The Resilient City: A Platform for Informed Decision-Making Process

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THE RESILIENT CITY:
A PLATFORM FOR INFORMED DECISION-MAKING PROCESS

by

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ABSTRACT

THE RESILIENT CITY: 
A PLATFORM FOR INFORMED DECISION-MAKING PROCESS

Jarutpong Vasuthanasub
Old Dominion University, 2019
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As over half of the world’s population lives in cities, the rapid growth in urbanization has made cities become more and more exposed and vulnerable to a broad spectrum of threats and hazards. In order to respond to such difficulties, a concept of resilience is considered a significant component for the long-term planning and sustainable development of cities. “Resilient City” is a new paradigm that challenges the idealistic principle of stability and resistance to change implicitly in sustainable development and long-term success. However, building a resilient city requires a holistic approach, as well as the appropriate adoption of knowledge and application of tools during the planning and management process. Although there are many studies intended at enhancing the capacity of city resiliency, few are explicitly focused on developing practical sequential steps of resilience building that the city can follow. Thus, this research aims to narrow a gap of that missing body of knowledge by developing a methodological framework, which involves procedural steps in assisting the planning and management processes of resilient city development. The platform proposed in this dissertation was developed based on a theoretical approach, called “Resilient Informed Decision-Making Process.” It integrates the use of concepts and techniques, including project management, risk and vulnerability assessment based serious gaming, multi-criteria decision analysis, and object-oriented programming. To demonstrate the efficacy of a platform, the methodology is incorporated with the urban planning simulation computer game “SimCity 2013” and the “City of Norfolk” as an example.
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This dissertation is dedicated to my families: Vasuthanasub – Vajaphattana – Wachapatthana.
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NOMENCLATURE

100RC  100 Resilient Cities
AHP    Analytic Hierarchy Process
CI     Critical Infrastructure
DSS    Decision Support System
EMSE   Engineering Management and Systems Engineering
ER     Evidential Reasoning
MAUT   Multi-Attributes Utility Theory
MCDA   Multi-Criteria Decision Analysis
MCDM   Multi-Criteria Decision-Making
LDW    Logical Decision for Window
IDS    Intelligent Decision System
IRRA   Integrated Regional Risk Assessment
NRC    Norfolk Resilient City
NRS    Norfolk Resilient Strategy
OOP    Object-Oriented Programming
PKS    Project KickStart
PM     Project Management
ReIDMP Resilient informed Decision-Making Process
RIDMP Risk Informed Decision-Making Process
RRA    Rapid Risk Assessment
VA     Vulnerability Assessment
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CHAPTER 1
INTRODUCTION

The world today, as of August 2018, is a home to 7.6 billion people (Population Reference Bureau, 2018), and the number is projected to escalate steadily to 8.5 billion by 2030, 9.7 billion in 2050, and 11.2 billion in 2100 in which India is expected to outnumber China around four to six years from now (United Nations Department of Economic and Social Affairs, 2015, 2017). As a matter of fact, cities have been the centers of human culture and economic activity for centuries and attracting skilled workers and productive businesses from around the world. In the upcoming several years, the majority of populations in most major cities will continually be increasing (Rockefeller Foundation & ARUP, 2014). Much more people from remote and rural areas will flow into the cities to seek the opportunities of their better lifestyle and living qualities. Regarding these pieces of information, Dobbs et al. (2012) projected that between 2010 and 2025, estimated 600 million inhabitants will populate in only around 440 cities, which are expected to generate roughly half of a global GDP growth. These people are drawn to cities by job opportunities, economic activities, and modern productivities. For this reason, Critical Infrastructures (CIs) will play as primary roles of city's system mechanism to support and ease human wellbeing.

