technology for PEV adoption	x25 Analyze potential aggregator operations	x26 Identify PEV requirements for aggregation markets	x27 Identify at-risk components	x28 Test at-risk components	x29 Develop distribution monitoring for local PEV load sharing	x30 Connection requirements for invertor	x31 Analyze distribution system impacts of PEV adoption	Veri
C.01 Reduce Ownership cost is addressed by this alternative.					Somewhat Agree	Strongly Agree	Agree	Somewh at Agree	Somewh at Agree				Somewh at Agree	Somewh at Agree	Somewh at Agree		Somewh at Agree	S a
C.02 Reduce Carbon emissions is addressed by this alternative.	Somewh at Agree	Agree	Somewh at Agree	Somewh at Agree		Somewh at Agree	Agree	Somewh at Agree		Somewh at Agree	Somewh at Agree	Somewh at Agree			Somewh at Agree	Somewh Agree		
C.03 Vehicle Reliability is addressed by this alternative.	Somewh at Agree	Somewha t Agree	Somewh at Agree	Agree	Agree	Agree	Strongly Agree		Agree	Somewh at Agree	Somewh at Agree	Somewh at Agree	Somewh at Agree	Somewh at Agree		Somewh at Agree	Agree	S a

Figure 24. Sample of a prioritization assessment matrix for ranking the enterprise initiatives

The four figures above describe all the stakeholder inputs that are needed in the analysis. Moreover, to improve the usability and the feasibility of the model, an executive summary will show up immediately after each stakeholder's selection is made, as shown in Figure 25. Describing the key findings from the analysis clearly in one executive summary page will improve the stakeholders' understanding of the influence of scenarios on priorities.

In addition, to improve the feasibility of the model, the impacts of most of the disruptive scenarios are illustrated using business planning and management simulation models. These simulation models were developed and used to improve the stakeholders' understanding when they were asked for their preferences during the analysis. Section 7.4 provides more information about the simulation modeling.

Top Ranked Initiatives	
1	Analysis of effects on battery
2	Establishing standards for PEV owners
3	Develop power electronics and energy storage components
4	Model Plug-in Electric Vehicle (PEV) penetration at Independent Systems Oper
5	Create interoperability standards
6	Analyze distribution system impacts of PEV adoption
7	Control methods from PEVs to utilities
8	Identify requirements for energy performance
9	Provide solution to enhance energy performance
10	Resource planning

Bottom Ranked Initiatives	
35	Develop charge controllers
34	Collaborate with OEMs
33	Develop distribution monitoring for local PEV load sharing
32	Tool for displaying technology's benefits
30	Identify PEV requirements for aggregation markets

Most Disruptive Scenarios	
1	S4. Electricity Market Shifts
2	S2. Private Support
3	S3. Private and Public Support
4	S1. Public Support

Most Resilient Initiatives	
1	Establishing standards for PEV owners
2	Analysis of effects on battery
3	Develop charge controllers
4	Develop power electronics and energy storage components
5	Model Plug-in Electric Vehicle (PEV) penetration at Independent Systems Oper
6	Create interoperability standards
7	Analyze distribution system impacts of PEV adoption

Least Resilient Initiatives	
35	Collaborate with OEMs
34	Develop distribution monitoring for local PEV load sharing
33	Tool for displaying technology's benefits
32	Testing of new PEV and charging infrastructure
31	Verify distribution system impacts
30	Test at-risk components

Figure 25. Executive summary for the enterprise resilience analytic framework findings

Robustness: The model inputs and boundaries, including initiatives, criteria, scenarios, and stakeholders, are iteratively updated during the analysis. Iterative analysis, such as the analysis used in this dissertation, improves the robustness of decision-making models, especially when considering different combinations of emergent and future conditions (Groves and Lempert 2007). In addition, the iterative analysis helps risk analysts to identify when in the analysis the stakeholders might have irrational preferences (Tversky and Kahneman 1985). As discussed in section 3.6.2 (Facilitated Stakeholder Conferences), the facilitated conferencing used in this dissertation helps the facilitator(s) to reframe the model inputs and boundaries during each decision workshop. Reframing the evaluation criteria in the light of new information is important for assessing the robustness of priorities (Connelly 2016). Moreover, considering new emergent and future conditions and/or stakeholders provides insight into the possible disruptiveness of this new information to priorities. Thus, this iterative analysis helps risk analysts to improve the robustness of the enterprise resilience framework by updating the modeling inputs and boundaries.

Transparency: French and Insua (2000) have noted that new methods should not be adopted if the end-users do not understand how to use them, and that graphical computing techniques have been successful in improving the transparency of new models. In addition to the user-friendly model described in the feasibility criteria above, the facilitated conferencing mode described in Chapter 3 (see section 3.6.2 Facilitated Stakeholder Conferences) was used to provide clarification and guidance for stakeholders in regard to the problem statement and how to insert their preferences into the analysis. This kind of facilitated conferencing is designed to minimize potential human error and unnecessarily confused thinking.

In addition, training sessions were given to the stakeholders during the monthly decision workshops to illustrate how they could insert their inputs into the model. A written procedure, discussed in section 3.6.2 Facilitated Stakeholder Conferences, was used by the facilitator(s) to improve model transparency and stakeholder engagement. The procedure describes the role of the facilitator(s), the modeling inputs and outputs, the stakeholder training sessions, the software workbooks, and other details.

In addition, as an extra step to improve the feasibility and transparency of the framework—one which is not part of the French and Insua (2000) validation criteria—quantitative and visual business planning simulation models for each of the Port of Virginia's facilities were created. Each facility simulation model simulated the Port's daily transactions for all the possible operational planning strategies and disruption scenarios. The model displayed the expected level of disruptiveness for each scenario, which helped the stakeholders to select their preferences across all the scenarios. Section 7.4 provides more information about the simulation modeling.

Compatibility with the decision context: Compatibility with the decision context: The resilience analytics framework presented in this dissertation is compatible with the decision context for two reasons. First, the framework addresses the influence of multiple stakeholders on priorities, and a research trend in the risk communication area focuses on addressing the influence of multiple stakeholders on decision making. Several scholars contend that a single perspective is insufficient for analyzing complex systems involving multiple stakeholders who have different objectives (Barker et al. 2017; Cairns, Goodwin, and Wright 2016; Haimes 2015). Stakeholders have different levels of influence on projects (Rose 2013), and they have different objectives, interests, and expectations that may or may not support development plans. Shaw, Grainger, and Achuthan (2017) argue that improving port resilience requires an understanding of how stakeholders interact with each other. Gharehgozli et al. (2017) note that several factors—

including environmental, economic, social, and political ones—need to be considered when analyzing the enterprise resilience of systems to the influence of disruptive scenarios.

The second reason that the proposed framework is compatible with the decision context is that several scholars have highlighted and addressed the influence of scenarios on priorities for systems that involve high levels of uncertainty (Thorisson et al. 2017; Connelly et al. 2015; Hamilton et al. 2012). The presented framework addresses the influences of two modes of disruptions to priorities: scenarios and multiple groups of stakeholders. Thus, integrating the influence of multiple stakeholders into the existing scenario-based preferences approaches builds on the existing literature in decision analysis.

Although several scholars have discussed various criteria for validating the decision process, stakeholder feedback has been proven to be a reliable and direct indicator of a successful decision process (You 2013). In the present study, a stakeholder satisfaction survey was distributed for the purpose of supporting compatibility between the decision context criteria and the enterprise resilience analytics framework. Appendix A shows a sample survey that was distributed to groups of stakeholders, along with their responses. A key stakeholder group, the Commonwealth Center for Advanced Logistics Systems, which was involved in the seaport case study (Chapter 6), gave the following feedback when asked about the usefulness of the framework:

> Mr. Mark Manasco, President and Executive Director at Commonwealth Center for Advanced Logistics Systems, said:
>
> Absolutely, yes, based on that case study the POV [Port of Virginia] adjusted one of their key performance indicators (KPIs) due mainly to the confidence they had in the analysis. Note these indicators had been in place for a substantial period of time and unchallenged. They were viewed as the best that could be achieved given the current tools and process used for measurement. It should also be noted this KPI was the key indicator of financial rewards for executive management, management that had the power to directly influence operation efficiency. This work reset the bar and established a new baseline for all planning efforts going forward.

> Mr. Thomas L. Polmateer, Logistics Research Systems Analyst at Commonwealth Center for Advanced Logistics Systems, said:
>
> Today, risks and uncertainty are magnified in large-scale systems such as global inter-modal port operations. In this specific case study, the research team identified several key themes of interest to the Port with regard to uncertainty, budgetary environments, capital expenditures, return on investment, and diversification of cargo types. The framework assisted key leaders in (1) optimizing the management's key performance indicators to reach their objectives and (2) refine their Strategic Plan.

In addition, when asked about the generalizability of the framework to other fields of application, the representatives of the Commonwealth Center for Advanced Logistics Systems gave the following feedback:

> Mr. Mark Manasco, President and Executive Director at Commonwealth Center for Advanced Logistics Systems, said:
>
> Absolutely yes I believe it has application to other fields. I think this is particularly true in the field of logistics. Technology is allowing machines or physical units of any kind to talk to one another. This will only become more pronounced as the technology advances. Government, industry, business, almost all endeavors of any size have what are characterized as logistical issues. In most logistics operations there are an infinite number of variables of all 'shapes and sizes'. Much is assumed and contingencies plans developed for the outlier emerging and future conditions. A tool like this would allow better analysis on a wider scale and thus a better utilization of resources.
>
> Mr. Thomas L. Polmateer, Logistics Research Systems Analyst at Commonwealth Center for Advanced Logistics Systems, said:
>
> When I think of fields of applications I think in terms of potential clients that can benefit from this framework. There is an application for the federal government; specifically DoD, FEMA, NASA and U.S. Post Office. These organizations have complex systems and diverse stakeholders that play a role in their strategic plans under emergent and future conditions. In addition, every trucking company, 3PL, and retailer, as a minimum, can use the framework to influence their economic business plan.

Based on the French and Insua (2000) validation method, a model that satisfies the discussed five evaluation criteria can be described as a satisfactory model. In addition, the above feedback and the other stakeholders' feedback (see Appendix A) support the usefulness of this resilience analytics framework in the risk analysis area and its generalizability to other fields of application. Future research can focus on providing further evidence to support the validation process.

7.4 Role of the Simulation Analysis

7.4.1 Purpose of Modeling

Business planning and management simulation models were created and used as supplemental support sources to increase stakeholders' understanding when they were asked for their preferences during the analysis and to support the validation approach. Quantitative and visual operational planning simulation models for each of the Port of Virginia's facilities were created. Each facility simulation model simulates the Port's daily transactions for all the possible operational planning strategies and disruption scenarios.

One specific area of study was forecasting the operational behavior of Virginia International Gateway (VIG) during its ongoing construction and change in conveyance. Different scenarios were considered in this simulation study, including traffic congestion, economic slowdowns, environmental regulations, and disruptive weather. The purposes of modeling the VIG simulation models included (but were not limited to) the following:

- Increasing the involvement of Port of Virginia planners, stakeholders, federal agencies, nonfederal agencies, and contractors in the VIG's operational planning process by visualizing and controlling the VIG's daily transactions.
- Exploring the VIG Port dynamic system's behavior for different operational planning strategies and disruption events.

- Forecasting the VIG's global key performance indicators (KPIs) (e.g., average truck turn time, customer satisfaction rate, environmental impact rates) and local key performance indicators (e.g., average processing time for each server, average truck queuing time) after implementing the reservation system.
- Indicating where there is a potential for overloaded daily transactions in the VIG operational planning process.
- Demonstrating where and when it is during the VIG's daily operational planning process that particular servers (In-Gate, Chassis Service Area, Cranes Area, Out-Gate) are at full capacity and might benefit from additional resources.
- Generating statistical information for the VIG's operational planning process, such as the average processing time for each server (e.g., In-Gate, Chassis Service Area), the average truck queuing time, the overall truck turn time, the overall customer satisfaction rate, the overall air pollution impact rate, and the overall water pollution impact rate.
- Implementing and optimizing new enterprise initiatives and modifying current strategies.

7.4.2 Data Availability and Truck Routing Sequences

The operational data from the VIG, dating from January 2015 through September 2015, was used in this analysis to estimate the truck arrival rate distribution, server processing time distributions, and other modeling parameters. Table 43 shows all the possible truck routing sequences in the VIG simulation models. The 19 different truck routing sequences were found in the VIG 2015 truck visit data.

Table 43. Truck visit routing sequences in the Norfolk International Terminal

Routing sequence					
In	Out				
In	Cranes	Out			
In	Chassis	Out			
In	Cranes	Chassis	Out		
In	Cranes	Cranes	Chassis	Out	
In	Cranes	Chassis	Cranes	Out	
In	Chassis	Cranes	Out		
In	Cranes	Chassis	Chassis	Cranes	Out
In	Chassis	Cranes	Cranes	Out	
In	Chassis	Cranes	Chassis	Out	
In	Chassis	Cranes	Cranes	Chassis	Out
In	Cranes	Chassis	Chassis	Out	
In	Chassis	Chassis	Cranes	Out	
In	Chassis	Chassis	Out		
In	Cranes	Chassis	Cranes	Chassis	Out
In	Chassis	Cranes	Chassis	Cranes	Out
In	Cranes	Cranes	Chassis	Chassis	Out

7.4.3 Simulation Methodology

The following is the methodology for computing and validating the key performance indicators:

1) Implementing new enterprise initiatives or modifying current strategies in the simulation model parameters (e.g., increasing number of gates)
2) Coding the KPIs before running the simulation model. Below are the KPIs which are applied in the VIG simulation models:
   - Average truck turn time
   - Average customer satisfaction rate = $\frac{\text{no. of transactions having turn time} \leq 60 \text{ mins}}{\text{total no. of transactions}}$
   - Average truck queuing waiting time
   - Average server processing time
   - Average server utilization percentage
   - Average truck emission rate
3) Replicating the simulation model to generate identically distributed and independent output samples.
4) Comparing the simulation outputs with the field observations. If a close match is found, then this is the end of the validation step. If not, the model parameters are modified, and the process returns to step 2 above.

7.4.4 Sample of the Simulation Results

This section shows sample outputs for the VIG simulation models when two scenarios are implemented. The first model is the VIG reservation model, where it is assumed that the VIG Port accepts only the trucks that have reservation appointments. The second model is the VIG complex model, where the VIG Port accepts trucks with and without reservation appointments. The goal is to study how these two operational scenarios influence the Port's key performance indicators (e.g., average truck turn time, customer satisfaction rate, average truck emission rate). Table 44 shows a comparison between the servers' processing time after running the two simulation models. This comparison provides insights into where improvements in the truck turn times are possible. It seems that the minimum processing time for the in-gates and the out-gates servers is about 5 minutes, whereas there is a possibility of speeding up the processing time in the cranes area and the chassis service area by 2 minutes.

Table 45 shows the crane processing time after breaking down the crane server into three sub-servers. The preparation time is the time when a truck parks in one of the five parking spots in the crane area and waits for the crane to serve it. The two-minutes improvement in the preparation time indicates that the reservation system helps to reduce the crane moving time by distributing the containers based on the truck arrival time.

Table 44. Servers average processing time in the Norfolk International Terminal (minutes)

Servers processing time	In-Gates	Cranes	CSA	Out-Gates
Reservation model	5	31	3	4
Complex model	5	33	5	4

Table 45. Automated crane average processing time in the Norfolk International Terminal (minutes)

Cranes	Preparation time	Loading time	Transfer time
Reservation model	20	6	5
Complex model	22	6	5

Table 46 indicates that the reservation model reduces the truck waiting time in the queue. For instance, the average truck turn time for the two multiple routing sequences in Table 46 (In–Chassis–Crane–Out, In–Cranes–Chassis–Out) improved because the truck queuing time was improved.

Table 47 shows the expected global improvement after implementing the reservation system in the VIG port. When the reservation system is applied to all visiting trucks, there is an expected improvement of 12 minutes in the truck turn time. After implementing the reservation system, the expected customer satisfaction rate is improved from 70% to 76%.

Table 46. Truck routing sequences average time in system the Norfolk International Terminal (minutes)

Routing sequence				Proportion %	Complex model turn time	Reservation model turn time
In	Out			14%	12	12
In	Chassis	Out		7%	49	27
In	Cranes	Out		32%	46	46
In	Chassis	Cranes	Out	9%	82	61
In	Cranes	Chassis	Out	28%	86	62

Table 47. Global improvement in the Norfolk International Terminal: average truck turn time and customer satisfaction rate

	Average Truck Turn Time (minutes)	Customer Satisfaction Rate
Reservation Model	42	0.76
Complex Model	54	0.7

The analysis above indicates that traffic congestion inside the VIG terminal due to unexpected truck arrivals in the system increases the truck waiting time by 12 minutes on average, whereas the scenario when the reservation system is implemented decreases the truck waiting time in the system. This traffic congestion has a negative impact on the environment, since it increases the truck idling emissions. The environmental sustainability plan is one of the planning strategies in the Port of Virginia's master plan. The total truck idling emissions in the VIG Port are estimated using the VIG simulation model results. The truck idling emission equation below is adopted from the work of Li et al. (2016):

$$Z = e \times w_T^O \times T \qquad (8)$$

where, e is the emission factor, w_T^O is the average truck idling time, T is the estimated number of trucks visiting the system, and Z is the estimated total daily idling emissions. From the VIG simulation model, the expected average truck idling time is 32 minutes, and the expected number of truck visits to the chassis service area and the crane area is 1417 trucks. Table 48 shows the expected total idling emissions in the VIG port.

Table 48. Estimated trucks idling emissions in the Norfolk International Terminal

	CO_2	Unit
e	4,640	g/hr
Idling emissions rate per truck	2,475	grams
Total idling emissions rate (Z)	3,506,603	grams

7.4.5 The Usefulness of the Simulation Analysis in Supporting the Enterprise Resilience

The purpose of building quantitative and visual operational planning simulation models was to support the validation of the resilience framework developed in this dissertation by improving the feasibility of the framework and increasing the involvement of many of the stakeholders in the analysis. Further details of the simulation modeling are given in Appendix B.

In Chapter 6, the resilience analytics framework concludes that scenario s_1, *Traffic Congestion*, followed by s_4, *Environmental Mitigation*, were the most disruptive scenarios to the priorities of the multiple groups of stakeholders. The simulation analysis confirmed these findings, since it found that the traffic congestion inside the container terminal increased the average truck turn time by 12 minutes on average, as shown in Table 47. This increase in the average truck turn time reduced the customer satisfaction and negatively impacted the surrounding environment by increasing the truck emissions rate, as shown in Table 48. Therefore, based on the simulation analysis, s_1, *Traffic Congestion* and s_4, *Environmental Mitigation* would negatively impact the Port's key performance indicators, including average truck turn time, customer satisfaction rate, and truck emissions rate.

7.5 Issues and Limitations

7.5.1 Bias Associated with Stakeholder Engagement

The first concern that might affect extending the approach to other engineering topics is the engagement of multiple groups of stakeholders, since the accuracy of the outcomes depends heavily on the quality of the stakeholders' inputs and their ability to state preferences. Stakeholders play an important role in identifying future projects, criteria, and emergent conditions. Several group meetings with a wide variety of stakeholder groups are required in order to introduce the advantages of using the framework and to illustrate how stakeholders can insert their preferences; the implementation of the framework cannot be done in one group meeting since updating the preferences of groups across scenarios requires several hours. It is difficult to deal with large groups of stakeholders, especially if they have less interest in the process or if the framework does not add value for them in the meantime.

7.5.2 Bias Associated with the Availability of Scenarios

The second concern in regard to this framework is that there is no guarantee that the groups of stakeholders will be able to define all the scenarios. This is because a future scenario is an emergent condition or a combination of emergent conditions that aims to represent an extreme case. This extreme case does not partition the space of other future scenarios. However, most risk analysis approaches require a complete set of scenarios or future events in order to determine their expected values. These approaches seek to maximize or minimize the value of the utility function, which is normally aggregated over a set of expected scenarios or events. In the framework presented in this dissertation, the modeling outcomes rely on the ability of stakeholder groups to define the set of scenarios. The more precise they are in defining the set of scenarios, the more accurate the modeling outcomes are, since the prioritization of initiatives is directly affected by the influences of scenarios.

Lowrance (1976) defined risk as the measure of the probability and the severity of effects, but this definition of risk is less helpful when assessing non-regular scenarios that have never happened before, as there may be insufficient information for assessing the probability of such extreme scenarios. However, the definition of risk has been reconceptualized as the influence of scenarios on priorities (**Almutairi** et al. 2017; Connelly and Lambert 2016; Connelly et al. 2016;

Karvetski and Lambert 2012; Lambert et al. 2012; Martinez, Lambert, and Karvetski 2011). This perspective on risk enables a risk analyst to use the preferences of stakeholders to capture the disruptiveness of scenarios to the existing priority setting.

This framework is not appropriate for a problem that needs a detailed quantitative risk assessment, since the analysis relies on an incomplete set of scenarios. It is nevertheless a beneficial method for dealing with problems when it is difficult to estimate the probability and severity of scenarios, since it filters risks based on the value of information provided by stakeholders instead of estimating the probability and severity of those scenarios. This framework does not seek an optimal solution that is suitable for all current and future stakeholders; rather, it seeks to enable the risk analyst to determine which of the future initiatives need a traditional risk assessment analysis by highlighting the most and least disruptive scenarios along with ranking the initiatives. Thus, the method aims to undertake risk analyses that matter to the priorities of an organization.

7.5.3 Bias Associated with Anchoring

Anchoring is a common problem in rational decision models. Most of the research which discusses the biases that affect people judgments is based on the work of of Tversky and Kahneman (1983). Anchoring begins when a stakeholder uses initial values at the baseline scenario, and then uses these values to estimate future values. This is true in the presented framework, since the stakeholders are asked to prioritize a set of initiatives at the baseline scenario, and then keep updating their preferences across different scenarios.

Insufficient adjustment bias could arise here if the stakeholders anchor on inappropriate estimates (Goodwin and Wright 2010). Thus, the stakeholders might underestimate or overestimate the influence of scenarios based on insufficient assessment in the baseline scenario.

Participants often believe that a desired outcome is more likely to occur (Goodwin and Wright 2010), and this is another bias that could affect the accuracy of the modeling outcomes. The stakeholders are asked to assess how well each initiative addresses each criterion, and how much each scenario changes the relative importance weight of each criterion. In both of these cases, the stakeholders might assign higher-ranking numbers to their desired initiatives or to the influences of the scenarios that they believe are more likely to happen.

7.5.4 Bias Associated with the Scalability of the Prioritization Interval

The scalability of prioritization used in the framework is sufficient for a small number of scenarios and initiatives. For example, if the number of prioritized initiatives is large (say, more than 100), then the difference between prioritization rank number 55 and number 60 does not imply any meaningful conclusion. However, the aim of this framework is to identify the most (top-ranked) and the least (low-ranked) robust initiatives, and the most (top-ranked) and the least (low-ranked) disruptive scenarios, instead of performing a detailed risk analysis. In other words, the aim of this framework is to identify extreme scenarios and initiatives that are most disruptive or supportive to enterprise resilience, such as the most disruptive scenarios, and the most robust initiatives, rather than analyzing the exact influence of each scenario and initiative.

7.6 Chapter Summary

This chapter has discussed the validation and the limitations of the presented enterprise resilience analytics framework. The framework was validated by addressing five criteria: axiomatic basis, feasibility, robustness, transparency, and compatibility with the decision context. In addition, to support the validation analysis and to assess the quality of the framework outputs, a survey was distributed to the stakeholders. A supplementary simulation modeling analysis for the purpose of improving the stakeholder engagement and supporting the validation analysis was also examined. Finally, the issues and limitations of the framework arising from stakeholder judgments were also discussed in this chapter.

CHAPTER 8: SUMMARY AND CONCLUSION

8.1 Overview

This chapter summarizes what this dissertation sought to accomplish. Section 8.2 reviews the purpose of this dissertation. Section 8.3 describes the main contributions of this work to theory, methodology, and practice of resilience and systems engineering and risk analysis. Section 8.4 discusses possible opportunities for future research. Section 8.5 concludes the dissertation.

8.2 Review of Purpose

The purpose of this dissertation was to address an existing gap in research regarding enterprise resilience. A disruptive event (e.g., an economic crisis, a natural disaster, etc.) changes the preferences of clients, stakeholders, decision makers, and others, which will lead to significant changes in enterprise and business processes (e.g., priority of future work, amount of future funds, etc.). The framework presented in this dissertation extends resilience analytics approaches (Thorisson et al. 2017b; Connelly and Lambert 2016; Connelly et al. 2015; Hamilton et al. 2012;

Karvetski et al. 2011; Martinez, Lambert, and Karvetski 2011) by integrating a stakeholder classification approach called *stakeholder mapping* (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981) with scenario-based preferences. Incorporating the stakeholder mapping approach helps to assess the influence of stakeholders to priority setting of enterprise initiatives across scenarios. Thus, the presented framework addresses the influences both of scenarios and of multiple groups of stakeholders to priorities.

The framework has been demonstrated in three case studies. The first mobile smart grid case study addressed the influences of scenarios to the priority setting of enterprise initiatives. The second mobile smart grid case study addressed the influences of scenarios and of multiple groups of stakeholders to the priority setting of enterprise initiatives. The third case study, which dealt with a maritime container port, addressed the influences of scenarios and of multiple groups of stakeholder to the priority setting of enterprise initiatives. The results from these case studies were used to guide groups of stakeholders to identify the most disruptive scenarios, the least disruptive scenarios, the most robust initiatives, the most robust and high-ranked initiatives, and how the dynamic role of stakeholder participation across scenarios impacted the modeling outcomes.

Chapter 1 introduced the motivation of this research, described the purpose and scope of developing the enterprise resilience analytics framework, and summarized the research contributions. Chapter 2 reviewed the literature relevant to stakeholder theory, stakeholder mapping, scenario-based preferences, and resilience analysis. Chapter 3 described the technical approach of the enterprise resilience analytics framework for a single group of stakeholders and for multiple groups of stakeholders. Chapter 4 demonstrated the framework with smart grid enterprise initiatives across the influence of scenarios only. Chapter 5 demonstrated the framework with smart grid enterprise initiatives across the influences both of scenarios and of groups of stakeholders. Chapter 6 demonstrated the framework with seaport enterprise initiatives across the influences both of scenarios and of groups of stakeholders. Chapter 7 reviewed the literature on validating rational decision models, described how the framework was validated, and discussed issues with and limitations of the presented framework.

A user-friendly software workbook for the presented framework, along with written guidelines for how the stakeholders could insert their preferences, was distributed to the stakeholders. The purpose of creating this software was to increase stakeholder engagement and the accuracy of the modeling outcomes by minimizing cognitive load and biases. In addition, training sessions were provided for the groups of stakeholders during the monthly decision workshops with them to improve their engagement in the analysis.

8.3 Research Contributions

This section describes the theoretical, methodological, and practical contributions of this research.

The **first contribution** of this research is the conceptualization of enterprise resilience when two modes of disruption (scenarios and multiple groups of stakeholders) change the preferences of stakeholder groups (e.g., users, clients, etc.). Recent literature highlights the need for conceptualizing the concept of resilience in enterprise and business processes (Connelly 2016). The presented framework enables risk analysts to study the influences of scenarios and groups of stakeholders to enterprise priority setting. This is a *major* contribution of this research.

The **second contribution** is the integration of the stakeholder mapping approach with scenario-based preferences modeling, bridging the gaps between stakeholder participatory management theory and the field of risk analysis. Considering how the roles of participants (i.e., the participation level of each stakeholder) change across scenarios provides insights into how a stakeholder who has a low impact on enterprise initiatives in the baseline scenario might have a high impact during other scenarios. This is a *major* contribution of this research.

The **third contribution** is the design, implementation, and distribution of an easy-to-use software workbook along with written procedures for how stakeholders can enter their preferences across scenarios in order to help managers and risk analysts study the influence of the deep uncertainties of scenarios and of multiple groups of stakeholders to enterprise initiatives. This is a *minor* contribution of this research.

The **fourth contribution** is the demonstration of the framework on mobile smart grids to support grid reliability and stability when the influence only of scenarios is considered in the analysis **(Almutairi et al. 2017b)**. In addition, the framework was also demonstrated on mobile smart grid technology when the influences both of scenarios and of multiple groups of stakeholders are considered in the analysis **(Almutairi et al. 2017c)**. This demonstration addresses the gap between stakeholder participatory management theory and scenario-based preferences modeling in the energy mobility sector. The changes in the role of participants (i.e., the participation level of each stakeholder) have a significant impact on enterprise initiatives. The results of the framework support enterprise resilience by identifying the most disruptive scenarios, the least disruptive scenarios, the most robust initiatives, and the most robust and high-ranked initiatives. This is a *minor* contribution of this research.

The **fifth contribution** is the demonstration of the framework on large-scale maritime container port development projects to support the development and resilience of seaports to the influences of possible disruptions, mainly from scenarios and from multiple groups of stakeholders **(Almutairi et al. 2017a)**. This is a *minor* contribution of this research.

Figure 26 provides a summary and timelines of the efforts, publications, conference presentations, and research milestones of this dissertation. This effort is the result of contributing to several research projects from August 2015 to the present, including analytics and logistics systems research for the Port of Virginia; analytics and logistics systems research for the resilience of power grid systems; data analytics and resilience research for transportation plans, including emergent and future conditions; and the FirstNet wireless broadband plan. The effort in this dissertation was supported in part by the National Science Foundation with grant 1541165 "CRISP Type 2: Collaborative Research: Resilience Analytics: A Data-Driven Approach for Enhanced Interdependent Network Resilience," the Commonwealth Center for Advanced Logistics Systems, the Port of Virginia, the Virginia Department of Transportation, and Kuwait University. A summary of the academic activities related to the projects that comprise this research is shown below.

Accepted Journal Papers:

- **Almutairi, Ayedh**, Heimir Thorisson, John P. Wheeler, David L. Slutzky, and James H. Lambert. 2017. “Scenario-Based Preferences in the Development of Advanced Mobile Grid Services and a Bidirectional Charger Network” *ASCE–ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*.

Submitted Journal Papers:

- **Almutairi, Ayedh**, John P. Wheeler, David L. Slutzky, and James H. Lambert. 2017. "Integrating Stakeholder Mapping and Risk Scenarios to Improve Resilience of Cyber–Physical–Social Networks" *Risk Analysis. Special Issue on Resilience Analytics for Cyber–Physical–Social Networks*.
- **Almutairi, Ayedh**, Zachary A. Collier, Daniel Hendrickson, José M. Palma-Oliveira, Thomas L. Polmateer, and James H. Lambert. 2017. “Stakeholder Mapping and Risk Scenarios with Application to the Resilience of a Container Port” *Journal of Reliability Engineering and System Safety*.

Presented Conference Paper:

- Thorisson, Heimir, **Ayedh Almutairi**, John P. Wheeler, David L. Slutzky, and James H. lambert. 2017. “Enterprise Management and Systems Engineering for a Mobile Power Grid” 25th International Conference on Systems Engineering, Las Vegas, NV, USA, 22–24 August.

Conference Presentations:

- Alsultan, Marwan. (presenting author), Heimir Thorisson, **Ayedh Almutairi**, Zachary A. Collier, David L. Slutzky, John P. Wheeler, and James H. Lambert. “Risk Analysis and

Systems Integration of Fleet Electric Vehicles with the Power Grid" Society for Risk Analysis 2016 Annual Meeting, San Diego, CA, December 2016.

- 2017 Finalist for Best Poster Award, **Ayedh Almutairi** and James H. Lambert. "Modeling and Simulation of Capacity Expansion at a Major Container Port" University of Virginia Engineering Research Symposium (UVERS), April 30, 2017.
- **Almutairi, Ayedh** (presenting author), and James H. Lambert. "Participatory Factors and the Influence of Scenarios to Priorities with Application to the Mobile Smart Grid" Society for Risk Analysis–Europe Annual Conference, Lisbon, Portugal, 21 June 2017.
- **Almutairi, Ayedh** (presenting author), and James H. Lambert. "How Resilience Analytics Addresses Several Participants' Disrupting Priorities for Infrastructure Systems" Society for Risk Analysis 2017 Annual Meeting, Arlington, VA December 2017.

Figure 27 shows the contributions of this research to the literature with regard to theory, methodology, and applications. Figure 28 describes the contributions of this dissertation, building on the previous literature in stakeholder theory, stakeholder mapping, scenario-based preferences, and resilience analytics.

Project Involvement

- Virginia Department of Transportation
- Port of Virginia
- Fermata LLC
- FirstNet wireless broadband

Publications and Conference Presentations

- Co-authored a conference paper for the *ICSEng 2017*
- Participated in the 2016 SRA Annual Meeting, San Diego, CA
- Finalist for Best Poster Award, Engineering Symposium
- Submitted paper to the *Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*
- Attended the 2017 SRA–E Meeting, Lisbon, Portugal
- Submitted revised paper to the *ASCE–ASME Journal*
- Submitted paper to the *Journal of Risk Analysis*
- Submitted paper to the *Journal of Reliability Engineering and System Safety*
- Accepted revised paper to the *ASCE–ASME Journal*
- The 2017 SRA Annual Meeting, Arlington, VA

Research Milestones

- Reviewed relevant literature
- Identified the research gap and defined the problem statement, philosophy, and overview
- Formulated the mathematical framework
- Demonstrated the work in mobile smart grids
- Demonstrated the framework in seaport projects
- Validated the work and stated the issues and limitations

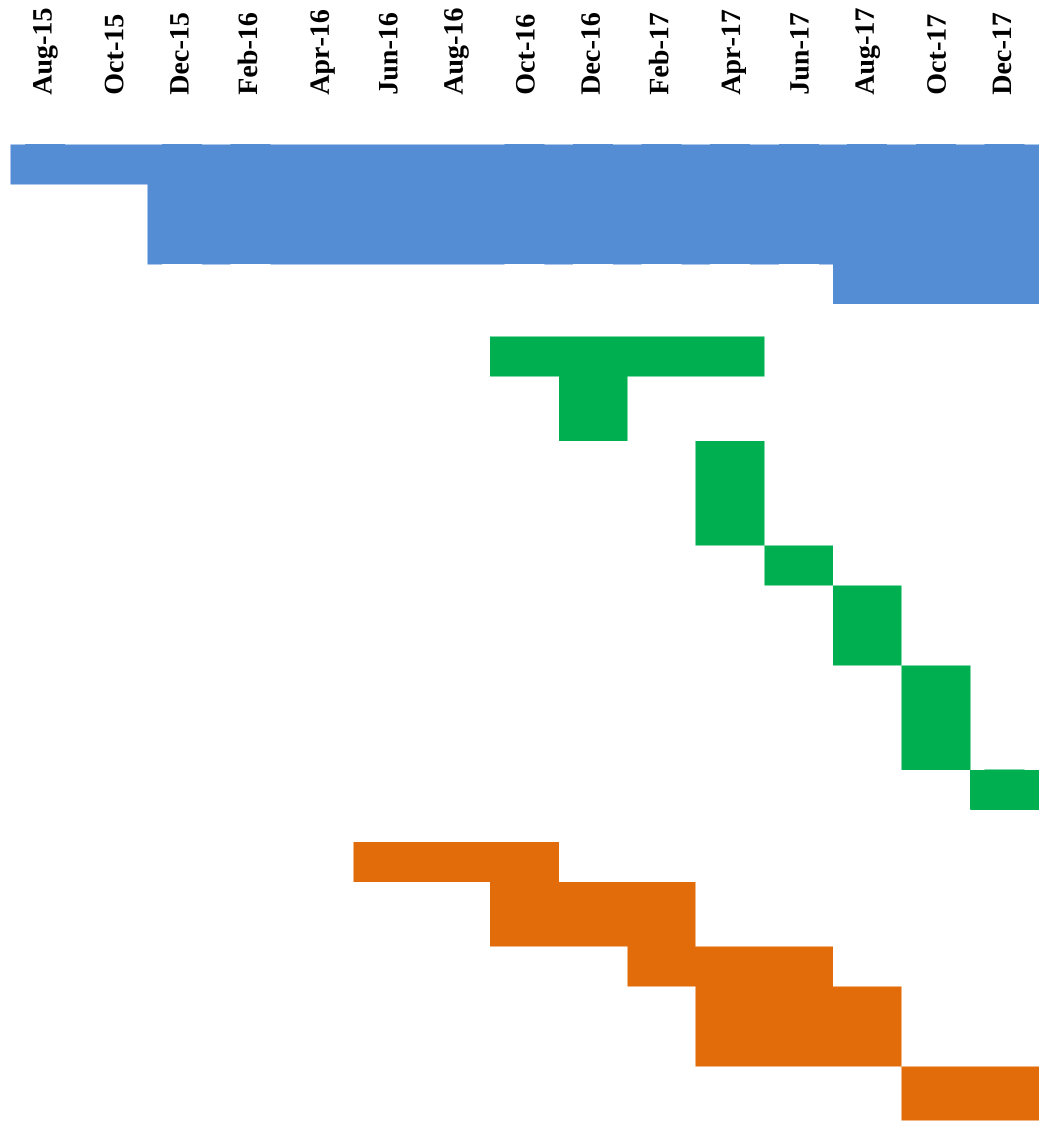


Figure 26. Timeline of the research efforts, publications, conference presentations, and research milestones of this dissertation.

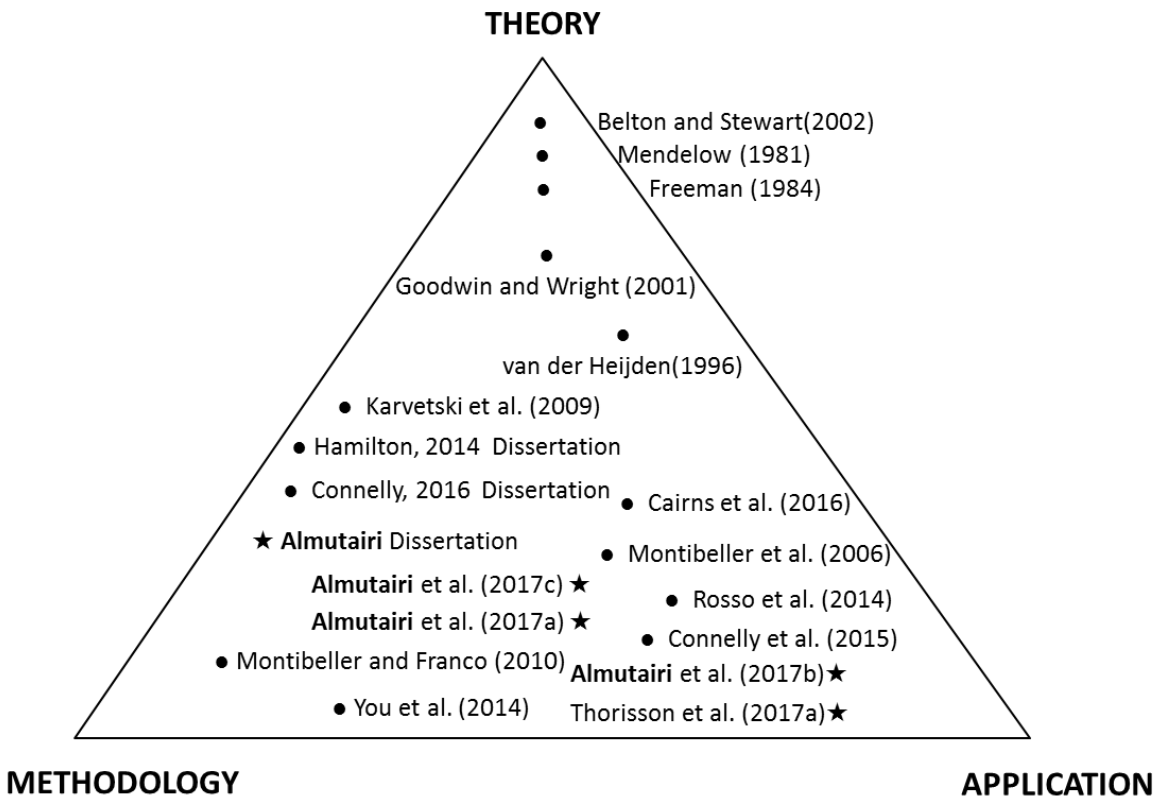


Figure 27. Contributions of the research to the risk analysis literature with regard to theory, methodology, and applications

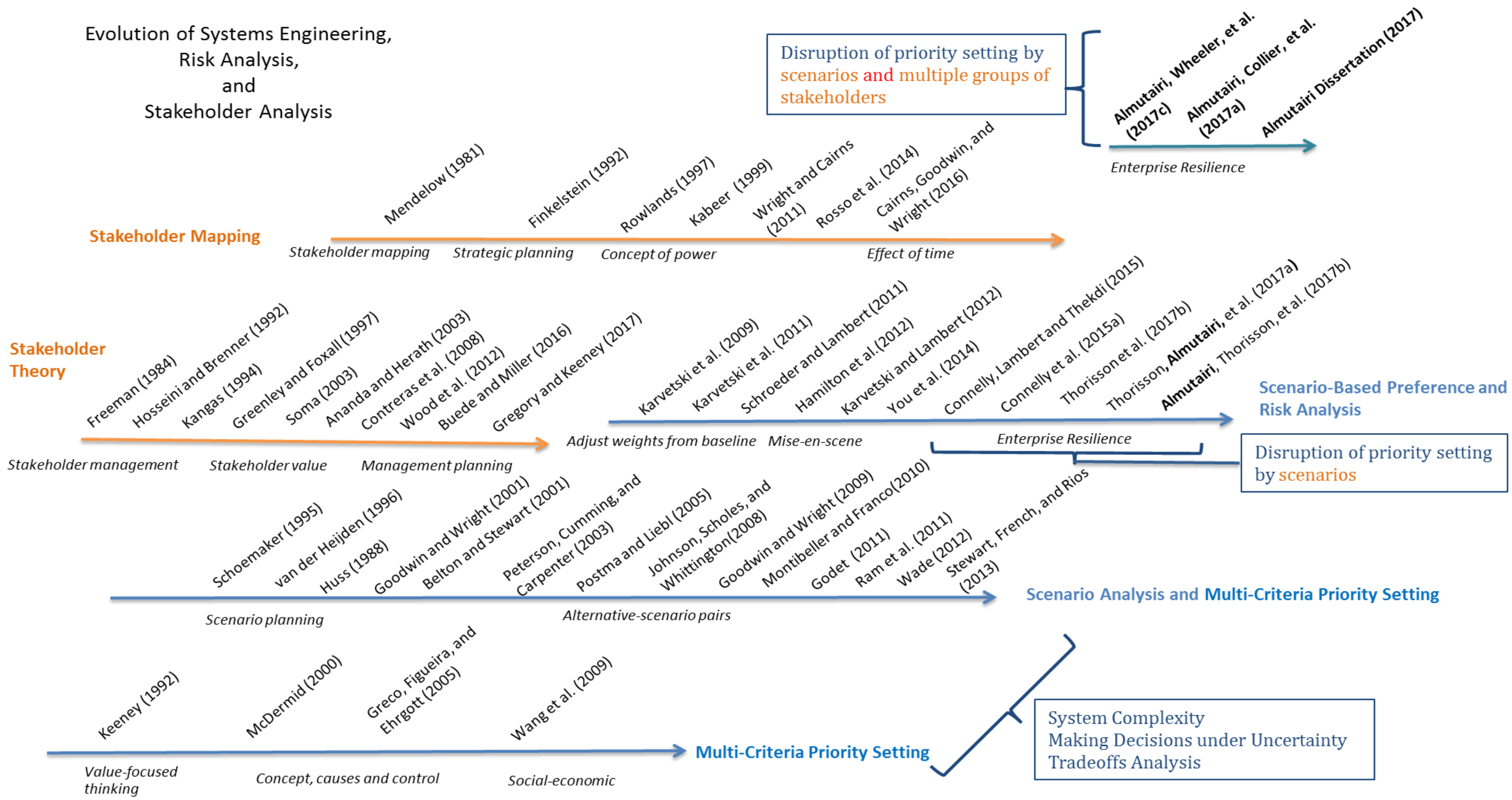


Figure 28. Contributions of this dissertation, building on the previous literature in stakeholder theory, stakeholder mapping, scenario-based preferences, and resilience analytics.

8.4 Future Research

This section discusses several opportunities for future research that can extend or improve the philosophy, methods, and outcomes of this dissertation effort.

8.4.1 Algorithms for Scenario Discovery

The aim of developing the enterprise resilience analytics framework presented in this dissertation has been to evaluate the influence of different disruptions to priority setting of multiple stakeholders. The analysis of this framework is built on an incomplete set of scenarios which do not partition the whole space of scenarios. A scenario has been defined as an emergent condition or a combination of emergent conditions. Ambiguities remain, however, as to how many combinations of emergent conditions there are. What are the possible effects of unaddressed scenarios on the final results? How can the number of unaddressed scenarios be minimized? The accuracy and the quality of the modeling analysis depend on the experience and the engagement of the stakeholders to define scenarios.

Recent literature has emphasized the importance of statistics, data-mining, and simulation algorithms in generating a set of scenarios in situations that involve high levels of uncertainty (Dalal et al. 2013; Gerst, Wang, and Borsuk 2013; Kwakkel, Auping, and Pruyt 2013; Bryant and Lempert 2010; Lempert, Bryant, and Bankes 2008). Model-based scenario discovery approaches are used to generate a large set of scenarios, but these scenarios might be unacceptable if they do not match certain policies or specific requirements. Gerst, Wang, and Borsuk (2013) describe a multidimensional scenario discovery method which aims to define acceptable scenarios using two steps. The first step is to group the outcomes from simulation models using a hierarchical clustering analysis. This clustering analysis groups the outcomes based on several evaluation attributes. The second step is to use a classification and regression analysis to define the acceptable scenarios. Future research can extend the aims of this dissertation by formulating a scenario discovery approach that will help increase the accuracy of the modeling outcomes.

8.4.2 A Community-Driven Hypothesis: A Solution to Stakeholder Coordination Failures

One of the main difficulties of resilience analysis and the study of scenarios is understanding the fluid role of the participation of each stakeholder. The innovation of the framework presented in this dissertation is that it addresses the influences of the dynamic behavior of multiple groups of stakeholders to priorities.

Projects that have multiple stakeholders are notorious for having a diversity of objectives and interests which generate conflicts and disagreements among stakeholders. These contexts are described as coordination failures, defined as a lack of consensus related to the tradeoffs and opportunities associated with the use of a property (Palma-Oliveira et al. 2017). The methods of this dissertation can be extended by providing a precise orientation on how to work directly with stakeholder groups to overcome particular kinds of coordination failure.

There are several proposals with this aim that differ in the amount of shared information and the amount of power given to the discussion process. The most recent of these is called *community-driven hypothesis testing*, which uses a two-step procedure that can address public mistrust (Palma-Oliveira et al. 2017). The procedure addresses initial public resistance to new projects using community-driven hypothesis testing to help overcome certain coordination failures.

8.4.3 The Granularity of the Prioritization Analysis

Future research can improve the granularity of the prioritization analysis. For example, if the number of prioritized initiatives is more than 100, then the difference between the 45th and the 50 rank is not really meaningful. This scalability issue can be addressed by providing a more granular prioritization scale or set of classifications. This research opportunity involves exploring the scalability of issues both for scenarios and for initiatives.

8.5 Conclusion

This research contributes to the theory, methodology, and practice of risk analysis by conceptualizing an enterprise resilience analytics framework for evaluating the influences of two modes of disruptions (i.e., scenarios and multiple groups of stakeholders) to priorities. The framework integrates and extends recent scenario-based preferences modeling (**Almutairi** et al. 2017b; Collier et al. 2017; Thorisson et al. 2017b; Collier et al. 2016; Hamilton et al. 2016; Connelly et al. 2015; Lambert et al. 2011) and a stakeholder mapping approach (Cairns, Goodwin, and Wright 2016; Rosso et al. 2014; Mendelow 1981). The innovation of the present study is that it addresses the influence of the participation level (i.e., the level of power and interest) of each group of stakeholders across all the scenarios. A group that has a high level of participation at the baseline scenario can have a significant impact on the prioritization of enterprise initiatives; however, this group will have less impact if its participation level is low in other scenarios.

This resilience analytics framework can be used as a guideline for identifying the most disruptive scenarios and the most robust initiatives for each group of stakeholders and for the multiple groups of stakeholders. This framework is recommended for projects that have limited resources, since the modeling outcomes are relatively important to all the groups of stakeholders based on their participation levels. In other words, the modeling outcomes are designed not only to satisfy the needs of one group, but also to satisfy the needs of almost all the groups, based on how high their participation levels are.

To conclude, the research accomplished in this dissertation has been disseminated in engineering systems and risk analysis journals (Almutairi et al. 2017a; Almutairi et al. 2017b; Almutairi et al. 2017c; Thorisson et al. 2017a) and in conference presentations (Almutairi and Lambert 2017a, 2017b, 2017c; Alsultan et al. 2016).

REFERENCES

AAPA, (American Association of Port Authorities). 2007. D-11: Embracing the Concept of Sustainability as a Standard Practice for Ports and the Association. http://aapa.files.cmsplus.com/PDFs/sustainability_resolutions.pdf.

Akhavan-Rezai, Elham, Mostafa F Shaaban, Ehab F El-Saadany, and Fakhri Karray. 2016. "Online Intelligent Demand Management of Plug-in Electric Vehicles in Future Smart Parking Lots." *IEEE Systems Journal* 10 (2):483-494.

Allen, CH. 2012. "Future Ports Scenarios for 21st Century Port Strategic Planning." *Journal of Transportation Law, Logistics & Policy* 79 (2):89 - 137.

Almutairi, Ayedh, Zachary A. Collier, Daniel Hendrickson, José M. Palma-Oliveira, Thomas L. Polmateer, and James H. lambert. 2017a. "Stakeholder Mapping and Risk Scenarios with Application to Resilience of a Container Port." *Journal of Reliability Engineering and System Safety*. (Submitted)

Almutairi, Ayedh, and James H. Lambert. 2017a. "How Resilience Analytics Addresses Several Participants Disrupting Priorities for Infrastructure Systems." Society for Risk Analysis 2017 Annual Meeting, Arlington, VA, USA, December 2017.

Almutairi, Ayedh, and James H. Lambert. 2017b. "Modeling and Simulation of Capacity Expansion at a Major Container Port." University of Virginia Engineering Research Symposium (UVERS), Charlottesville, VA, usa, April 30, 2017.

Almutairi, Ayedh, and James H. Lambert. 2017c. "Participatory Factors and the Influence of Scenarios to Priorities with Application to Mobile Smart Grid." Society for Risk Analysis-Europe Annual Conference, Lisbon, Portugal, 21 June 2017.

Almutairi, Ayedh, Heimir Thorisson, John P. Wheeler, David L. Slutzky, and James H. Lambert. 2017b. "Scenario-Based Preferences in Development of Advanced Mobile Grid Services and a Bidirectional Charger Network." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*.

Almutairi, Ayedh, John P. Wheeler, David L. Slutzky, and James H. Lambert. 2017c. "Integrating Stakeholder Mapping and Risk Scenarios to Improve Resilience of Cyber-Physical-Social Networks." *Wiley Journal Risk Analysis. Special issue on Resilience Analytics for Cyber-Physical-Social-Networks*. (Submitted)

Alsultan, Marwan, Heimir Thorisson, **Ayedh Almutairi**, Zachary A. Collier, David L. Slutzky, John P. Wheeler, and James H. Lambert. 2016. "Risk Analysis and Systems Integration of Fleet Electric Vehicles with the Power Grid." Society for Risk Analysis 2016 Annual Meeting, San Diego, CA, USA, December 2016.

Andrijcic, Eva, and Yacov Y Haimes. 2016. "Metamodeling of Interdependent Systems: Application to Bridge Infrastructure Management." *Journal of Infrastructure Systems* 23 (2):04016028.

Aven, Terje. 2011. "On Some Recent Definitions and Analysis Frameworks for Risk, Vulnerability, and Resilience." *Risk Analysis* 31 (4):515-522.

Ayyub, Bilal M. 2014a. "Systems Resilience for Multihazard Environments: Definition, Metrics, and Valuation for Decision Making." *Risk Analysis* 34 (2):340-355.

Ayyub, Bilal M. 2014b. "Systems Resilience for Multihazard Environments: Definition, Metrics, and Valuation for Decision Making." *Risk Analysis: An International Journal* 34 (2):340-355.

Bakker, Sjoerd, Kees Maat, and Bert van Wee. 2014. "Stakeholders Interests, Expectations, and Strategies Regarding the Development and Implementation of Electric Vehicles: The Case of the Netherlands." *Transportation Research Part A: Policy and Practice* 66:52-64.

Barker, Kash, James H Lambert, Christopher W Zobel, Andrea H Tapia, Jose E Ramirez-Marquez, Laura Albert, Charles D Nicholson, and Cornelia Caragea. 2017. "Defining Resilience Analytics for Interdependent Cyber-Physical-Social Networks." *Sustainable and Resilient Infrastructure* 2 (2):59-67.

Belton, Valerie, and Theodor Stewart. 2002a. *Multiple Criteria Decision Analysis: An Integrated Approach*: Springer Science & Business Media.

Belton, Valerie, and Theodor J. Stewart. 2002b. *Multiple Criteria Decision Analysis: An Integrated Approach*. Boston: Kluwer Academic Publishers.

Bentaleb, Fatimazahra, Charif Mabrouki, and Alami Semma. 2015. "A Multi-Criteria Approach for Risk Assessment of Dry Port-Seaport System." Supply Chain Forum: An International Journal.

Berle, Øyvind, Bjørn Egil Asbjørnslett, and James B. Rice. 2011. "Formal Vulnerability Assessment of a Maritime Transportation System." *Reliability Engineering and System Safety* 96 (6):696-705. doi: 10.1016/j.ress.2010.12.011.

Blumsack, Seth. 2017. "Regional Transmission Organizations." https://www.eeducation.psu.edu/eme801/node/535.

Brooke, J. 2002. "Stakeholder Participation in Port Development Decision Making: How?, Where? And When." Proceedings of the 30th International Navigation Congress (PIANC 2002), Sydney, Australia.

Bryant, Benjamin P., and Robert J. Lempert. 2010. "Thinking inside the Box: A Participatory, Computer-Assisted Approach to Scenario Discovery." *Technological Forecasting and Social Change* 77 (1):34-49. doi: http://dx.doi.org/10.1016/j.techfore.2009.08.002.

Buede, Dennis M, and William D Miller. 2016. *The Engineering Design of Systems: Models and Methods*: John Wiley & Sons.

Cairns, George, Paul Goodwin, and George Wright. 2016. "A Decision-Analysis-Based Framework for Analysing Stakeholder Behaviour in Scenario Planning." *European Journal of Operational Research* 249 (3):1050-1062.

Coeck, C., E. Haezendonck, and T. Notteboom. 1999. *The Competitiveness of Seaports: Business and Government Agenda's in Strategic Planning*: RUCA.

Collier, Zachary A., Elizabeth B. Connelly, Thomas L. Polmateer, and James H. Lambert. 2017a. "Value Chain for Next-Generation Biofuels: Resilience and Sustainability of the Product Life Cycle." *Environment Systems and Decisions* 37 (1):22-33.

Collier, Zachary A., Elizabeth B. Connelly, Heimir Thorisson, James H. Lambert, F. Asce, and F. Sra. 2016. "Resilience of Initiatives to Shifting Management Priorities under Emergent and Future Conditions." Systems Conference (SysCon), 2016 Annual IEEE.

Collier, Zachary A., Daniel Hendrickson, Thomas L. Polmateer, and James H. Lambert. 2017b. "Scenario Analysis and Pert/Cpm with Application to Strategic Investment at an

Automated Container Port." *IEEE Transactions on Engineering Management*. (Submitted)

Connelly, Elizabeth. 2016. "Resilience Analysis and Value of Information with Application to Aviation Biofuels." University of Virginia.

Connelly, Elizabeth B, Lisa M Colosi, Andres F Clarens, and James H Lambert. 2015. "Risk Analysis of Biofuels Industry for Aviation with Scenario-Based Expert Elicitation." *Systems Engineering* 18 (2):178-191.

Connelly, Elizabeth B, and James H Lambert. 2016. "Resilience Analytics of a Future Supply Chain for Aviation Biofuels." *Transportation Research Record: Journal of the Transportation Research Board* (2600):39-48.

Connelly, Elizabeth B, James H Lambert, F Asce, and F Sra. 2016a. "Resilience Analytics in Systems Engineering with Application to Aviation Biofuels." Systems Conference (SysCon), 2016 Annual IEEE.

Connelly, Elizabeth B, Heimir Thorisson, L James Valverde Jr, and James H Lambert. 2016b. "Asset Risk Management and Resilience for Flood Control, Hydropower, and Waterways." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 2 (4):04016001.

Connelly, Elizabeth B., Heimir Thorisson, James L. Valverde, and James H. Lambert. 2016c. "Asset Risk Management and Resilience for Flood Control, Hydropower, and Waterways." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 2 (4):04016001.

Dalal, S., B. Han, R. Lempert, A. Jaycocks, and A. Hackbarth. 2013. "Improving Scenario Discovery Using Orthogonal Rotations." *Environmental Modelling & Software* 48:49-64. doi: http://dx.doi.org/10.1016/j.envsoft.2013.05.013.

Damiano, Alfonso, Gianluca Gatto, Ignazio Marongiu, Mario Porru, and Alessandro Serpi. 2014. "Vehicle-to-Grid Technology: State-of-the-Art and Future Scenarios." *Journal of Energy and Power Engineering* 8 (1):152.

De Langen, Peter W. 2006. "Stakeholders, Conflicting Interests and Governance in Port Clusters." *Research in Transportation Economics* 17:457-477.

Dean, Jr James W., and Mark P. Sharfman. 1993. "Procedural Rationality in the Strategic Decision-Making Process." *Journal of Management Studies* 30 (4):587-610.

Denholm, P, and W Short. 2006. "An Evaluation of Utility System Impacts and Benefits of Optimally Dispatched." *National Renewable Energy Laboratory, Tech. Rep. NREL/TP-620-40293*.

Denktas-Sakar, Gul, and Cimen Karatas-Cetin. 2012. "Port Sustainability and Stakeholder Management in Supply Chains: A Framework on Resource Dependence Theory." *The Asian Journal of Shipping and Logistics* 28 (3):301-319.

Dooms, Michael, and Cathy Macharis. 2003. "A Framework for Sustainable Port Planning in Inland Ports: A Multistakeholder Approach."

Fath, Brian D., Carly A. Dean, and Harald Katzmair. 2015. "Navigating the Adaptive Cycle: An Approach to Managing the Resilience of Social Systems." *Ecology & Society* 20 (2):292-301. doi: 10.5751/ES-07467-200224.

Fernandez, Luis Pieltain, Tomás Gomez San Roman, Rafael Cossent, Carlos Mateo Domingo, and Pablo Frias. 2011. "Assessment of the Impact of Plug-in Electric Vehicles on Distribution Networks." *IEEE Transactions on Power Systems* 26 (1):206-213.

Finlay, Paul N, and Morteza Forghani. 1998. "A Classification of Success Factors for Decision Support Systems." *The Journal of Strategic Information Systems* 7 (1):53-70.

Freeman, Edward R. 1984. *Strategic Management: A Stakeholder Approach (Boston: Pitman, 1984)*.

Gallego-Ayala, Jordi, and Dinis Juízo. 2014. "Integrating Stakeholders' Preferences into Water Resources Management Planning in the Incomati River Basin." *Water resources management* 28 (2):527-540.

Gerst, M. D., P. Wang, and M. E. Borsuk. 2013. "Discovering Plausible Energy and Economic Futures under Global Change Using Multidimensional Scenario Discovery." *Environmental Modelling & Software* 44:76-86. doi: http://dx.doi.org/10.1016/j.envsoft.2012.09.001.

Gharehgozli, Amir Hossein, Joan Mileski, Alyssa Adams, and Wyndylyn Von Zharen. 2017. "Evaluating a "Wicked Problem": A Conceptual Framework on Seaport Resiliency in the Event of Weather Disruptions." *Technological Forecasting & Social Change* 121:65-75. doi: 10.1016/j.techfore.2016.11.006.

Godet, Michel. 2011. *Scenarios and Strategic Management*: Boston: Butterworths.

Goodwin, P., and G. Wright. 2010. *Decision Analysis for Management Judgment*. Fourth ed: Wiley.

Goodwin, Paul, and George Wright. 2001. "Enhancing Strategy Evaluation in Scenario Planning: A Role for Decision Analysis." *Journal of Management Studies* 38 (1):1-16.

Goss, Richard O. 1990. "Economic Policies and Seaports: The Economic Functions of Seaports." *Maritime Policy & Management* 17 (3):207-219.

Gravener, Mark H, and Chika Nwankpa. 1999. "Available Transfer Capability and First Order Sensitivity." *IEEE Transactions on Power Systems* 14 (2):512-518.

Greco, Salvatore, J Figueira, and M Ehrgott. 2005. "Multiple Criteria Decision Analysis." *Springer's International series*.

Greenley, Gordon E, and Gordon R Foxall. 1997. "Multiple Stakeholder Orientation in Uk Companies and the Implications for Company Performance." *Journal of Management Studies* 34 (2):259-284.

Gregory, Robin, and Ralph L Keeney. 2017. "A Practical Approach to Address Uncertainty in Stakeholder Deliberations." *Risk Analysis* 37 (3):487-501.

Grigalunas, Thomas, Meifeng Luo, and Yong-Tae Chang. 2001. Comprehensive Framework for Sustainable Container Port Development for the United States East Coast: Year One Final Report.

Groves, David G., and Robert J. Lempert. 2007. "A New Analytic Method for Finding Policy-Relevant Scenarios." *Global Environmental Change* 17 (1):73-85. doi: https://doi.org/10.1016/j.gloenvcha.2006.11.006.

Haimes, Yacov Y. 2009a. "On the Complex Definition of Risk: A Systems-Based Approach." *Risk analysis* 29 (12):1647-1654.

Haimes, Yacov Y. 2012. "Systems-Based Guiding Principles for Risk Modeling, Planning, Assessment, Management, and Communication." *Risk analysis* 32 (9):1451-1467.

Haimes, Yacov Y. 2009b. "On the Definition of Resilience in Systems." *Risk Analysis: An International Journal* 29 (4):498-501. doi: 10.1111/j.1539-6924.2009.01216.x.

Haimes, Yacov Y. 2015. *Risk Modeling, Assessment, and Management*: John Wiley & Sons.

Hamilton, Michelle. 2014. "Scenario-Based Preferences in Risk Analysis and Systems Engineering: Evolution through Time Frames." Doctoral dissertation PHD Systems Engineering, 2014.

Hamilton, Michelle C, James H Lambert, and L James Valverde Jr. 2015. "Climate and Related Uncertainties Influencing Research and Development Priorities." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 1 (2):04015005.

Hamilton, Michelle C., James H. Lambert, Elizabeth B. Connelly, and Kash Barker. 2016. "Resilience Analytics with Disruption of Preferences and Lifecycle Cost Analysis for Energy Microgrids." *Reliability Engineering & System Safety* 150:11-21.

Hamilton, Michelle C., James H. Lambert, Jeffrey M. Keisler, Franklin H. Holcomb, and Igor Linkov. 2012. "Research and Development Priorities for Energy Islanding of Military and Industrial Installations." *Journal of Infrastructure Systems* 19 (3):297-305.

Hamilton, Michelle C., James H. Lambert, and James L. Valverde. 2015. "Climate and Related Uncertainties Influencing Research and Development Priorities." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 1 (2):04015005.

Han, Sekyung, and Soohee Han. 2013. "Economic Feasibility of V2g Frequency Regulation in Consideration of Battery Wear." *Energies* 6 (2):748-765.

Henesey, Lawrence, Theo Notteboom, and Paul Davidsson. 2003. "Agent-Based Simulation of Stakeholders Relations: An Approach to Sustainable Port and Terminal Management." *Multi-Agent Systems for Container Terminal Management* 99.

Hines, Paul, Jeff Frolik, Jeffrey Marshall, Pooya Rezaei, Andrew Seier, Andrew Fuhrmann, Jonathan Dowds, and Alexander Hilshey. 2014. Understanding and Managing the Impacts of Electric Vehicles on Electric Power Distribution Systems.

Hiranandani, Vijay. 2014. "Sustainable Development in Seaports: A Multi-Case Study." *WMU Journal of Maritime Affairs* 13 (1):127-172.

Holling, C S. 1973. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics* 4 (1):1-23. doi: 10.1146/annurev.es.04.110173.000245.

Hosseini, Seyedmohsen, Kash Barker, and Jose E. Ramirez-Marquez. 2016. "A Review of Definitions and Measures of System Resilience." *Reliability Engineering & System Safety* 145 (Supplement C):47-61. doi: https://doi.org/10.1016/j.ress.2015.08.006.

Huss, William R. 1988. "A Move toward Scenario Analysis." *International Journal of Forecasting* 4 (3):377-388. doi: http://dx.doi.org/10.1016/0169-2070(88)90105-7.

International Energy Agency. 2013. "Global Ev Outlook: Understanding the Electric Vehicle Landscape to 2020."

Johnson, Gerry, Kevan Scholes, and Richard Whittington. 2008. *Exploring Corporate Strategy: Text & Cases*: Pearson Education.

Kabeer, Naila. 1999. *The Conditions and Consequences of Choice: Reflections on the Measurement of Women's Empowerment*. Vol. 108: UNRISD Geneva.

Karvetski, C. W., and J. H. Lambert. 2012a. "Evaluating Deep Uncertainties in Strategic Priority-Setting with an Application to Facility Energy Investments." *Syst. Eng.* 15:483.

Karvetski, Christopher W, and James H Lambert. 2012b. "Evaluating Deep Uncertainties in Strategic Priority-Setting with an Application to Facility Energy Investments." *Systems Engineering* 15 (4):483-493.

Karvetski, Christopher W, James H Lambert, Jeffrey M Keisler, Bruce Sexauer, and Igor Linkov. 2011. "Climate Change Scenarios: Risk and Impact Analysis for Alaska Coastal Infrastructure." *International Journal of Risk Assessment and Management* 15 (2-3):258-274.

Karvetski, Christopher W, James H Lambert, and Igor Linkov. 2009. "Emergent Conditions and Multiple Criteria Analysis in Infrastructure Prioritization for Developing Countries." *Journal of Multi‐Criteria Decision Analysis* 16 (5-6):125-137.

Karvetski, Christopher W. 2011. "Scenario-Based Preferences with Multicriteria Analysis for Strategic Design." 2011.

Keeney, Ralph L. 1992. Value-Focused Thinking: A Path to Creative Decision Analysis. Harvard University Press, Cambridge.

Kempton, Willett, and Jasna Tomić. 2005. "Vehicle-to-Grid Power Fundamentals: Calculating Capacity and Net Revenue." *Journal of power sources* 144 (1):268-279.

Kempton, Willett, Victor Udo, Ken Huber, Kevin Komara, Steve Letendre, Scott Baker, Doug Brunner, and Nat Pearre. 2008. "A Test of Vehicle-to-Grid (V2g) for Energy Storage and Frequency Regulation in the Pjm System." *Results from an Industry-University Research Partnership* 32.

Kendall, M. G., and B. Babington Smith. 1939. "The Problem of M Rankings." *Ann. Math. Statist.* 10 (3):275-287. doi: 10.1214/aoms/1177732186.

Kwakkel, Jan H., Willem L. Auping, and Erik Pruyt. 2013. "Dynamic Scenario Discovery under Deep Uncertainty: The Future of Copper." *Technological Forecasting and Social Change* 80 (4):789-800. doi: http://dx.doi.org/10.1016/j.techfore.2012.09.012.

Lambert, J. H. 2012. "Prioritizing Infrastructure Investments in Afghanistan with Multiagency Stakeholders and Deep Uncertainty of Emergent Conditions." *J. Infrastruct. Syst.*:155.

Lambert, James H, Christopher W Karvetski, David K Spencer, Barbara J Sotirin, Dawn M Liberi, Hany H Zaghloul, John B Koogler, Samuel L Hunter, William D Goran, and Renae D Ditmer. 2011. "Prioritizing Infrastructure Investments in Afghanistan with Multiagency Stakeholders and Deep Uncertainty of Emergent Conditions." *Journal of Infrastructure Systems* 18 (2):155-166.

Lambert, James H, Christopher W Karvetski, David K Spencer, Barbara J Sotirin, Dawn M Liberi, Hany H Zaghloul, John B Koogler, Samuel L Hunter, William D Goran, and Renae D Ditmer. 2012a. "Prioritizing Infrastructure Investments in Afghanistan with Multiagency Stakeholders and Deep Uncertainty of Emergent Conditions." *Journal of Infrastructure Systems* 18 (2):155-166.

Lambert, James H., Yao-Jan Wu, Haowen You, Andres Clarens, and Brian Smith. 2012b. "Climate Change Influence on Priority Setting for Transportation Infrastructure Assets." *Journal of Infrastructure Systems* 19 (1):36-46.

Lambert, James H., Yao-Jan Wu, Haowen You, Andres Clarens, and Brian Smith. 2013. "Climate Change Influence on Priority Setting for Transportation Infrastructure Assets." *Journal of Infrastructure Systems* 19 (1):36-46. doi: 10.1061/(asce)is.1943-555x.0000094.

Lempert, Robert J, Benjamin P Bryant, and Steven C Bankes. 2008. "Comparing Algorithms for Scenario Discovery." *RAND, Santa Monica, CA.*

Li, Na, Gang Chen, Kannan Govindan, and Zhihong Jin. 2016. "Disruption Management for Truck Appointment System at a Container Terminal: A Green Initiative." *Transportation*

Research Part D: Transport and Environment. doi: https://doi.org/10.1016/j.trd.2015.12.014.

Louis, Garrick E., and Luna Magpili. 2007. "A Life-Cycle Capacity-Based Approach to Allocating Investments in Municipal Sanitation Infrastructure." *Structure and Infrastructure Engineering* 3 (2):121-131.

Lowrance, William W. 1976. *Of Acceptable Risk: Science and the Determination of Safety*. Los Altos, Calif: W. Kaufmann.

Ma, Zhongjing, Duncan S Callaway, and Ian A Hiskens. 2013. "Decentralized Charging Control of Large Populations of Plug-in Electric Vehicles." *IEEE Transactions on Control Systems Technology* 21 (1):67-78.

Mansouri, Mo, Roshanak Nilchiani, and Ali Mostashari. 2009. "A Risk Management-Based Decision Analysis Framework for Resilience in Maritime Infrastructure and Transportation Systems." Systems Conference, 2009 3rd Annual IEEE.

Mansouri, Mo, Brian Sauser, and Dr. John Boardman. 2009. "Applications of Systems Thinking for Resilience Study in Maritime Transportation System of Systems." IEEE SysCon 2009 —3rd Annual IEEE International Systems Conference, Vancouver, Canada.

Marashi, Emad, and John P. Davis. 2006. "An Argumentation-Based Method for Managing Complex Issues in Design of Infrastructural Systems." *Reliability Engineering & System Safety* 91 (12):1535-1545.

Markel, T, A Meintz, K Hardy, B Chen, and T Bohn. 2015. Multi-Lab Ev Smart Grid Integration Requirements Study. NREL.

Martinez, Lauro J., James H. Lambert, and Christopher W. Karvetski. 2011. "Scenario-Informed Multiple Criteria Analysis for Prioritizing Investments in Electricity Capacity Expansion." *Reliability Engineering & System Safety* 96 (8):883-891.

Masoum, Amir S, Sara Deilami, PS Moses, MAS Masoum, and Ahmed Abu-Siada. 2011. "Smart Load Management of Plug-in Electric Vehicles in Distribution and Residential Networks with Charging Stations for Peak Shaving and Loss Minimisation Considering Voltage Regulation." *IET Generation, Transmission & Distribution* 5 (8):877-888.

McDermid, John A. 2000. "Complexity: Concept, Causes and Control." Engineering of Complex Computer Systems, 2000. ICECCS 2000. Proceedings. Sixth IEEE International Conference on.

Mendelow, Aubrey L. 1981. "Environmental Scanning-the Impact of the Stakeholder Concept." ICIS.

Merrill, Christopher H, Vincent H Lam, Max J Van Vleet, Murat S Chatti, Madeleine C Brannon, Elizabeth B Connelly, James H Lambert, David L Slutzky, and John P Wheeler. 2015. "Modeling and Simulation of Fleet Vehicle Batteries for Integrated Logistics and Grid Services." Systems and Information Engineering Design Symposium (SIEDS), 2015.

Moffatt & Nichol. 2016. Draft Consulting Engineer's Report Mofatt & Nichol, Long Beach, CA, USA. http://www.portofvirginia.com/wp-content/uploads/2016/09/160914-2016-PoV-Consulting-Engineers-Report-Draft-_Redacted.pdf.

Mok, Ka Yan, Geoffrey Qiping Shen, and Jing Yang. 2015. "Stakeholder Management Studies in Mega Construction Projects: A Review and Future Directions." *International Journal of Project Management* 33 (2):446-457.

Montibeller, Gilberto, and Alberto Franco. 2010. "Multi-Criteria Decision Analysis for Strategic Decision Making." *Handbook of multicriteria analysis*:25-48.

Moslehi, Khosrow, and Ranjit Kumar. 2010. "A Reliability Perspective of the Smart Grid." *IEEE Transactions on Smart Grid* 1 (1):57-64.

Muttoni, Ignacio Bautista. 2015. Ev-Smart Grid Integration. LGI Consulting. http://www.lgi-consulting.com/wp-content/uploads/2016/01/Innovation-outlook-EV-grid.pdf.

Neslo, R. E. J., and R. M. Cooke. 2011. "Modeling and Validating Stakeholder Preferences with Probabilistic Inversion." *Applied Stochastic Models in Business & Industry* 27 (2):115 -130. doi: 10.1002/asmb.888.

Nguyen, Lam Canh, and Theo Notteboom. 2016. "A Multi-Criteria Approach to Dry Port Location in Developing Economies with Application to Vietnam." *The Asian Journal of Shipping and Logistics* 32 (1):23-32.

Nijdam, MH. , and IV. Romochkina. 2012. Cassandra – D6.1 - Final – Stakeholder Analysis. EUROPEAN COMMISSION. http://www.cassandraproject.eu/userdata/file/Public%20deliverables/Cassandra%20D6.1%20-%20FINAL%20-Stakeholder%20analysis.pdf.

Pajunen, Kalle. 2006. "Stakeholder Influences in Organizational Survival." *Journal of Management Studies* 43 (6):1261-1288.

Palma-Oliveira, José Manuel, Benjamin D. Trump, Matthew D. Wood, and Igor Linkov. 2017. "Community-Driven Hypothesis Testing: A Solution for the Tragedy of the Anticommons." *Risk Analysis*.

Peris-Mora, E., Diez JM. Orejas, A. Subirats, S. Ibáñez, and P. Alvarez. 2005. "Development of a System of Indicators for Sustainable Port Management." *Marine Pollution Bulletin* 50 (12):1649-1660.

Peterson, Garry D, Graeme S Cumming, and Stephen R Carpenter. 2003. "Scenario Planning: A Tool for Conservation in an Uncertain World." *Conservation biology* 17 (2):358-366.

Phillips, Lawrence D. 2007. "Decision Conferencing." In *Advances in Decision Analysis: From Foundations to Applications*, edited by D. von Winterfeldt, R. F. Miles Jr and W. Edwards, 375-399. Cambridge: Cambridge University Press.

Pless, Jacquelyn, Douglas J Arent, Jeffrey Logan, Jaquelin Cochran, Owen Zinaman, and Camila Stark. 2015. Pathways to Decarbonization. Natural Gas and Renewable Energy. Lessons Learned from Energy System Stakeholders. National Renewable Energy Laboratory (NREL), Golden, CO (United States).

Pomeroy, Robert, and Fanny Douvere. 2008. "The Engagement of Stakeholders in the Marine Spatial Planning Process." *Marine Policy* 32 (5):816-822.

Port of Virginia. 2015. 2065 Master Plan: Executive Summary. Port of Virginia, Norfolk, VA, USA. http://www.portofvirginia.com/wp-content/uploads/2016/02/TPOV-master-plan-2065-final-020316.pdf.

Postma, Theo J. B. M., and Franz Liebl. 2005. "How to Improve Scenario Analysis as a Strategic Management Tool?" *Technological Forecasting & Social Change* 72 (2):161-173. doi: 10.1016/j.techfore.2003.11.005.

Qureshi, ME, Steve R Harrison, and MK Wegener. 1999. "Validation of Multicriteria Analysis Models." *Agricultural Systems* 62 (2):105-116.

Rezaei, Pooya, Jeff Frolik, and Paul DH Hines. 2014. "Packetized Plug-in Electric Vehicle Charge Management." *IEEE Transactions on Smart Grid* 5 (2):642-650.

Rogerson, Ellen C., and James H. Lambert. 2012. "Prioritizing Risks Via Several Expert Perspectives with Application to Runway Safety." *Reliability Engineering & System Safety* 103:22-34.

Rose, Kenneth H. 2013. "A Guide to the Project Management Body of Knowledge (Pmbok® Guide)—Fifth Edition." *Project Management Journal* 44 (3):e1-e1. doi: 10.1002/pmj.21345.

Rosso, Maurizio, M. Bottero, S. Pomarico, S. La Ferlita, and Elena Comino. 2014. "Integrating Multicriteria Evaluation and Stakeholders Analysis for Assessing Hydropower Projects." *Energy Policy* 67:870-881.

Saaty, Thomas L. 2008. "Decision Making with the Analytic Hierarchy Process." *International journal of services sciences* 1 (1):83-98.

Schilling, Martin S, Nadine Oeser, and Cornelius Schaub. 2007. "How Effective Are Decision Analyses? Assessing Decision Process and Group Alignment Effects." *Decision Analysis* 4 (4):227-242.

Schoemaker, Paul JH. 1995. "Scenario Planning: A Tool for Strategic Thinking." *Sloan management review* 36 (2):25.

Schwabe, Paul, Michael Mendelsohn, Felix Mormann, and Doug Arent. 2012. "Mobilizing Public Markets to Finance Renewable Energy Projects: Insights from Expert Stakeholders."

SEBoK. 2017. "Systems Engineering Management." Hoboken, NJ: The Trustees of the Stevens Institute of Technology ©2017, Last Modified 2 December 2015 13:58 UTC Accessed

02 Jul 2017. http://sebokwiki.org/w/index.php?title=Systems_Engineering_Management&oldid=51742.

Shaw, Duncan R., Andrew Grainger, and Kamal Achuthan. 2017. "Multi-Level Port Resilience Planning in the Uk: How Can Information Sharing Be Made Easier?" *Technological Forecasting and Social Change* 121:126-138.

Shepard, Scott, and John Gartner. 2013. Executive Summary: Vehicle to Grid Technologies. Navigant Consulting, Inc. http://www.navigantresearch.com/wp-content/uploads/2013/10/V2G-13-Executive-Summary.pdf.

Sheskin, David J. 2003. *Handbook of Parametric and Nonparametric Statistical Procedures*: crc Press.

Starr, Randy, Jim Newfrock, and Michael Delurey. 2003. "Enterprise Resilience: Managing Risk in the Networked Economy." *Strategy and Business* 30:70-79.

Stewart, Theodor J. 1996. "Robustness of Additive Value Function Methods in Mcdm." *Journal of Multi‐Criteria Decision Analysis* 5 (4):301-309.

Stewart, Theodor J, Simon French, and Jesus Rios. 2013. "Integrating Multicriteria Decision Analysis and Scenario Planning—Review and Extension." *Omega* 41 (4):679-688.

Talantsev, Anton. 2017. "Who Gains and Who Loses in the Shift to Electric Vehicles: Impact Assessment through Multi-Criteria Multi-Stakeholder Analysis." *Procedia Environmental Sciences* 37:257-268.

Teng, Kuei-Yung, Shital A. Thekdi, and James H. Lambert. 2012. "Identification and Evaluation of Priorities in the Business Process of a Risk or Safety Organization." *Reliability Engineering & System Safety* 99:74-86.

Thorisson, Heimir, **Ayedh Almutairi**, John P Wheeler, David L Slutzky, and James H lambert. 2017a. "Enterprise Management and Systems Engineering for a Mobile Power Grid." 25th International Conference on Systems Engineering, Las Vegas, NV, USA, 22-24 August

Thorisson, Heimir, James H. Lambert, John J. Cardenas, and Igor Linkov. 2017b. "Resilience Analytics with Application to Power Grid of a Developing Region." *Risk Analysis* 37 (7):1268-1286. doi: 10.1111/risa.12711.

Thorisson, Heimir, James H. Lambert, John J. Cardenas, and Igor Linkov. 2017c. "Resilience Analytics with Application to Power Grid of a Developing Region." *Risk Analysis*:n/a-n/a. doi: 10.1111/risa.12711.

Timmermans, Daniëlle, and Charles Vlek. 1996. "Effects on Decision Quality of Supporting Multi-Attribute Evaluation in Groups." *Organizational Behavior and Human Decision Processes* 68 (2):158-170.

Tomić, Jasna, and Willett Kempton. 2007. "Using Fleets of Electric-Drive Vehicles for Grid Support." *Journal of Power Sources* 168 (2):459-468.

Tremblay, Olivier, Louis-A Dessaint, and Abdel-Illah Dekkiche. 2007. "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles." Vehicle Power and Propulsion Conference, 2007. VPPC 2007. IEEE.

Tversky, Amos, and Daniel Kahneman. 1983. "Extensional Versus Intuitive Reasoning: The Conjunction Fallacy in Probability Judgment." *Psychological review* 90 (4):293.

Tversky, Amos, and Daniel Kahneman. 1985. "The Framing of Decisions and the Psychology of Choice." In *Environmental Impact Assessment, Technology Assessment, and Risk Analysis*, 107-129. Springer.

Tweed, Katherine. 2014. "What the Court Decision on Ferc Order 745 Means for Demand Response." Accessed 04/10/2017. https://www.greentechmedia.com/articles/read/what-us-appeals-court-decision-on-ferc-order-745-means-for-demand-response.

U.S. Department of Energy. 2014a. 2014 Strategic Sustainability Performance Plan. http://energy.gov/sites/prod/files/2014/10/f18/doe_sspp_2014.pdf.

U.S. Department of Energy. 2014b. Strategic Sustainability Performance Plan. http://energy.gov/sites/prod/files/2014/10/f18/doe_sspp_2014.pdf.

U.S. Energy Information Administration. 2015. Annual Energy Outlook 2015. https://www.eia.gov/outlooks/archive/aeo15/pdf/0383(2015).pdf.

van der Heijden, Kees. 1996. *Scenarios: The Art of Strategic Conversation*. Chichester, England, New York: John Wiley & Sons.

Von Winterfeldt, Detlof, and Ward Edwards. 1986. *Decision Analysis and Behavioral Research*. Cambridge [Cambridgeshire], New York: Cambridge University Press.

Wade, Woody. 2012. *Scenario Planning: A Field Guide to the Future*. Hoboken, New Jersey: Wiley. Electronic Books.

Walker, Brian, Stephen Carpenter, John Anderies, Nick Abel, Graeme Cumming, Marco Janssen, Louis Lebel, Jon Norberg, Garry D. Peterson, and Rusty Pritchard. 2002. "Resilience Management in Social-Ecological Systems: A Working Hypothesis for a Participatory Approach." *Conservation Ecology (11955449)* 6 (1):203 - 219.

Walker, Derek HT, Lynda Margaret Bourne, and Arthur Shelley. 2008. "Influence, Stakeholder Mapping and Visualization." *Construction Management and Economics* 26 (6):645-658.

Wang, Jiang-Jiang, You-Yin Jing, Chun-Fa Zhang, and Jun-Hong Zhao. 2009. "Review on Multi-Criteria Decision Analysis Aid in Sustainable Energy Decision-Making."

Renewable and Sustainable Energy Reviews 13 (9):2263-2278. doi: 10.1016/j.rser.2009.06.021.

Wood, Matthew D, Ann Bostrom, Todd Bridges, and Igor Linkov. 2012. "Cognitive Mapping Tools: Review and Risk Management Needs." *Risk Analysis* 32 (8):1333-1348.

Wright, George, and George Cairns. 2011. "Augmented Scenario Approaches: Delving Deeper and Stretching Wider." In *Scenario Thinking: Practical Approaches to the Future,* 83-102. London: Palgrave Macmillan UK.

Yang, Yi-Chih, and Shu-Ling Chen. 2016. "Determinants of Global Logistics Hub Ports: Comparison of the Port Development Policies of Taiwan, Korea, and Japan." *Transport Policy* 45:179-189.

Yavuz, Mesut, Basar Oztaysi, Sezi Cevik Onar, and Cengiz Kahraman. 2015. "Multi-Criteria Evaluation of Alternative-Fuel Vehicles Via a Hierarchical Hesitant Fuzzy Linguistic Model." *Expert Systems with Applications* 42 (5):2835-2848.

You, Haowen. 2013. "Priority Setting and Integrated Assessment of Transportation System Vulnerabilities to Deep Uncertainties." Doctoral dissertation PHD, 2013.

You, Haowen, Elizabeth B. Connelly, James H. Lambert, and Andres F. Clarens. 2014a. "Climate and Other Scenarios Disrupt Priorities in Several Management Perspectives." *Environment Systems and Decisions* 34 (4):540-554.

You, Haowen, James H Lambert, Andres F Clarens, and Benjamin J McFarlane. 2014b. "Quantifying the Influence of Climate Change to Priorities for Infrastructure Projects." *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 44 (2):133-145.

APPENDIX A: SUPPORT OF MODEL VALIDATION: STAKEHOLDER SATISFACTION SURVEY

A.1 Overview

The appendix contains a sample of survey that was distributed to stakeholders to collect their feedback about the usefulness of the model and to assess the quality of the modeling outputs. This survey was submitted to stakeholders from the Commonwealth Center for Advanced Logistics Services (CCALS) and Fermata Energy LLC.

A.2 Research Description

The purpose of this dissertation is to fill an existing gap in systems engineering and risk analysis regarding the enterprise resilience. A disruptive event (e.g., economic crisis, natural disaster, etc.) changes the preferences of clients, stakeholders, decision makers, and others, which will lead to significant changes in the prioritization of the enterprise initiatives (e.g., priority of future projects, amount of future funds, etc.). The framework presented in this dissertation integrates a stakeholder classification approach called stakeholder mapping with scenario-based preferences modeling. Incorporating the stakeholder mapping approach helps to assess the influence of the participation levels of stakeholders across scenarios. Thus, the presented framework addresses the influences both of scenarios and of multiple groups of stakeholders to priorities.

The innovation of the present study is to address the influence of the participation level (i.e., the level of power and interest) of each group of stakeholders across all the scenarios. A group that has a high level of participation at the baseline scenario can have a significant impact on strategic plans; however, this group has less impact on the strategic plans if the participation level of this group is low at the time of some other scenario. This risk assessment framework can be used as a guideline for identifying the most disruptive scenarios and the most robust initiatives for each group of stakeholders and for the multiple groups of stakeholders. This framework is recommended for projects that have limited resources, since the modeling outcomes are relatively important to all the groups of stakeholders based on their participation levels. In other words, the modeling outcomes do not only satisfy the needs of one group, but are designed to satisfy the needs of almost all the groups based on how high their participation levels are.

A.3 Feedback from, Mr. Mark Manasco, President and Executive Director at the Commonwealth Center for Advanced Logistics Systems (CCALS)

1. Do you think that the resilience analytics framework demonstrated in the container port strategic planning case study offers an improvement on port strategic planning? (If possible, write 2-3 sentences)

   Absolutely, yes, based on that case study the POV adjusted one of their key performance indicators (KPIs) due mainly to the confidence they had in the analysis. Note these indicators had been in place for a substantial period of time and unchallenged. They were viewed as the best that could be achieved given the current tools and process used for measurement. It should also be noted this KPI was the key indicator of financial rewards for executive management, management that had the power to directly influence operation efficiency. This work reset the bar and established a new baseline for all planning efforts going forward.

2. Do you think that the resilience analytics framework improves the ability of risk analysts to prioritize sources of disruptions? (If possible, write 2-3 sentences)

   Yes, this framework provides a more granular approach to modeling. It allows a more detail approach to possible variations that influence the scope and scale of decisions. Consequences to immediate actions can be better traced and alternatives evaluated based on a set of desired outcome. Risk can be furthered modeled to better control outcomes.

3. Do you think that the resilience analytics framework improves the ability of risk analysts to prioritize planning initiatives based on their robustness to disruption? (If possible, write 2-3 sentences)

   Yes, see answer to #2. Planning in its simplest form is taking the future and brings it into the present in order to model it. The unknown (robustness to disruption) is always the greatest risk. The search is always for an ordered way to measure and bring it into the present to be factored it. The resilience analytics framework, in my view, accomplishes this. The Port operation is a very complex operation with multiple variables. It is not just several large variables that have multiple possibilities, but rather a huge amount of dynamic variable with multiple outcomes.

4. Do you think that integrating the stakeholder mapping approach with scenario-based preferences modeling is useful in this context? (If possible, write 2-3 sentences)

   Yes, this is why this approach is of interest to the customer. The Port sees the value of bring the other large variables into the equation (rail, shipping) to create a more holistic model. It is only by bringing the other two large variables into the equation can a true dynamic solutions be achieved.

5. Do you think that updating the modeling inputs after each decision workshop increases the usefulness of the methods? (If possible, write 2-3 sentences)

   Yes, it is a learning process. It is more incremental learning from the professionals as they have conformation on what they know to be true through experience and see through this tool what was previously unknown. Periodic updating reinforces the learning as it continues to draw on experience and known outcomes.

6. Do you think that the computational feasibility and transparency of the software workbook are useful in this context? (If possible, write 2-3 sentences)

   Not sure I understand the question. Transparency is always a useful thing when looking to have something widely adopted. The tool needs to be understood and the logic behind made plain to be used.

7. Do you think that this resilience analytics framework is generalizable to other fields of applications? (If possible, write 2-3 sentences)

   Absolutely yes I believe it has application to other fields. I think this is particular true in the fired of logistics. Technology is allowing machines or physical units of any kind to talk to one another. This will only become more pronounced as the technology advances. Government, industry, business, almost all endeavors of any size have what are characterized as logistical issues. In most logistics operations there are an infinite number of variables of all 'shapes and sizes'. Much is assumed and contingencies plans developed for the outlier emerging and future conditions. A tool like this would allow better analysis on a wider scale and thus a better utilization of resources.

A.4 Feedback from, Mr. Thomas Polmateer, a Logistics Research Systems Analyst at the Commonwealth Center for Advanced Logistics Systems (CCALS)

1. Do you think that the resilience analytics framework demonstrated in the container port strategic planning case study offers an improvement on port strategic planning? (If possible, write 2-3 sentences)

   Today, risks and uncertainty are magnified in large-scale systems such as global inter-modal port operations. In this specific case study, the research team identified several key themes of interest to the Port with regard to uncertainty, budgetary environments, capital expenditures, return on investment, and diversification of cargo types. The framework assisted key leaders in (1) optimizing the management's key performance indicators to reach their objectives and (2) refine their Strategic Plan.

2. Do you think that the resilience analytics framework improves the ability of risk analysts to prioritize sources of disruptions? (If possible, write 2-3 sentences)

   The framework links risks and strategy by identifying the key criteria and metrics that are important to the organization's mission, vision, and strategic plan. The process assessed relative disruptiveness in different future states and reported the key vulnerabilities and resilience of the initiatives. For the Port the framework reinforced some of their decisions, but more importantly, caused them to reexamine other capital improvement plans based on prioritized sources of disruption.

3. Do you think that the resilience analytics framework improves the ability of risk analysts to prioritize planning initiatives based on their robustness to disruption? (If possible, write 2-3 sentences)

   Probably the most important result for the Port was the value-added by examining initiatives in the context of robustness to disruptions. The key vulnerabilities and resilience of initiatives provides direct insights into short, medium, and long-term scheduling and planning.

4. Do you think that integrating the stakeholder mapping approach with scenario-based preferences modeling is useful in this context? (If possible, write 2-3 sentences)

   This is the next direction the Port is interested in. They feel in order to optimize their internal operations they need transparency and identified levels of interest and power with their external partners/stakeholders. The initial interests are with the container shipping stakeholders, the Class I railroads, barges, and trucking companies.

5. Do you think that updating the modeling inputs after each decision workshop increases the usefulness of the methods? (If possible, write 2-3 sentences)

   The models data is not static and stakeholders participation evolves. Updating the model inputs does a number of key actions. First, the decision workshop captures expert insights and captures intellectual buy-in from the participants. Second, it confirms the credibility of the model and methodology by continual refinement to ongoing initiatives and disruptions. Third, it sets the stage for the next effort to meet the evolving needs of the client.

6. Do you think that the computational feasibility and transparency of the software workbook are useful in this context? (If possible, write 2-3 sentences)

   I need more information on the intent and content of the software workbook. That being said, to institutionalize a model, systems, or process the underlying computations and project workbook are necessary tools.

7. Do you think that this resilience analytics framework is generalizable to other fields of applications? (If possible, write 2-3 sentences)

   When I think of fields of applications I think in terms of potential clients that can benefit from this framework. There is an application for the federal government; specifically DoD, FEMA, NASA and U.S. Post Office. These organizations have complex systems and diverse stakeholders that play a role in their strategic plans under emergent and future conditions. In addition, every trucking company, 3PL, and retailer, as a minimum, can use the framework to influence their economic business plan.

APPENDIX B: SIMULATION MODLEING

B.1 Overview

This appendix summarizes the effort and the scope of work for the simulation modeling. It lists all the site visits to the Port of Virginia along with purpose and date of each visit. In addition, it contains screenshots that show sample of simulation features, codes, and outputs. Finally, it shows a simulation poster that was selected for the University of Virginia graduate student award in the 13th Annual University of Virginia Engineering Research Symposium, March 30th, 2017.

B.2 Purpose of the Study

Table 49 describes the purpose of each group meeting with the Port of Virginia representatives, location of meeting, date, and the deliverables.

Table 49 Summary of the group meetings with the Port of Virginia representative along with the purpose of the meeting, location, date, and deliverables.

Purpose	Location of Meeting	Date	Deliverable
Describing the purpose and the scope of work of the study	Web-Meeting	November, 23rd 2015	PowerPoint Slides
Discussing an early prototype simulation model for VIG	Web-Meeting	December, 10th 2015	Simulation Model & PowerPoint Slides
Summary Statistics for Simulation Runs	Web-Meeting	February, 2nd 2016	Simulation Model & PowerPoint Slides
Exploring The VIG Port Dynamic System Behavior (Simulation Model)	Systems and Information Engineering Dept., University of Virginia	February, 9th 2016	Simulation Model & PowerPoint Slides
VIG Complex System Simulation Model Analysis VIG Enterprise Reservation System Simulation Model Analysis VIG Environmental Impacts Study	Port of Virginia, World Trade Center, Norfolk, VA	May, 9th 2016	Simulation Model & PowerPoint Slides
Port of Virginia Progress Report	Submitting via Email	May, 24th 2016	Cumulative Progress Report
VIG Semi-Automated Container Handling Equipment Analysis	Port of Virginia, World Trade Center, Norfolk, VA	July, 19th 2016	Simulation Model & PowerPoint Slides
NIT Straddle Carriers Simulation Model Analysis NIT Semi- Automated Simulation Model Analysis	Systems and Information Engineering Dept., University of Virginia	August, 23rd 2016	Simulation Model & PowerPoint Slides
NIT Straddle Carriers Simulation Model Analysis NIT Semi- Automated Simulation Model Analysis	Port of Virginia, World Trade Center, Norfolk, VA	October , 6th 2016	Simulation Model & PowerPoint Slides

Purpose	Location of Meeting	Date	Deliverable
NIT Number of Gates Simulation Model Analysis NIT Chassis Service Area Simulation Model Analysis	Port of Virginia, World Trade Center, Norfolk, VA	October , 17th 2016	Simulation Model & PowerPoint Slides
NIT Number of Gates Simulation Model Analysis NIT Chassis Service Area Simulation Model Analysis	Port of Virginia, World Trade Center, Norfolk, VA	January , 12th 2017	Simulation Model & PowerPoint Slides
Formulating the Vessel Scheduling Problem	Port of Virginia, World Trade Center, Norfolk, VA	February , 17th 2017	PowerPoint Slides
Quay Cranes Assignment Simulation Model Analysis	Port of Virginia, World Trade Center, Norfolk, VA	March , 23rd 2017	Simulation Model & PowerPoint Slides
Port of Virginia Progress Report	Submitting via Email	April, 5th 2017	Cumulative Progress Report
Quay Cranes Assignment Simulation Model Analysis	Port of Virginia, World Trade Center, Norfolk, VA	April , 21st 2017	Simulation Model & PowerPoint Slides
Impact of Large Ships on the Daily Vessel Schedule Analysis	Web-Meeting	June , 1st 2017	Simulation Model & PowerPoint Slides
Impacts of a 12-Hour SNIT Closure on Operational Performance Analysis	Port of Virginia, World Trade Center, Norfolk, VA	July , 27th 2017	Simulation Model & PowerPoint Slides
Insights from Simulation Modeling to Enterprise Resilience	Systems and Information Engineering Dept., University of Virginia	October, 5th 2017	Enterprise Resilience Model & PowerPoint Slides

B.3 University of Virginia Graduate Student Award

Finalist (Top 16), **Ayedh Almutairi.** Modeling and Simulation of Intermodal Freight Capacity Investments at a Major Container Port. University of Virginia Engineering Research Symposium, School of Engineering and Applied Science, University of Virginia, March 2017.

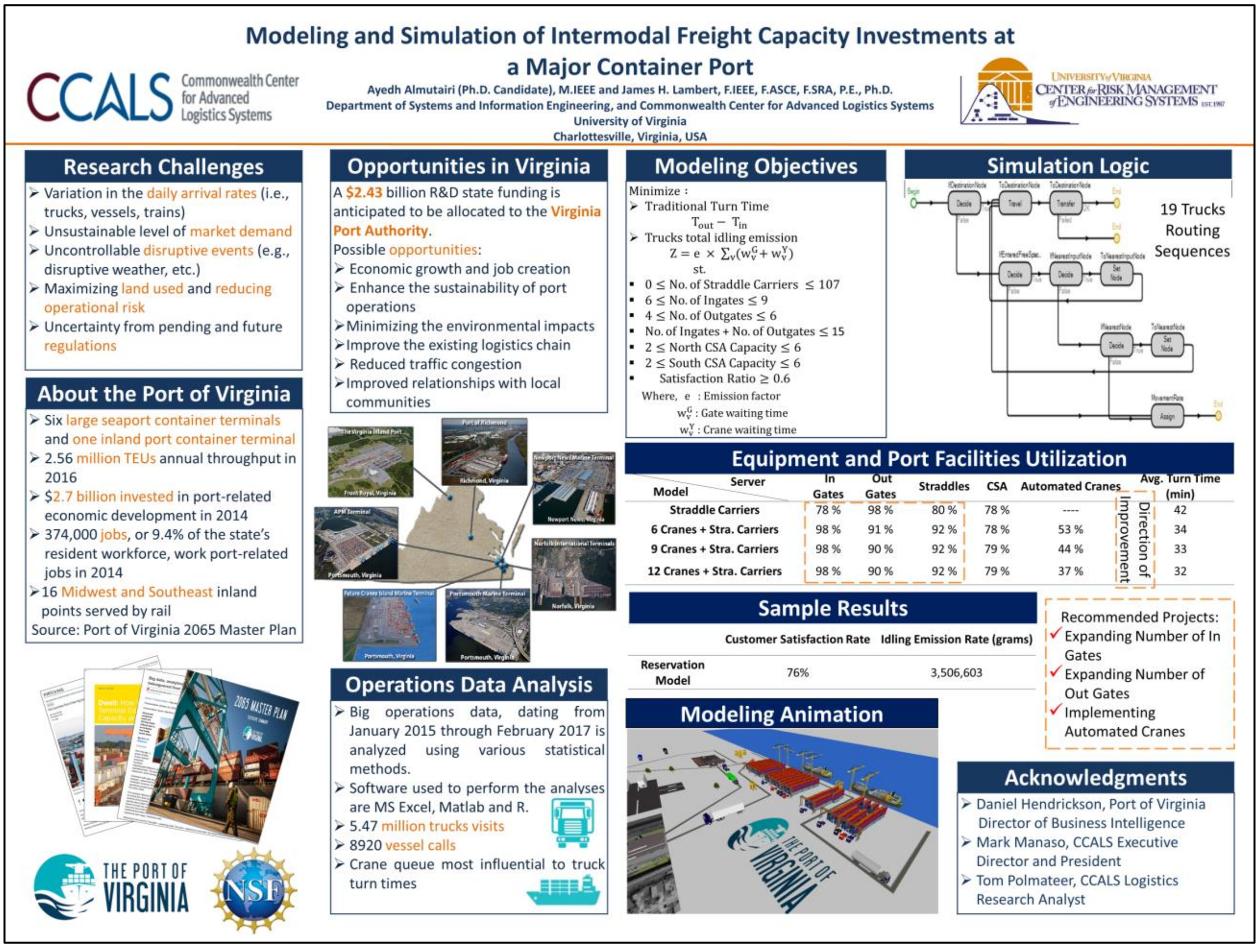


Figure 29 Modeling and Simulation of Capacity Expansion at a Major Container Port

B.4 Sample of the Simulation Model Software features and codes

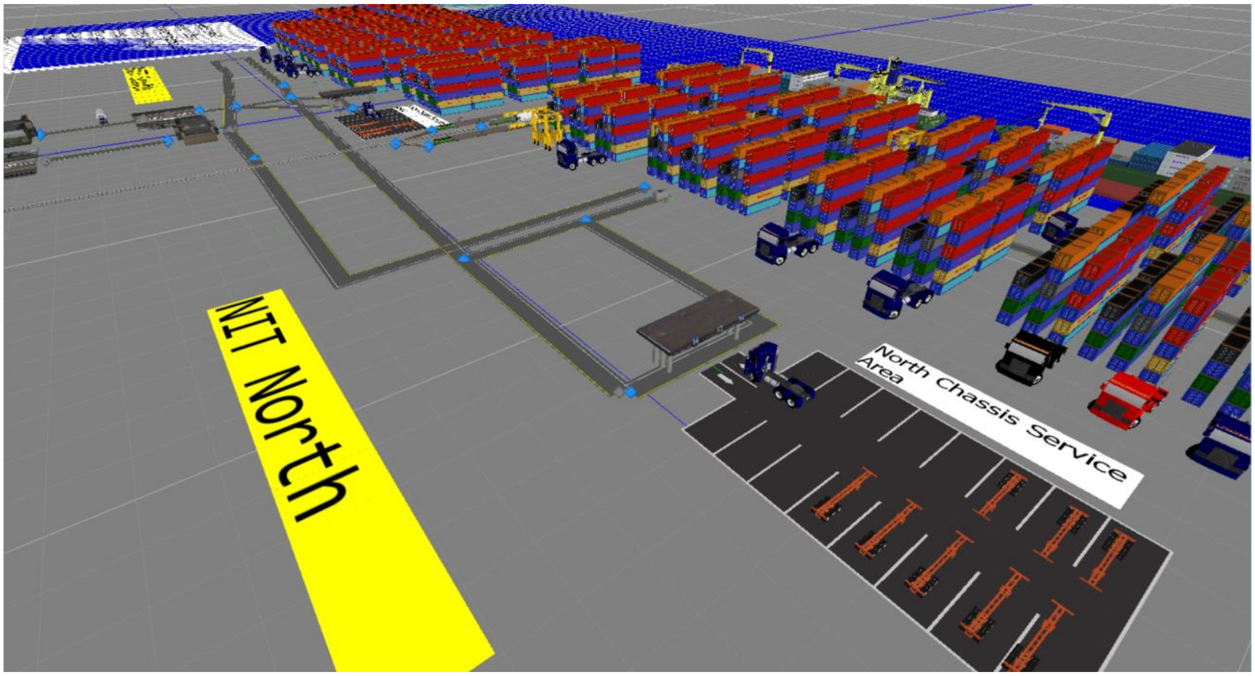


Figure 30 Screenshot of "Norfolk International Terminal Facility Layout (View 1)"

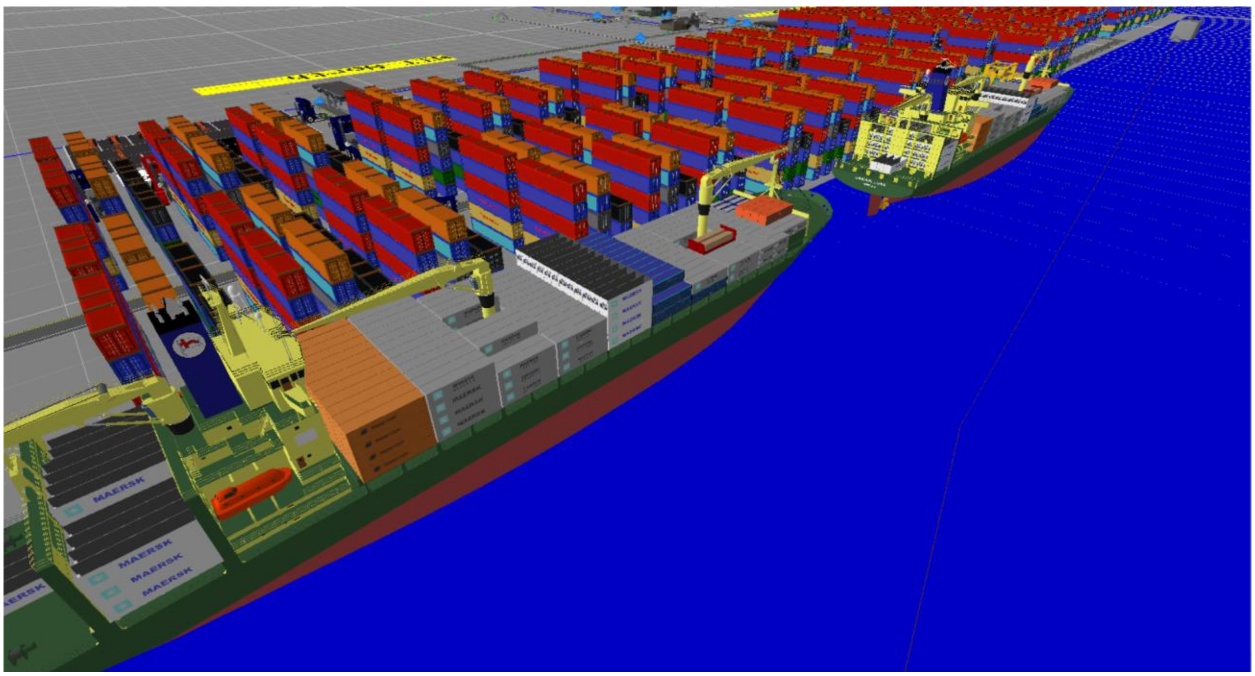


Figure 31 Screenshot of "Norfolk International Terminal Facility Layout (View 2)"

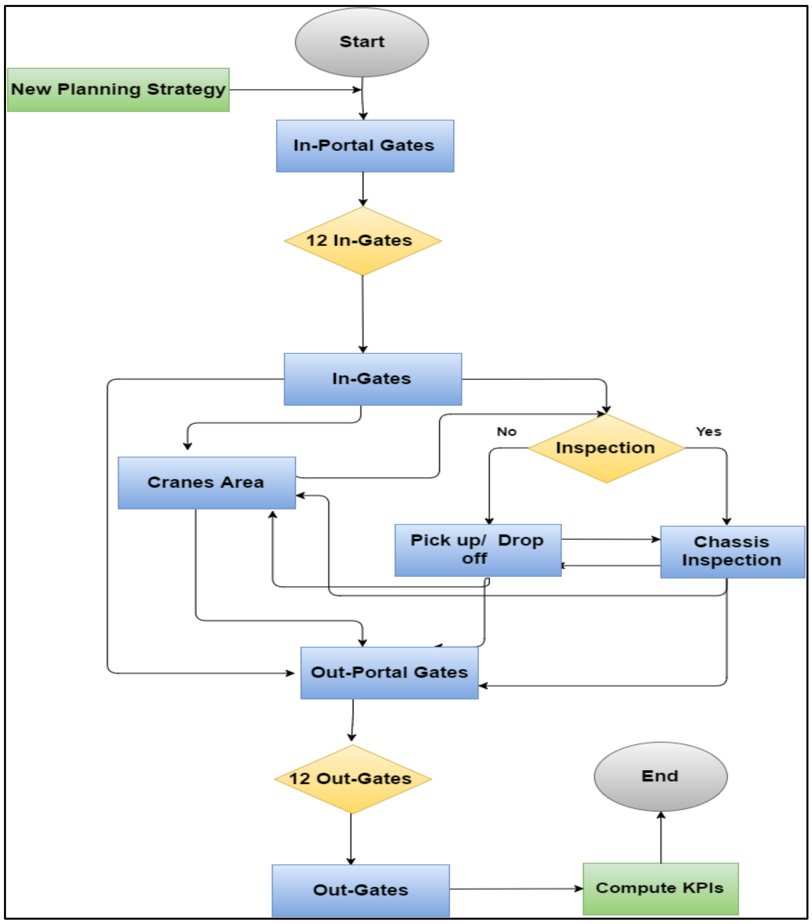


Figure 32 Sample of the simulation flowchart for the Virginia International Terminal model

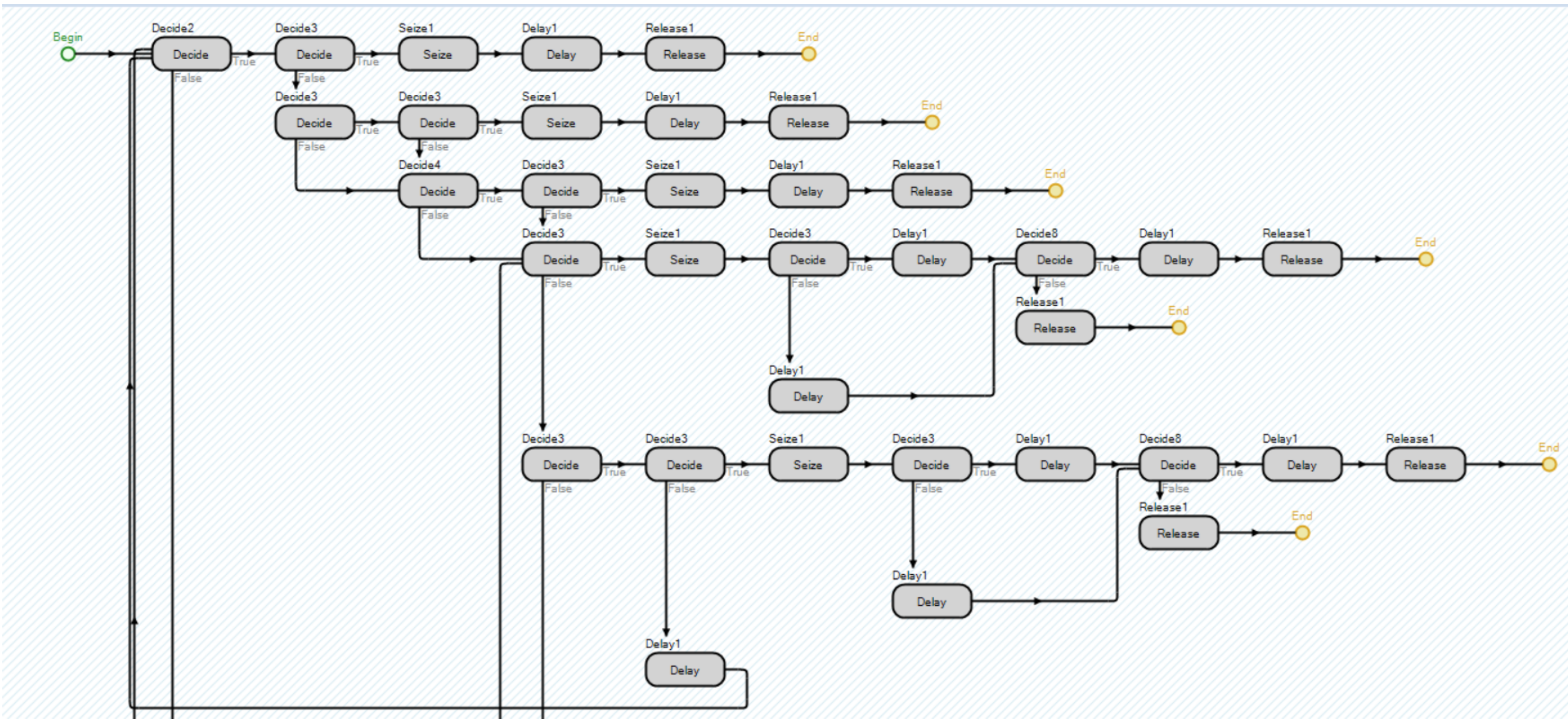


Figure 33 Screenshot of "a sample of simulation codes for allocation and stacking containers at Virginia International Terminal"

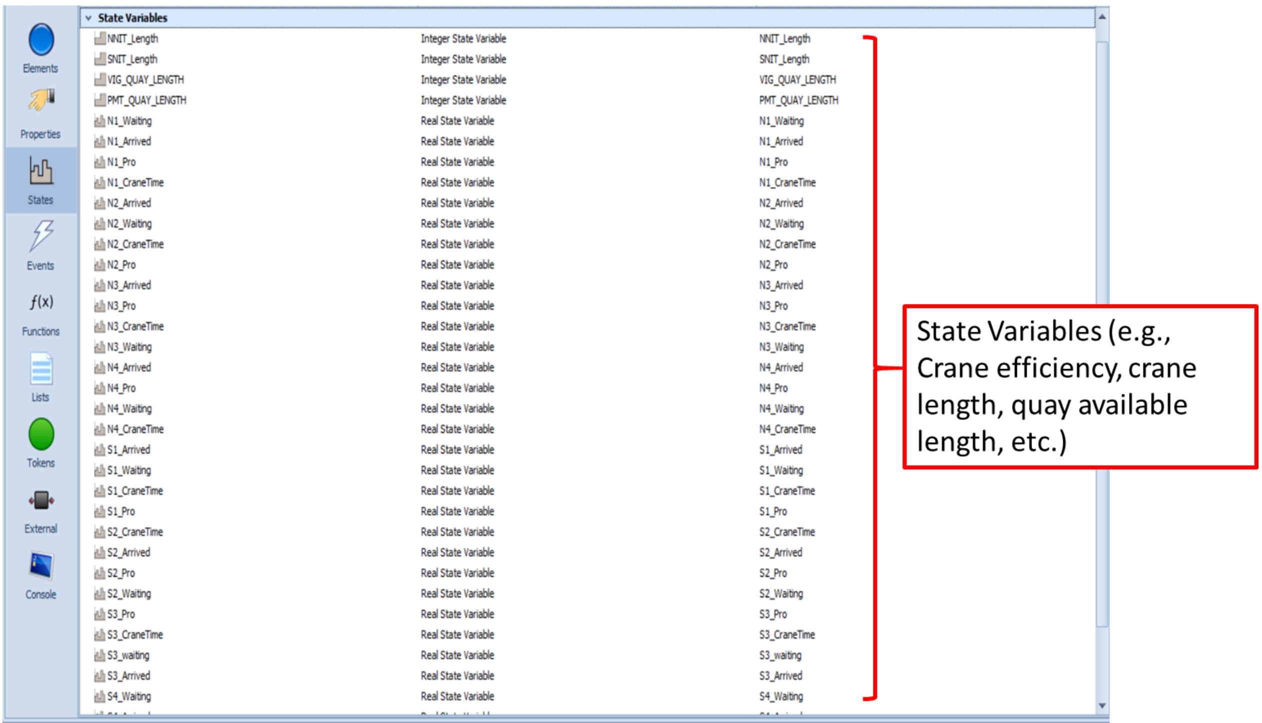


Figure 34 Screenshot of "a list of state variables that used for tracking the port performance across scenarios"

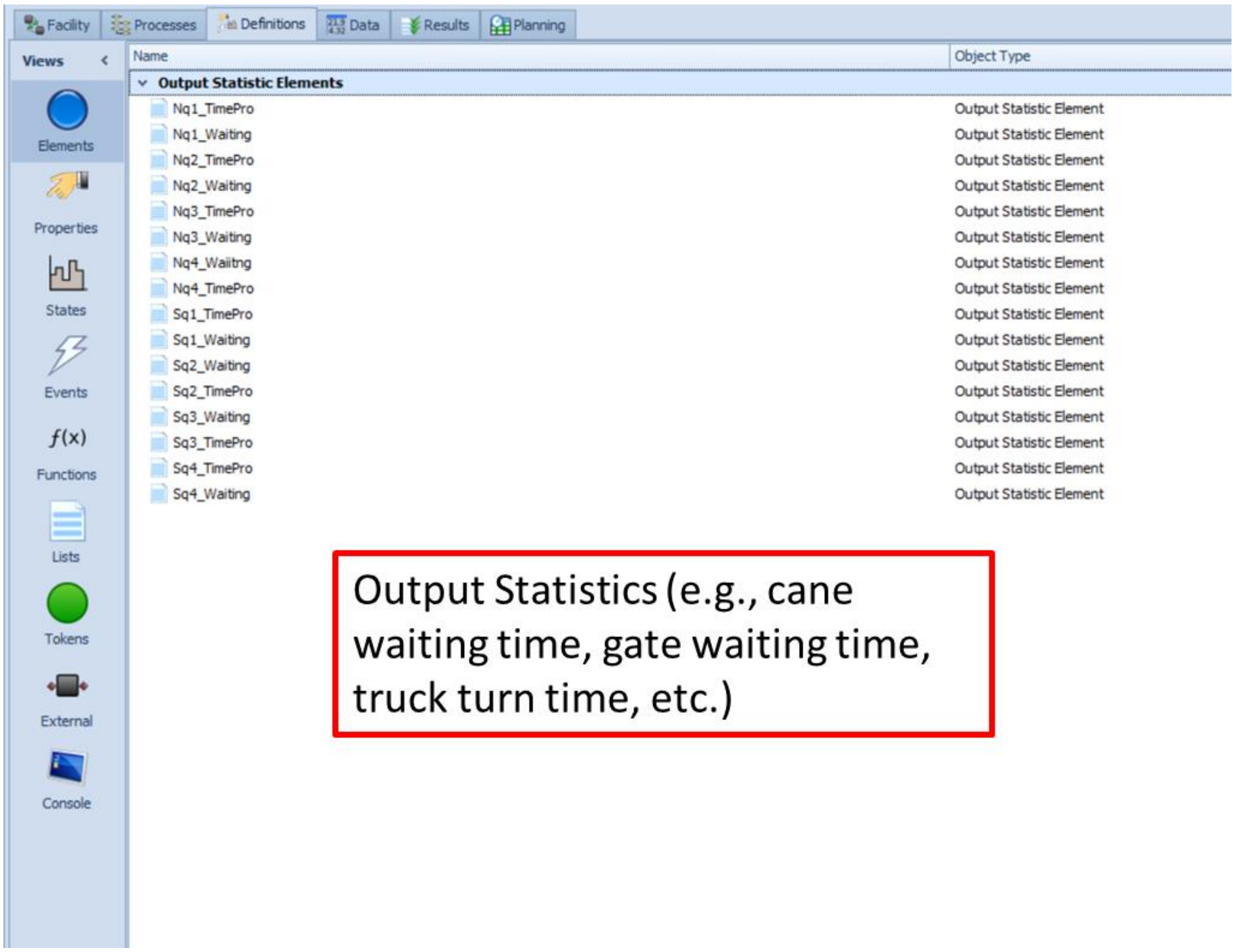


Figure 35 Screenshot of "Output statistics that will show up after each simulation run"

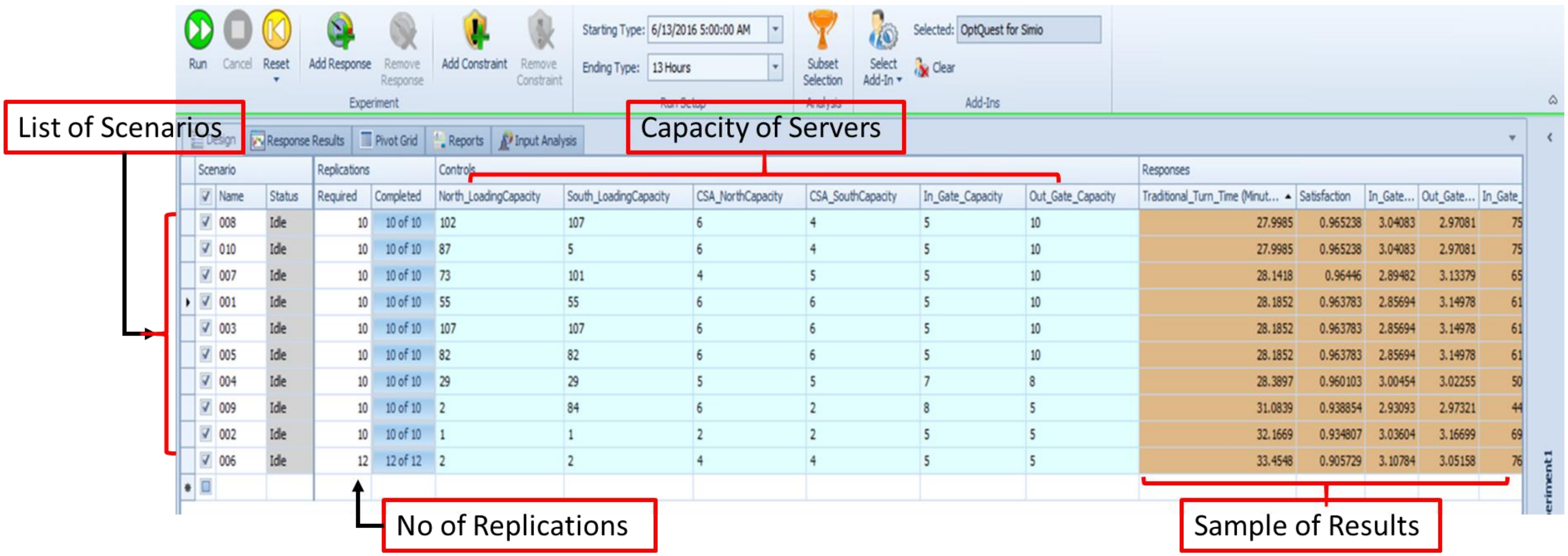
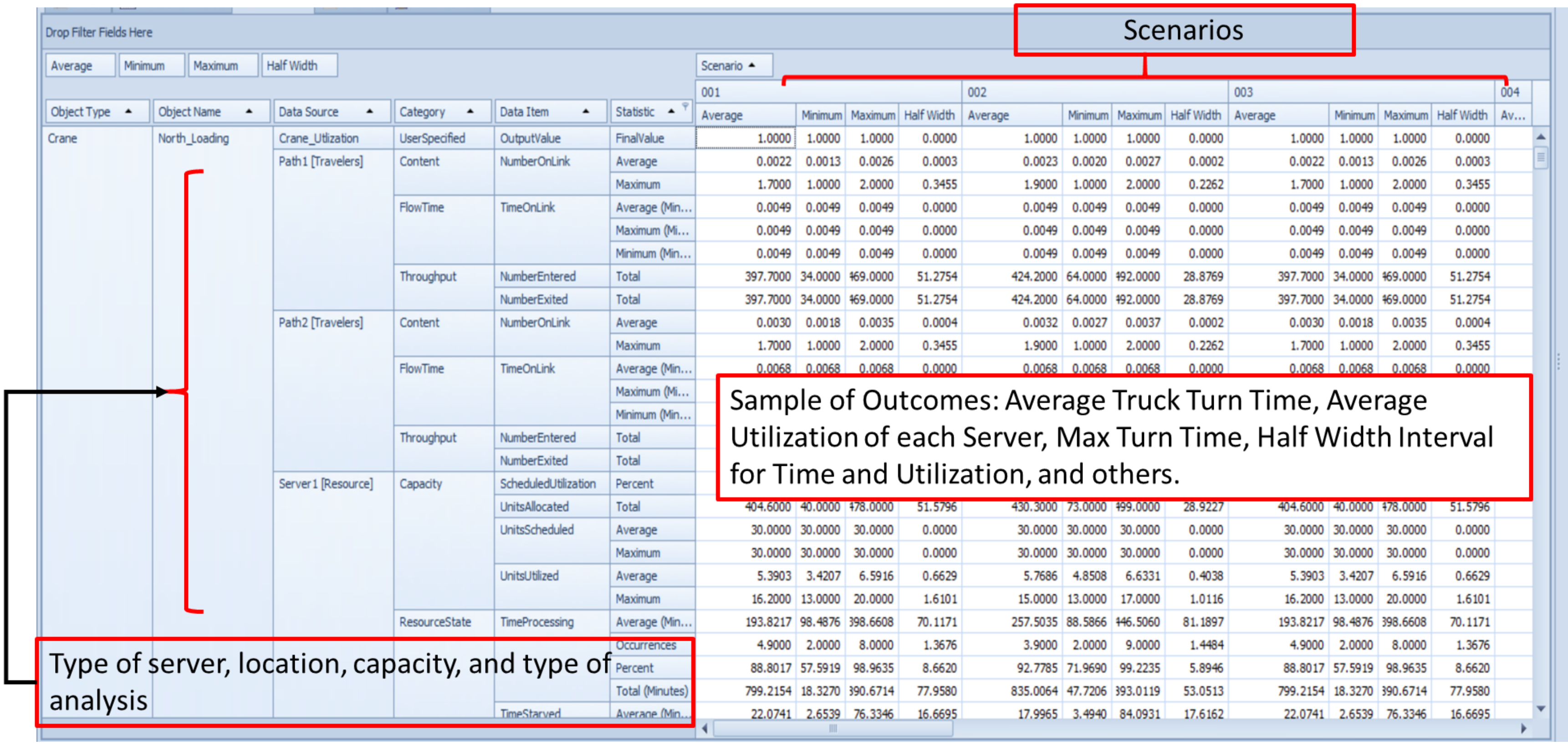


Figure 36 Screenshot of "sample of the VIG simulation inputs (e.g., list of scenarios, capacity of servers, etc.) and sample of the simulation outcomes"



Drop Filter Fields Here

Object Type	Object Name	Data Source	Category	Data Item	Statistic	001 Average	001 Minimum	001 Maximum	001 Half Width	002 Average	002 Minimum	002 Maximum	002 Half Width	003 Average	003 Minimum	003 Maximum	003 Half Width	004 Av...
Crane	North_Loading	Crane_Utlization	UserSpecified	OutputValue	FinalValue	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	0.0000	
		Path1 [Travelers]	Content	NumberOnLink	Average	0.0022	0.0013	0.0026	0.0003	0.0023	0.0020	0.0027	0.0002	0.0022	0.0013	0.0026	0.0003	
					Maximum	1.7000	1.0000	2.0000	0.3455	1.9000	1.0000	2.0000	0.2262	1.7000	1.0000	2.0000	0.3455	
			FlowTime	TimeOnLink	Average (Min...	0.0049	0.0049	0.0049	0.0000	0.0049	0.0049	0.0049	0.0000	0.0049	0.0049	0.0049	0.0000	
					Maximum (Mi...	0.0049	0.0049	0.0049	0.0000	0.0049	0.0049	0.0049	0.0000	0.0049	0.0049	0.0049	0.0000	
					Minimum (Min...	0.0049	0.0049	0.0049	0.0000	0.0049	0.0049	0.0049	0.0000	0.0049	0.0049	0.0049	0.0000	
			Throughput	NumberEntered	Total	397.7000	34.0000	469.0000	51.2754	424.2000	64.0000	492.0000	28.8769	397.7000	34.0000	469.0000	51.2754	
				NumberExited	Total	397.7000	34.0000	469.0000	51.2754	424.2000	64.0000	492.0000	28.8769	397.7000	34.0000	469.0000	51.2754	
		Path2 [Travelers]	Content	NumberOnLink	Average	0.0030	0.0018	0.0035	0.0004	0.0032	0.0027	0.0037	0.0002	0.0030	0.0018	0.0035	0.0004	
					Maximum	1.7000	1.0000	2.0000	0.3455	1.9000	1.0000	2.0000	0.2262	1.7000	1.0000	2.0000	0.3455	
			FlowTime	TimeOnLink	Average (Min...	0.0068	0.0068	0.0068	0.0000	0.0068	0.0068	0.0068	0.0000	0.0068	0.0068	0.0068	0.0000	
					Maximum (Mi...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
					Minimum (Min...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
			Throughput	NumberEntered	Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
				NumberExited	Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		Server1 [Resource]	Capacity	ScheduledUtilization	Percent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
				UnitsAllocated	Total	404.6000	40.0000	478.0000	51.5796	430.3000	73.0000	499.0000	28.9227	404.6000	40.0000	478.0000	51.5796	
				UnitsScheduled	Average	30.0000	30.0000	30.0000	0.0000	30.0000	30.0000	30.0000	0.0000	30.0000	30.0000	30.0000	0.0000	
					Maximum	30.0000	30.0000	30.0000	0.0000	30.0000	30.0000	30.0000	0.0000	30.0000	30.0000	30.0000	0.0000	
				UnitsUtilized	Average	5.3903	3.4207	6.5916	0.6629	5.7686	4.8508	6.6331	0.4038	5.3903	3.4207	6.5916	0.6629	
					Maximum	16.2000	13.0000	20.0000	1.6101	15.0000	13.0000	17.0000	1.0116	16.2000	13.0000	20.0000	1.6101	
			ResourceState	TimeProcessing	Average (Min...	193.8217	98.4876	398.6608	70.1171	257.5035	88.5866	446.5060	81.1897	193.8217	98.4876	398.6608	70.1171	
					Occurrences	4.9000	2.0000	8.0000	1.3676	3.9000	2.0000	9.0000	1.4484	4.9000	2.0000	8.0000	1.3676	
					Percent	88.8017	57.5919	98.9635	8.6620	92.7785	71.9690	99.2235	5.8946	88.8017	57.5919	98.9635	8.6620	
					Total (Minutes)	799.2154	18.3270	390.6714	77.9580	835.0064	47.7206	393.0119	53.0513	799.2154	18.3270	390.6714	77.9580	
				TimeStarved	Average (Min...	22.0741	2.6539	76.3346	16.6695	17.9965	3.4940	84.0931	17.6162	22.0741	2.6539	76.3346	16.6695	

Figure 37 Screenshot of “pivot table shows the VIG simulation outcomes for different scenarios”

Scenario Comparison Report

Project: NIT_New carneTime_Nov16_18CranesNorthOneTimeFrame

Run Date: 10/20/17 01:15

Model: Model (Academic, COMMERCIAL USE PROHIBITED)

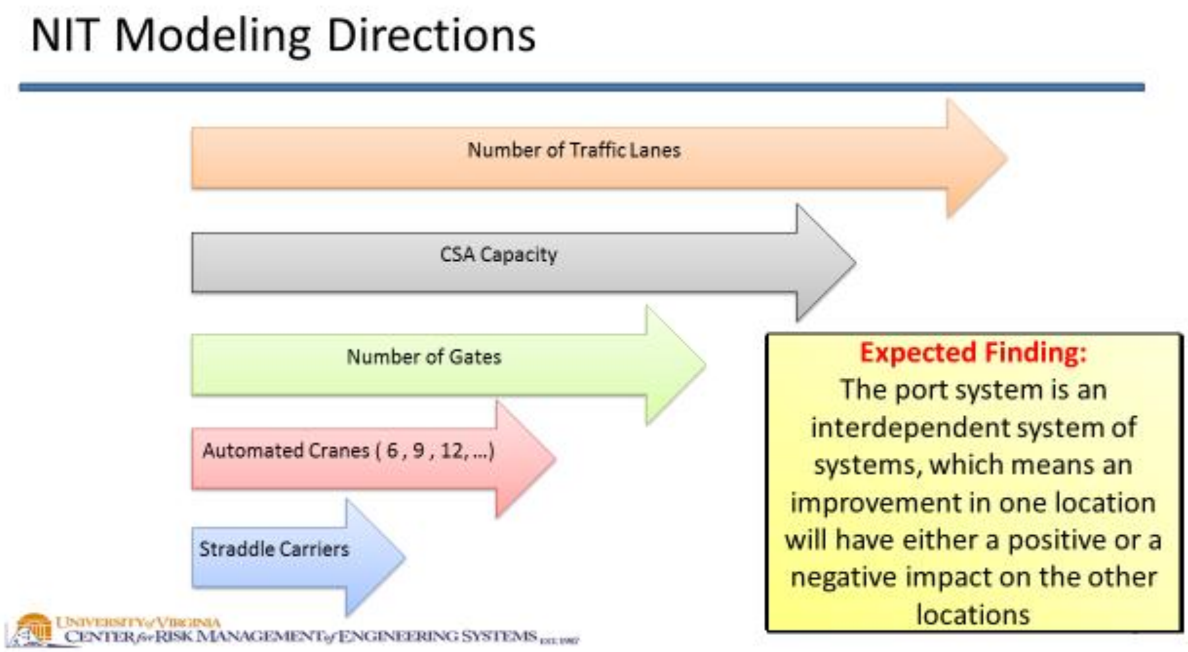
Analyst Name: AYEDH ALMUTAIRI

North_Loading - NumberEntered - Total

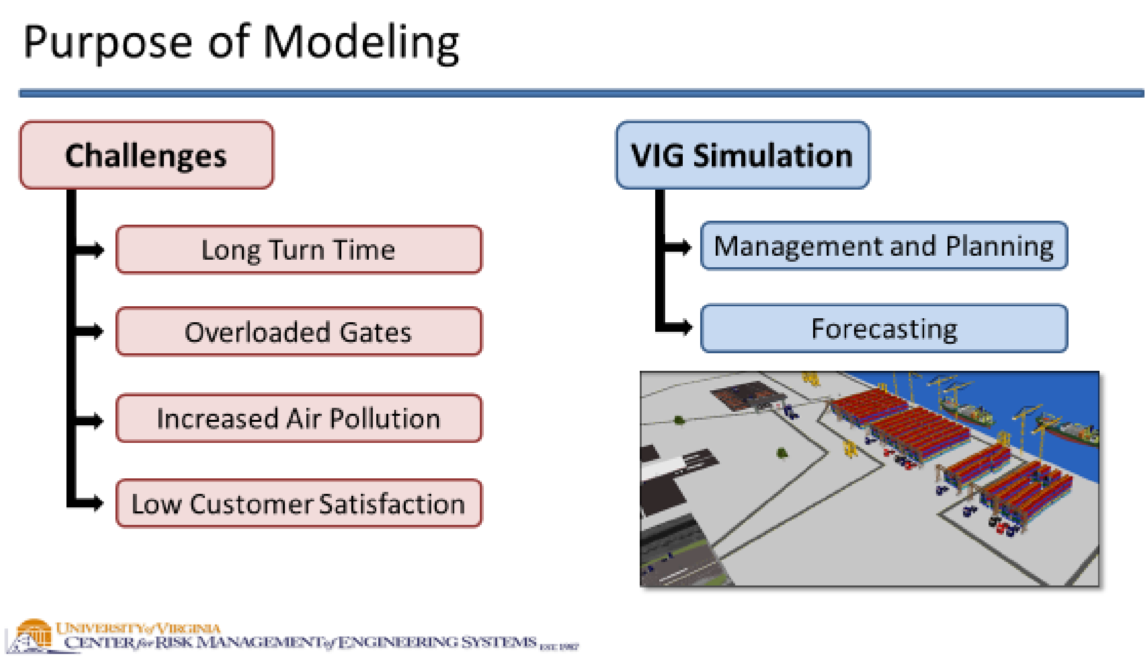
Scenario	Data Source	Category	Average	Half Width	Minimum	Maximum
001	Path1 [Travelers]	Throughput	397.7	51.27538	234	469
002	Path1 [Travelers]	Throughput	424.2	28.87692	364	492
003	Path1 [Travelers]	Throughput	397.7	51.27538	234	469
004	Path1 [Travelers]	Throughput	434.8	40.85511	351	523
005	Path1 [Travelers]	Throughput	397.7	51.27538	234	469
006	Path1 [Travelers]	Throughput	457.08333	19.60687	413	521
007	Path1 [Travelers]	Throughput	413.4	56.2872	234	488
008	Path1 [Travelers]	Throughput	461.5	26.79248	400	527
009	Path1 [Travelers]	Throughput	449.1	28.00265	379	511
010	Path1 [Travelers]	Throughput	461.5	26.79248	400	527
001	Path2 [Travelers]	Throughput	396.1	50.95662	233	466
002	Path2 [Travelers]	Throughput	423	29.09111	360	490
003	Path2 [Travelers]	Throughput	396.1	50.95662	233	466
004	Path2 [Travelers]	Throughput	433.5	41.1704	350	523
005	Path2 [Travelers]	Throughput	396.1	50.95662	233	466
006	Path2 [Travelers]	Throughput	455.58333	19.15812	410	517
007	Path2 [Travelers]	Throughput	411.9	56.22176	233	485
008	Path2 [Travelers]	Throughput	459.8	26.50565	400	524
009	Path2 [Travelers]	Throughput	447.5	28.3493	377	510
010	Path2 [Travelers]	Throughput	459.8	26.50565	400	524
001	Server1.InputBuffer	Throughput	404.6	51.57955	240	478
002	Server1.InputBuffer	Throughput	430.3	28.92266	373	499
003	Server1.InputBuffer	Throughput	404.6	51.57955	240	478
004	Server1.InputBuffer	Throughput	440.3	41.06089	358	530
005	Server1.InputBuffer	Throughput	404.6	51.57955	240	478
006	Server1.InputBuffer	Throughput	462.58333	20.46593	418	532
007	Server1.InputBuffer	Throughput	419.5	56.31249	240	498
008	Server1.InputBuffer	Throughput	468.6	27.23433	408	541

Figure 38 Screenshot of "sample of the NIT simulation model report for different scenarios"

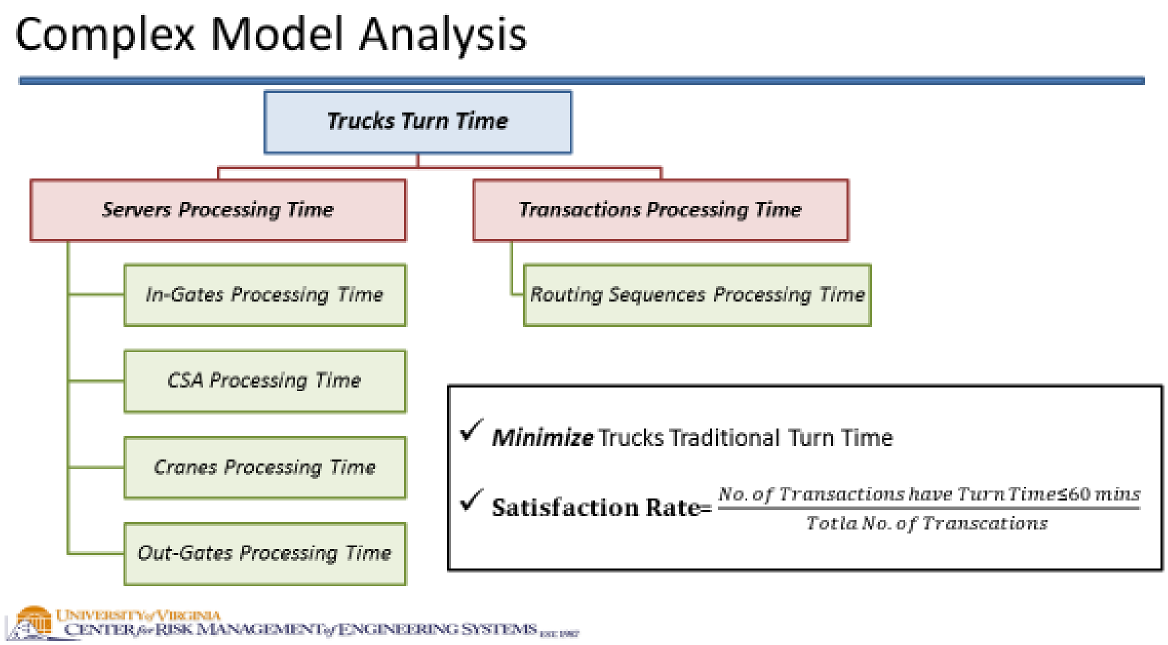
B.5 Sample of the Simulation Analysis



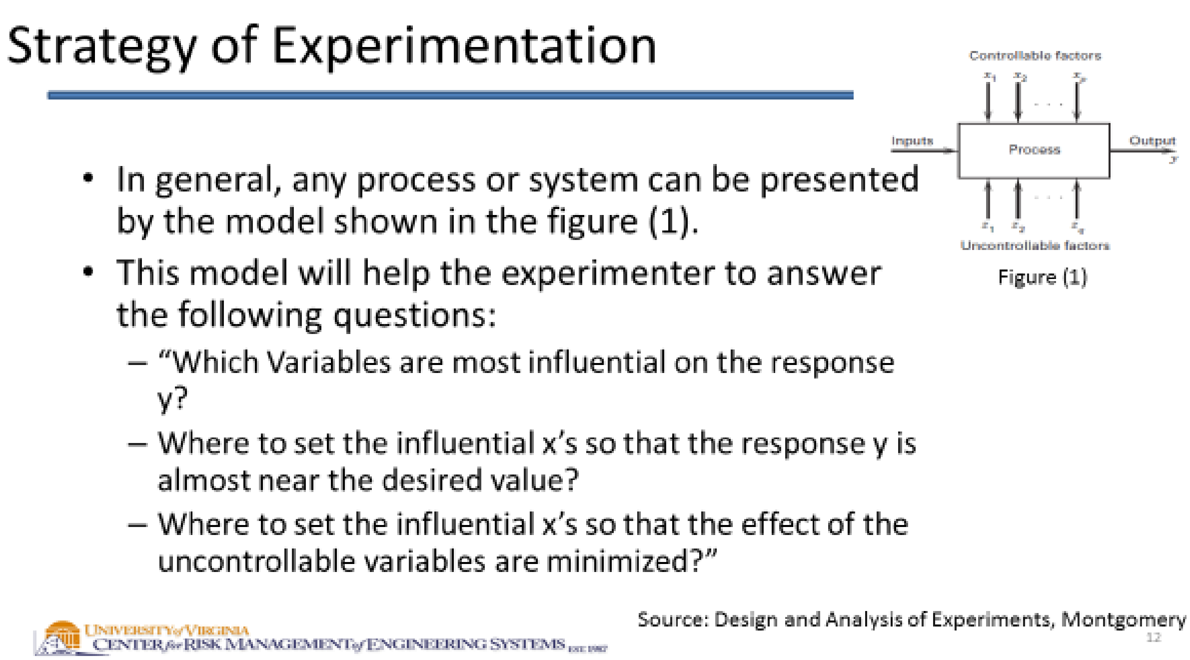
Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, November, 23rd 2015



Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, November, 23rd 2015

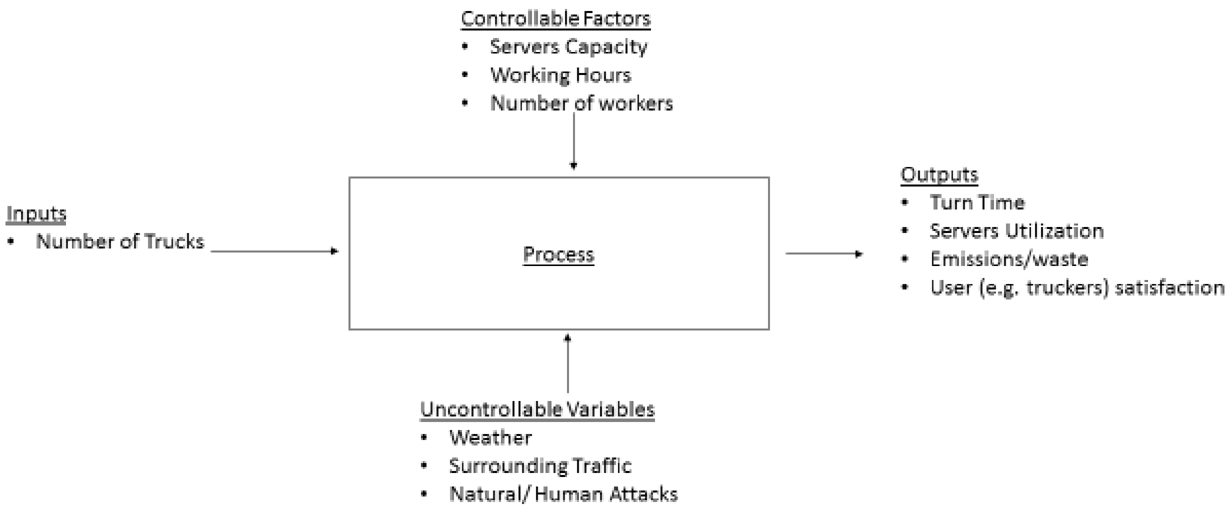


Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, November, 23rd 2015



Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, November, 23rd 2015

Cont: Strategy of Experimentation for Port of Virginia



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Capacity for Each Server

Server	Capacity Type	Capacity Size
In Portal	Detection Camera	2
In Gate	Worker	13
In chassis area	Inspector	*Vary
Loading Zone	Crane	15
Out Portal	Detection Camera	2
Out Gate	Worker	13

*The simulation model is very sensitive to the capacity of the chassis area could range between 3 to 5 inspectors. Therefore, the model is run for different number of inspectors in the chassis area. Comparisons for run outcomes for different number of inspectors in the chassis area will be shown in the next slides.

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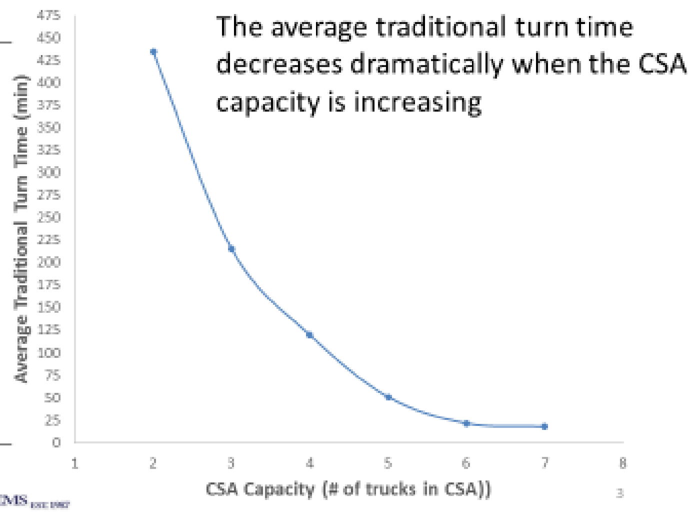
Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

Traditional Turn Time vs. Chassis Service Area Capacity

Scenarios	Traditional Turn Time (Minutes)	
CSA Capacity	Average	Maximum
2	434	2,065
3	216	1,198
4	120	727
5	51	354
6	22	123
7	18	96



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Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

Servers Average Utilization % vs. Chassis Service Area Capacity

CSA Capacity	In Portal	In Gate	Chassis Services Area	Loading Zone	Out Portal	Out Gate
			99	19	4	17
			98	29	6	27
4	8	43	97	37	8	34
5	11	52	95	47	10	43
6	12	60	87	52	12	49
7	11	56	72	49	11	46

The utilization for the CSA is high while the utilization for the other servers is considered low.

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Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

Average Traditional Turn Time (min) for all the Routing Sequences

Routing sequence						Trad_Turn Time (min)
In	Out					29
In	Cranes	Out				44
In	Chassis	Out				70
In	Cranes	Chassis				70
In	Cranes	Cranes				71
In	Cranes	Chassis	Cranes	Out		77
In	Chassis	Cranes	Out			78
In	Cranes	Chassis	Chassis	Cranes	Out	85
In	Chassis	Cranes	Cranes	Out		88
In	Chassis	Cranes	Chassis	Out		92
In	Chassis	Cranes	Cranes	Chassis	Out	97
In	Cranes	Chassis	Chassis	Out		97
In	Chassis	Chassis	Cranes	Out		101
In	Chassis	Chassis	Out			106
In	Cranes	Chassis	Cranes	Chassis	Out	108
In	Chassis	Cranes	Chassis	Cranes	Out	118
In	Cranes	Cranes	Chassis	Chassis	Out	171

The traditional turn time is less than 60 min for the truck that does not visit the CSA

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Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

CSA Dynamic Capacity

Start Time	Duration	End Time	Capacity
5:00 AM	7 hours	12:00 PM	5
12:00 PM	1 hour	1:00 PM	0
1:00 PM	11 hours	12:00 AM	5

Average Traditional Turn Time (min)	
Fixed Capacity	Dynamic Capacity
51	71

Servers Average Utilization %						
CSA Capacity	In Portal	In Gate	CSA	Loading Zone	Out Portal	Out Gate
5	11	52	95	47	10	43
Dynamic	10	49	95	43	10	47

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Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

Summary Statistics

Truck Routing Logic	Routing Description	Number of Trucks	Percentage
CSA*	Truck Visits Only the CSA	23,555	9%
CSA_Loading	Truck Visits the CSA then the Loading Area	30,061	12%
Loading_CSA	Truck Visits the Loading Area then CSA	95,060	38%
Loading	Truck Visits Only the Loading Area	103,237	41%
	Total	**251,913**	

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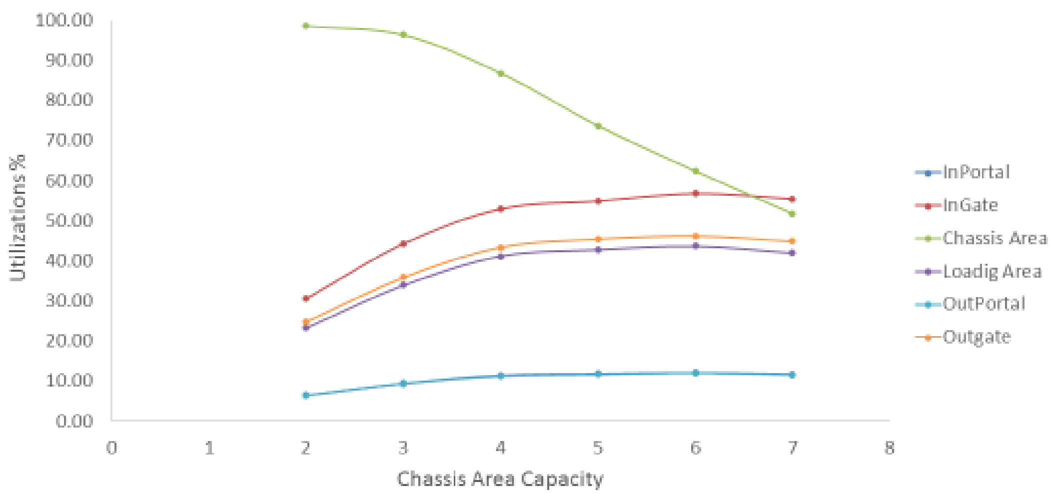
*CSA : Chassis Service Area

3

Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

Cont: Servers Average Utilizations %



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Prepared and presented by Ayedh Almutairi in the Port of Virginia meeting, December, 10th 2015

Complex Model Analysis (Cont.)

Servers Processing Time

Servers	In-Gates	Cranes	CSA	Out-Gates
Average Processing Time	5	33	5	4
Utilization %	58	82	87	45

large Cranes Processing Time

LTADATE	LTACRANESTARTED	LTACRANEFINISHED
6:17:12 AM	6:48:38 AM	6:52:11 AM
6:17:56 AM	6:38:42 AM	6:43:30 AM
6:18:12 AM	6:31:17 AM	6:34:01 AM

Cranes	Preparation Time	Loading Time	Transfer Time	
Average Processing Time	22	6	5	= 33

All time in minutes

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Complex Model Analysis (Cont.)

Transactions Processing Time

Multiple Transactions effects

Routing sequence				Proportion %	Turn Time (min)
In	Out			14.24%	12
In	Chassis	Out		7.27%	49
In	Cranes	Out		31.94%	46
In	Chassis	Cranes	Out	9.05%	82
In	Cranes	Chassis	Out	28.34%	86

All time in minutes

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Enterprise Reservation Model Analysis

Servers Processing Time

Servers Processing Time	In-Gates	Cranes	CSA	Out-Gates
Reservation Model	5	32	4	4
Complex Model	5	33	5	4

Two minutes of improvement

Cranes	Preparation Time	Loading Time	Transfer Time
Reservation Model	21	6	5
Complex Model	22	6	5

All time in minutes

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Enterprise Reservation Model Analysis (Cont.)

Transactions Processing Time

Improvement in CSA Queuing Time & Cranes Preparation Time

Routing sequence				Proportion %	Complex Model Turn Time	Appt Model Turn Time
In	Out			14%	12	12
In	Chassis	Out		7%	49	27
In	Cranes	Out		32%	46	46
In	Chassis	Cranes	Out	9%	82	61
In	Cranes	Chassis	Out	28%	86	62

All time in minutes

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Enterprise Reservation Model Analysis (Cont.)

Waiting Time

CSA Queuing Time is reduced

	CSA	Cranes	
		Queuing Time	Preparation Time
Reservation Model	10	1	21
Complex Model	33	2	22

60%

Global Improvements

	Average Traditional Turn Time	Customer Satisfaction Rate
Reservation Model	42	0.76
Complex Model	54	0.7

All time in minutes

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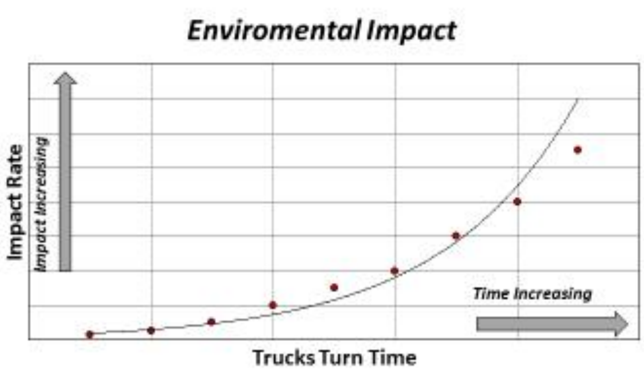
Environmental Impacts Study



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Environmental impacts (Cont.)

Trucks total idling emission

$$Z = e \times \sum_v (w_v^G + w_v^Y)$$

Where,

- e : Emission factor
- w_v^G : Gate waiting time
- w_v^Y : Crane waiting time

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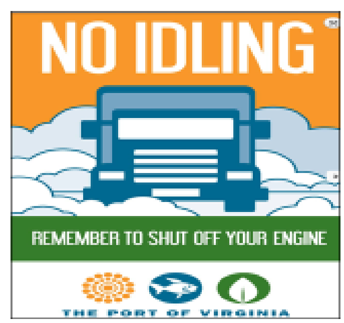
Environmental impacts (Cont.)

Trucks Status

	Busy	Idle
In-Portal	√	
In-Gate	√	
CSA	√	√
Cranes	√	√
Out-Portal	√	
Out-Gate	√	



Appointment Model	CSA	Cranes		Total
		Queuing Time	Preparation Time	
Idling Time	10	1	21	32

All time in minutes

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Environmental impacts (Cont.)

Let:

- ✓ w_T^O $\mathit{Average\ Trucks\ Idling\ Time} = 32\ \mathit{minutes}$
- ✓ T $\mathit{Estimated\ Number\ of\ Trucks\ Visiting\ CSA\ or/and\ Cranes\ Area} = 1417\ \mathit{Trucks}$
- ✓ Z $\mathit{Estimated\ Total\ Daily\ Idling\ Emission}$

$$Z = e \times w_T^O \times T$$

	CO_2	Unit
e	4,640	g/hr
Idling Emission Rate per Truck	2,475	grams
Total Idling Emission Rate	3,506,603	grams

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Analysis of the Straddle Carriers Model

Locations	Average Processing Time (mins)	Utilization %
Out Gates	1.6	78
In Gates	4.6	98
North Straddles	19	80
South Straddles	19	96
CSA	4	78

Average Truck's Traditional Turn Time	**42**
Satisfaction Rate	0.85

High Utilization % !!
Expand # of In Gates and/or Expand # of Straddle Carriers

Run's Parameters:
12 In Gates
4 Out Gates
6 Inspectors in CSA
100 Replications

All time in minutes

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Analyses of the Automated Cranes Models

Servers Utilization %

Servers	In Gates	Out Gates	N. Straddles	S. Straddles	CSA	Automated Cranes	Avg. Turn Time (min)
Straddle Carriers Model	78 %	98 %	80 %	96 %	78 %	----	42
6 Cranes + Stra. Carriers	98 %	91 %	92 %	70 %	78 %	53 %	34
9 Cranes + Stra. Carriers	98 %	90 %	92 %	58 %	79 %	44 %	33
12 Cranes + Stra. Carriers	98 %	90 %	92 %	50 %	79 %	37 %	32

Recommended Projects:
1. Expanding Number of In Gates
2. Expanding Number of Out Gates
3. Automated Cranes

Run's Parameters:
12 In Gates
4 Out Gates
6 Inspectors in CSA
100 Replications

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Improving the Utilization of the North & South Stra. Carriers

Two possible future projects for improving the utilization of the stra. carriers:

1. Implementing semi-automated cranes (6, 9, 12, … etc.)
2. Better Allocation of the Straddle Carriers

Server	Capacity Type	Previous Capacity Size	New Capacity Size
North Loading Zone	Straddle Carriers	14	18
South Loading Zone	Straddle Carriers	27	23

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Better Allocation of the Straddle Carriers

Run's Parameters:
12 In Gates
4 Out Gates
6 Inspectors in CSA

23 South Stra. Carriers
18 North Stra. Carriers

Servers	In Gates	Out Gates	N. Straddles	S. Straddles	CSA	Automated Cranes	Avg. Turn Time (min)
6 Cranes + Stra. Carriers	98 %	90 %	73 %	81 %	79 %	53 %	33
9 Cranes + Stra. Carriers	98 %	89 %	72 %	68 %	79 %	44 %	32
12 Cranes + Stra. Carriers	98 %	90 %	73 %	59 %	79 %	37 %	31

27 South Stra. Carriers
14 North Stra. Carriers

One Minute of Improvement

Servers	In Gates	Out Gates	N. Straddles	S. Straddles	CSA	Automated Cranes	Avg. Turn Time (min)
6 Cranes + Stra. Carriers	98 %	91 %	92 %	70 %	78 %	53 %	34
9 Cranes + Stra. Carriers	98 %	90 %	92 %	58 %	79 %	44 %	33
12 Cranes + Stra. Carriers	98 %	90 %	92 %	50 %	91 %	37 %	32

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Expanding Number of Gates

Run's Parameters:
26 In Gates
13 Out Gates
6 Inspectors in CSA
100 Replications

Servers Utilization %

Servers	In Gates	Out Gates	N. Straddles	S. Straddles	CSA	Automated Cranes	Avg. Turn Time (min)
6 Cranes + Stra. Carriers	57 %	28 %	73 %	80 %	92 %	53 %	43
9 Cranes + Stra. Carriers	57 %	28 %	73 %	68 %	93 %	44 %	41
12 Cranes + Stra. Carriers	57 %	28 %	73 %	59 %	94 %	61 %	39

14 In Gates
4 Out Gates

Servers	In Gates	Out Gates	N. Straddles	S. Straddles	CSA	Automated Cranes	Avg. Turn Time (min)
6 Cranes + Stra. Carriers	98 %	90 %	73 %	81 %	79 %	53 %	33
9 Cranes + Stra. Carriers	98 %	89 %	72 %	68 %	79 %	44 %	32
12 Cranes + Stra. Carriers	98 %	90 %	73 %	59 %	79 %	37 %	31

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Expanding the CSA Capacity

Run's Parameters:
26 In Gates
13 Out Gates
10 Inspectors in CSA
100 Replications

Servers Utilization %

Servers	In Gates	Out Gates	N. Straddles	S. Straddles	CSA	Automated Cranes	Avg. Turn Time (min)
6 Cranes + Stra. Carriers	53 %	28 %	73 %	75 %	56 %	58 %	34
9 Cranes + Stra. Carriers	54 %	28 %	73 %	63 %	56 %	48 %	34
12 Cranes + Stra. Carriers	58 %	29 %	73 %	54 %	60 %	39 %	32
15 Cranes + Stra. Carriers	53 %	29 %	73 %	48 %	56 %	35 %	31
18 Cranes + Stra. Carriers	53 %	29 %	63 %	49 %	56 %	31 %	30

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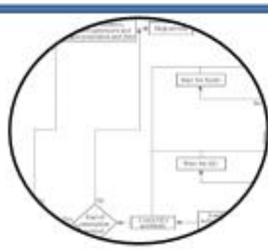

Simulation

✓ Explores future plans
but
× Assumes no variation and uncertainty in the system
× No way to assess or mitigate the underlying risk

Risk-based Planning and Scheduling

✓ Accounts for underlying variation and uncertainty in the system
such as
machine breakdowns, bad weather, processes varying in time, material arriving late, etc.

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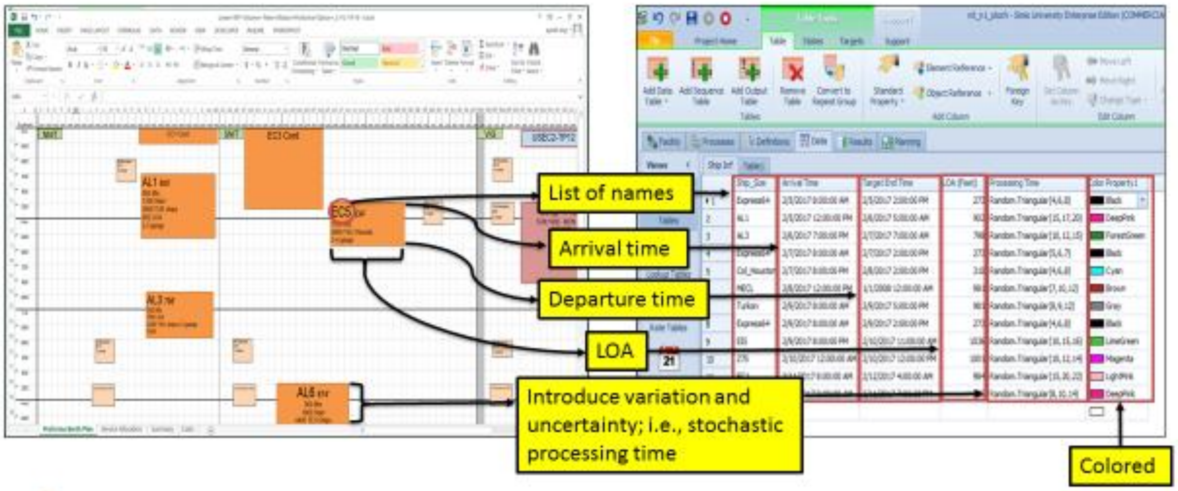
Formulating the Vessel Scheduling Problem (cont.)



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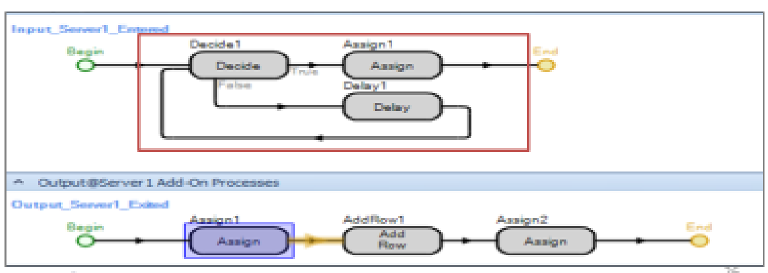
Simulation Logic

N-NIT Berth Allocation Rule:

- Decide: $Ship\ Length \leq (Remaining\ Quay\ Length - 100)\ Feet$
  - If yes
    - Start the job
    - Assign: $New\ Remaining\ Quay\ Length = Old\ Remaining\ Quay\ Length - Ship\ Length$
  - If no
    - Wait for x minutes
    - Repeat



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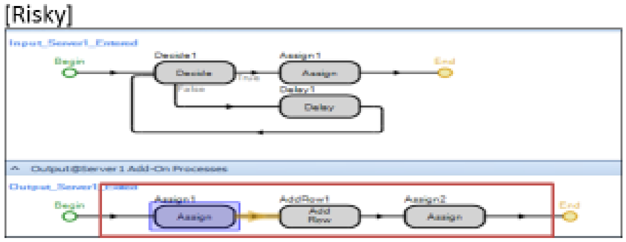
Simulation Logic (Cont.)

Analyze the risk associated with the plan:

- First: Introduce sources of uncertainty: High wind, heavy rain, etc.
- Second: Create output table:
  - Create Target(s): Minimize (x), Maximize (y)
  - Create Constraint(s): Upper bound (t), Lower bound (t)
    - e.g., Upper bound = Ship arrival time + processing time
      - If ship departure time < Upper bound [Safe]
      - If ship departure time > Upper bound [Risky]



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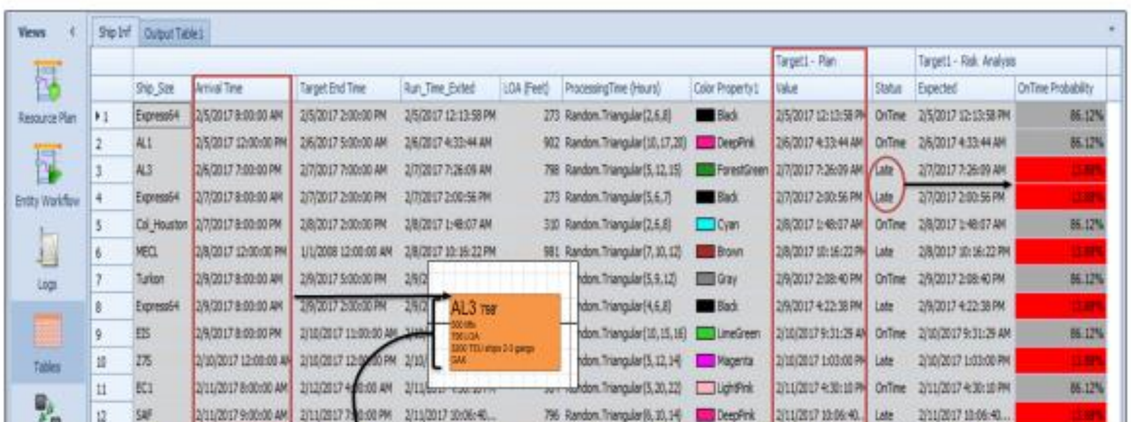
N-NIT Stochastic Vessel Schedule



Views | Ship Inf | Output Table1

	Ship_Size	Arrival Time	Target End Time	Run_Time_Exited	LOA (Feet)	ProcessingTime (Hours)	Color Property1	Target1 - Plan Value	Status	Target1 - Risk Analysis Expected	OnTime Probability
1	Express64	2/5/2017 8:00:00 AM	2/5/2017 2:00:00 PM	2/5/2017 12:13:58 PM	273	Random.Triangular[2,6,8]	Black	2/5/2017 12:13:58 PM	OnTime	2/5/2017 12:13:58 PM	86.12%
2	AL1	2/5/2017 12:00:00 PM	2/6/2017 5:00:00 AM	2/6/2017 4:33:44 AM	902	Random.Triangular[10,17,20]	DeepPink	2/6/2017 4:33:44 AM	OnTime	2/6/2017 4:33:44 AM	86.12%
3	AL3	2/6/2017 7:00:00 PM	2/7/2017 7:00:00 AM	2/7/2017 7:26:09 AM	798	Random.Triangular[5,12,15]	ForestGreen	2/7/2017 7:26:09 AM	Late	2/7/2017 7:26:09 AM	[illegible]
4	Express64	2/7/2017 8:00:00 AM	2/7/2017 2:00:00 PM	2/7/2017 2:00:56 PM	273	Random.Triangular[5,6,7]	Black	2/7/2017 2:00:56 PM	Late	2/7/2017 2:00:56 PM	[illegible]
5	Col_Houston	2/7/2017 8:00:00 PM	2/8/2017 2:00:00 PM	2/8/2017 1:48:07 AM	310	Random.Triangular[2,6,8]	Cyan	2/8/2017 1:48:07 AM	OnTime	2/8/2017 1:48:07 AM	86.12%
6	MECL	2/8/2017 12:00:00 PM	1/1/2008 12:00:00 AM	2/8/2017 10:16:22 PM	981	Random.Triangular[7,10,12]	Brown	2/8/2017 10:16:22 PM	Late	2/8/2017 10:16:22 PM	[illegible]
7	Turkon	2/9/2017 8:00:00 AM	2/9/2017 5:00:00 PM	2/9/2[illegible]	[illegible]	[illegible]ndom.Triangular[5,9,12]	Gray	2/9/2017 2:08:40 PM	OnTime	2/9/2017 2:08:40 PM	86.12%
8	Express64	2/9/2017 8:00:00 AM	2/9/2017 2:00:00 PM	2/9/2[illegible]	[illegible]	[illegible]ndom.Triangular[4,6,8]	Black	2/9/2017 4:22:38 PM	Late	2/9/2017 4:22:38 PM	[illegible]
9	EIS	2/9/2017 8:00:00 PM	2/10/2017 11:00:00 AM	[illegible]	[illegible]	[illegible]ndom.Triangular[10,15,16]	LimeGreen	2/10/2017 9:31:29 AM	OnTime	2/10/2017 9:31:29 AM	86.12%
10	275	2/10/2017 12:00:00 AM	2/10/2017 12:00:00 PM	2/10/[illegible]	[illegible]	[illegible]ndom.Triangular[5,12,14]	Magenta	2/10/2017 1:03:00 PM	Late	2/10/2017 1:03:00 PM	[illegible]
11	EC1	2/11/2017 8:00:00 AM	2/12/2017 4:00:00 AM	2/11/[illegible]	[illegible]	[illegible]ndom.Triangular[5,20,22]	LightPink	2/11/2017 4:30:10 PM	OnTime	2/11/2017 4:30:10 PM	86.12%
12	SAF	2/11/2017 9:00:00 AM	2/11/2017 7:00:00 PM	2/11/2017 10:06:40...	796	Random.Triangular[6,10,14]	DeepPink	2/11/2017 10:06:40...	Late	2/11/2017 10:06:40...	[illegible]

Ship Arrival Time + Expected Processing Time = Target: Upper Bound

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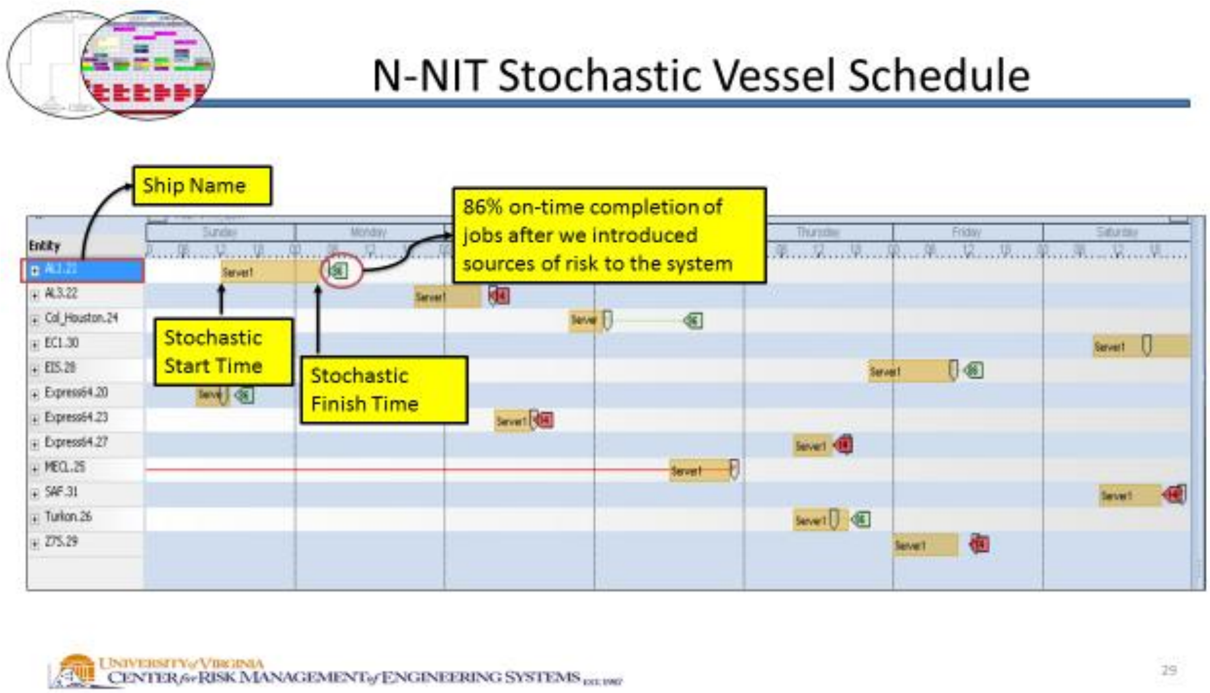

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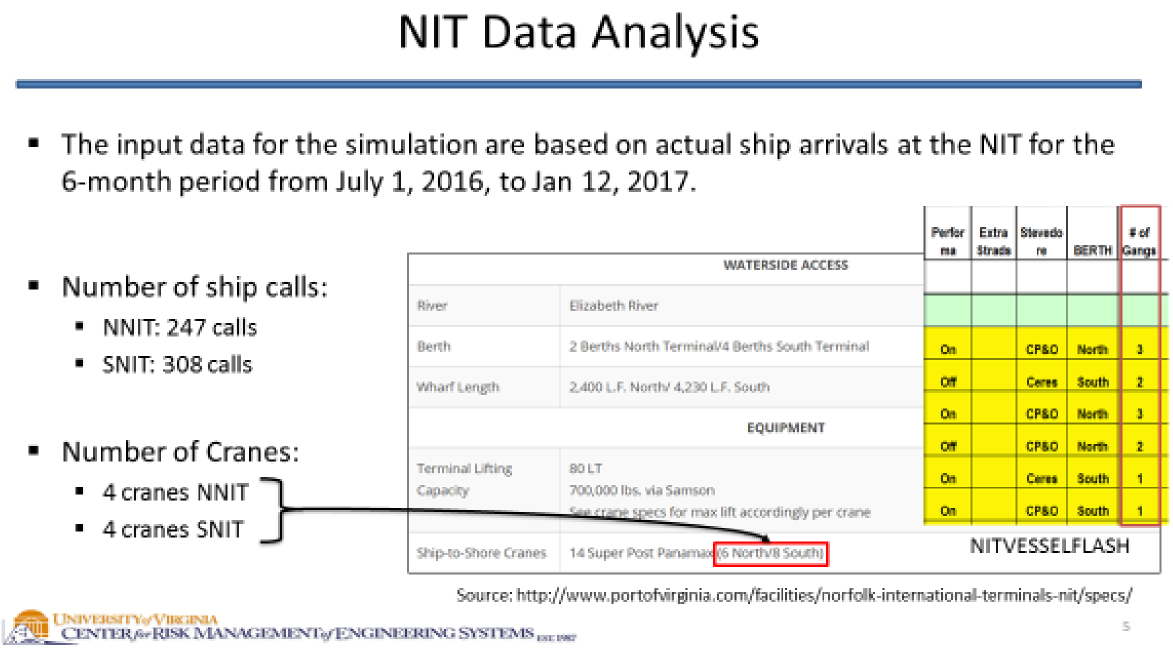

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NIT Data Analysis (Cont.)

- Categorized ships based on number of lifts:
  1. First class: $\leq$ 500 $lifts$
  2. Second class: $501 \leq lifts \leq 1000$
  3. Third class: $1001 \leq lifts$

Total Imports	Total Exports	Total Restows	Total Moves	ST	OT
203,053	219,933	5,712	428,698	4,139	11,015
958	931	48	1,937	12.0	61.5
286	146	0	430	12.0	1.0
122	236	6	364	0.0	16.0
346	322	12	680	0.0	26.0
122	204	30	356	0.0	12.5
48	0	0	48	0.0	1.5
35	24	0	59	0.0	4.5

NITVESSELFLASH

Class of ships (Lifts)	NNIT	SNIT	Percentage
$\leq$ 500	99	129	43%
$501 \leq lifts \leq 1000$	89	36	23%
$1001 \leq lifts$	55	128	34%
percentage	45%	55%	

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Quay Cranes Assignment Analysis

No. of QCs assigned per ship in the NNIT

Classes of Ships	1 QC	2 QCs	3 QCs	4 QCs	Percentage
$\leq$ 500	41	52	5	1	41%
$501 \leq lifts \leq 1000$	0	16	70	3	37%
$1001 \leq lifts$	0	0	27	28	22%
Percentage	17%	28%	42%	13%	

No. of QCs assigned per ship in the SNIT

Classes of Ships	1 QC	2 QCs	3 QCs	4 QCs	Percentage
$\leq$ 500	96	28	2	2	44%
$501 \leq lifts \leq 1000$	0	2	31	3	12%
$1001 \leq lifts$	0	2	59	67	44%
Percentage	32%	11%	32%	25%	

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Quay Cranes Assignment Analysis (Cont.)

Percentage of QCs assigned per class of ship in the NNIT

Classes of Ship	1 QC	2 QCs	3 QCs	4 QCs
≤ 500	41%	53%	5%	1%
$501 \leq lifts \leq 1000$	-	18%	79%	3%
$1001 \leq lifts$	-	-	49%	51%

Percentage of QCs assigned per class of ship in the SNIT

Classes of Ship	1 QC	2 QCs	3 QCs	4 QCs
≤ 500	75%	22%	2%	1%
$501 \leq lifts \leq 1000$	-	6%	86%	8%
$1001 \leq lifts$	-	2%	46%	52%

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Quay Cranes Assignment Analysis (Cont.)

NNIT	1QC	2QC	3QC	4QC
Avg. Processing Time (hrs.)	11.8	11.6	12.9	12.07

SNIT	1QC	2QC	3QC	4QC
Avg. Processing Time (hrs.)	6.8	8.6	18.9	19.3

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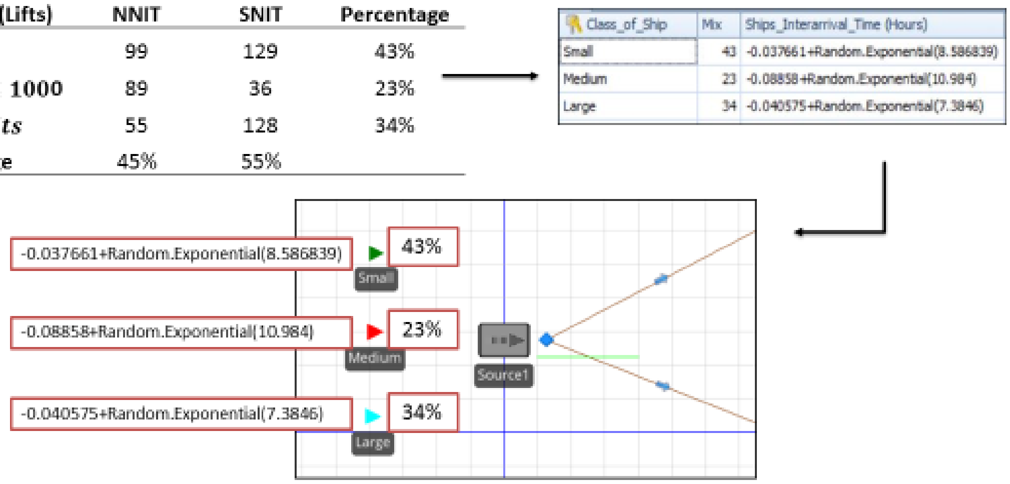
Formulating the NIT Port's Vessel Scheduling Problem (Cont.)

Class of ships (Lifts)	NNIT	SNIT	Percentage
≤ 500	99	129	43%
$501 \leq lifts \leq 1000$	89	36	23%
$1001 \leq lifts$	55	128	34%
percentage	45%	55%	



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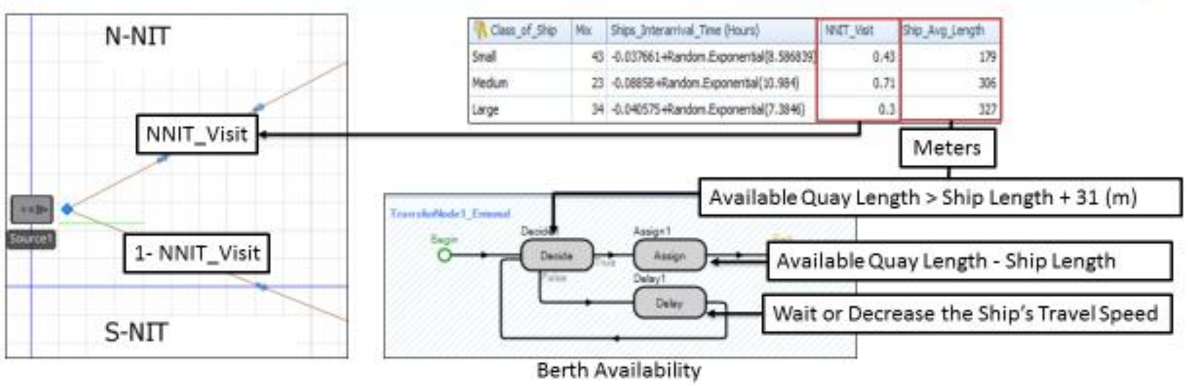
Formulating the NIT Port's Vessel Scheduling Problem (Cont.)



The same logic is implemented for the SNIT terminal.

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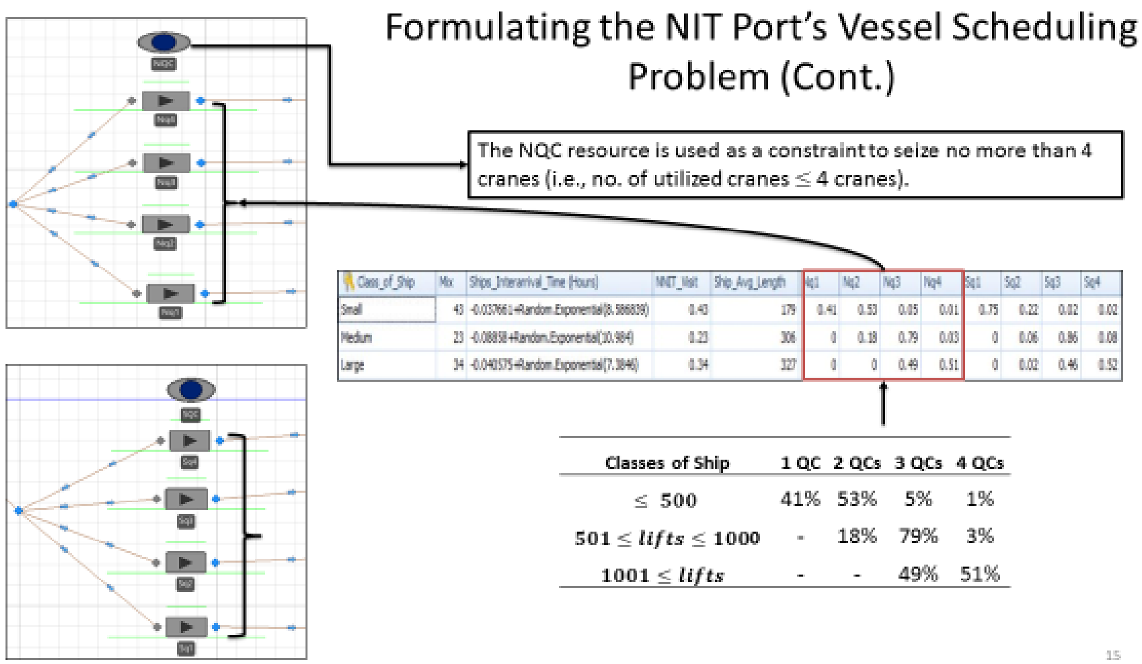

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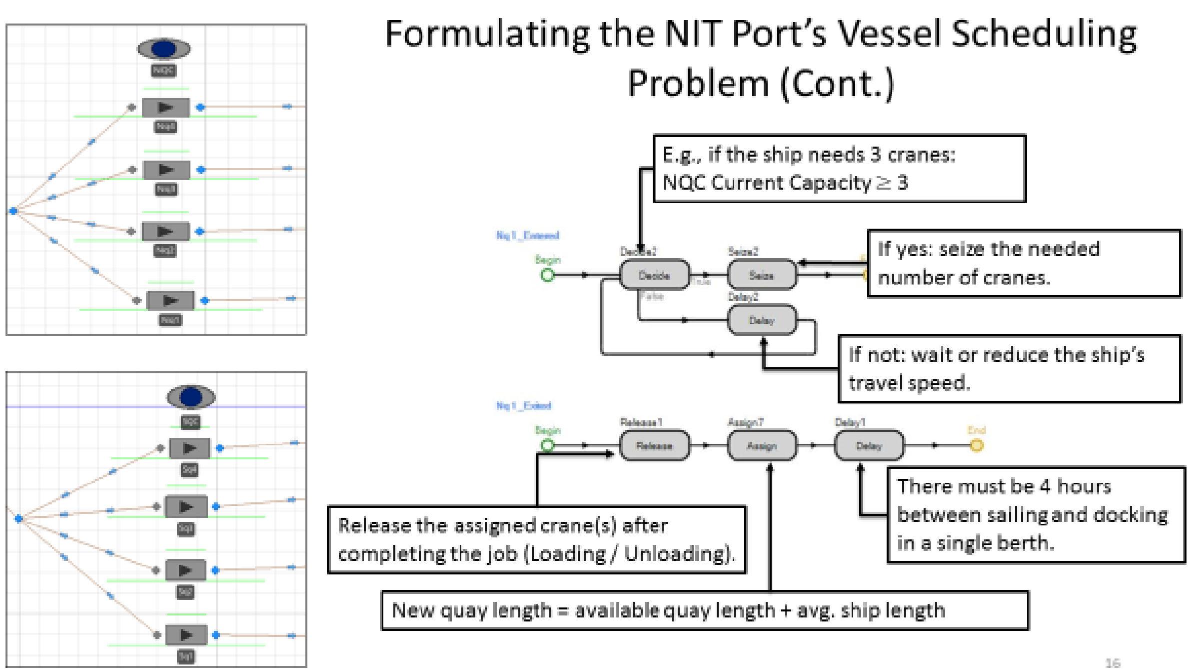

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Crane Assignment Analysis

- The input data for the simulation are based on actual ship arrivals at the NIT for the 6-month period from July, 2016 to January, 2017.

- Number of Cranes:

Container Terminal	N.o of Cranes	Max N.o of Operated Cranes per Ship
N-NIT	6	4
S-NIT	8	4
VIG	8	4
PMT	6	3

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Crane Assignment Analysis

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PMT	6	3

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Crane Assignment Analysis (Cont.)

Avg. Processing Time (hrs.)

Container Terminal	1 QC	2 QCs	3 QCs	4 QCs
N-NIT	11.8	11.6	12.9	12.07
S-NT	6.8	8.6	18.9	19.3
VIG	6	11.1	17.2	19
PMT	9.1	9.2	15.9	-

Time Between Failures (hrs.)

N	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
225	20.3	18.7	13	0	85	1.2	1.3

Time to Repair (hrs.)

N	Mean	StDev	Median	Minimum	Maximum	Skewness	Kurtosis
225	0.3	0.6	0	0	4.7	3.2	13.7

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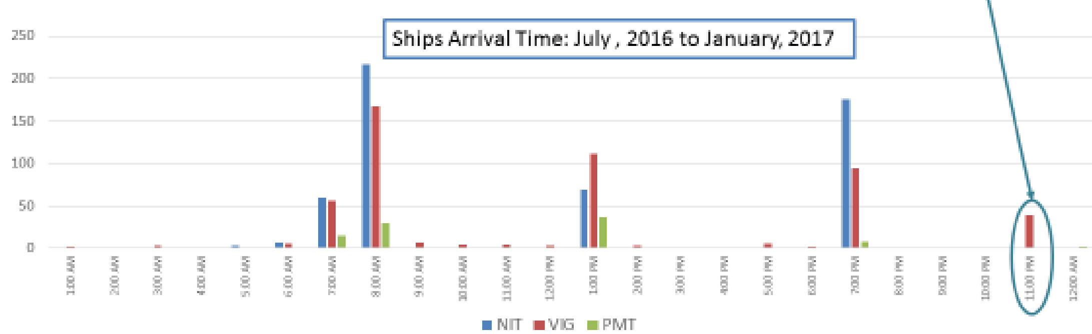
Crane Assignment Analysis (Cont.)

Arrival Time	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM
NIT	0	0	0	0	3	7	59	217	0	0	0	0
VIG	2	1	3	1	1	5	56	167	6	4	4	3
PMT	0	0	0	0	0	1	14	29	0	0	0	0
Arrival Time	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM
NIT	68	1	0	0	1	1	175	0	0	0	0	1
VIG	111	3	0	1	5	2	94	0	0	0	39	1
PMT	36	0	0	0	0	0	8	0	1	0	0	2



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