1.1 Problem Background

As the 21st century unfold, the occurrences of catastrophic and unforeseen events, such as climate change, disease pandemics, economic fluctuations, and terrorist attacks, have played out at a global scale. The levels of urban risk and vulnerability tend to keep increasing due to the number of people living in the cities (International Council of Local Environmental Initiatives...
They are also exceedingly unpredictable due to the complexity of city systems, especially CIs, and the uncertainty of external variables (Rockefeller Foundation & ARUP, 2014). A concept of resilience is considered a significant component for a long-term planning and sustainable development of the cities (ICLEI, 2015). As of cities all over the world are facing numerous risks and vulnerabilities posed by particularly climate change, natural disasters, and economic recession, the terms of “Resilient City” and “City Resilience” (cities that are able to withstand and recover from any disturbance or disruption of unexpected events while maintaining its essential functions, structures, and identity) has emerged over recent years in responding to the needs of more security and protection on CI (ARUP & Engineers Without Borders UK, 2012). However, the current efforts on the subject are more likely to be practical or feasible in the short-term, as they are only seeking to improve existing technological and infrastructural systems, by evidencing from the past experience (Yañez & Kernaghan, 2014). In other words, climate change, disease pandemics, economic fluctuations, and terrorist attacks are not a set of threatening events in which the simplistic implementation or remediation plans can provide the city with sustainment and resilience solutions. ARUP & Engineers Without Borders UK (2012) indicated that applying a concept of resilience to city requires different sets of professional and practical entry points, and especially different scales of multiple collaborations. These approaches would create a serious challenge in attempting to clearly define city resilience in a way that can be succinctly communicated and cautiously implemented.

Under these circumstances, the analysis and assessment of risks and vulnerabilities will certainly continue to play the important roles in planning and development of existing and next generation CIs. Additionally, stakeholders, including governments, donors, investors, and policymakers must also ensure that their investments, strategies, regulation, and decisions will reduce or
even eliminate the potential risks and vulnerabilities, in the meantime, enhance city's resilience. Thus, it is a crucial moment that a concept of resilience is not only needed to enlighten the development direction of cities, but a resilience-based action is also required to ensure the performability and capability of city systems in the future (Yañez & Kernaghan, 2014).

1.2 Critical Infrastructures at Risks

CIs are a sector or a set (systems) of national assets, facilities, and service (infrastructures), whether physical or virtual. They are so vital and ubiquitous to the nation that their destruction or incapacitation would cause a debilitating effect on the national security, economic, safety, healthcare, or any combination of those matters (U.S. Department of Homeland Security (DHS), 2013). The high level of development and functionality in human society assumes a longer list of CIs and a more severe dependence on them and interdependence among them. According to DHS (2009, 2013), most notable CI sectors are, including chemicals, commercial facilities, communications, critical manufacturing, dams, defense industrial bases, emergency services, energy, financial service, food and agriculture, government facilities, healthcare and public health, information technology, nuclear reactors – materials – waste, transportation systems, and water supply and wastewater systems.

Over the last decades, the advancements in CIs, such as modern information, cloud technology, clean energy, intelligent transportation system, and better healthcare systems, have significantly changed human and societal wellbeing (Moteff, 2005). Many new inventions and technologies have aided the world with comfort and convenience available on a daily basis, society has become dependent upon them to survive. CIs, however, can have service interruptions due to many reasons. A service interruption to any infrastructure systems would have more or less negative impact on
the typical functionality of society. The Internet, for instance, is now an integral part of human life and business activities. An unexpected interruption with its service would result in being unable to perform their normal routines or operations. CIs in the digital era are indispensable. They are functioning to support various types of activities across the nation, from food and agricultural production to electricity and power generation. Moreover, the interconnection and interdependence between CIs also allow participants’ greater control, faster response times, and more information access than traditional (simple) system models. However, with such a high level of interconnection and interdependence, it is hard to determine where exactly one system ends and another begins (Gheorghe, Masera, Weijnen, & De Vries, 2006). The overlapping characterizations of CIs have developed to the level of risk and vulnerability inherent in any systems, which requires a comprehensive and elaborate study on the subject to determine their long-term ramifications. Every possible risk and vulnerability to CIs need to be individually considered, measured, and addressed in order to prepare the implementation plan (Gheorghe, 2005). The complexity of CI systems is required complete analysis and assessment for their typical operating scenarios, for example, how they are supposed to function on a daily basis and especially how they are expected to perform in specific circumstances or events. Systems are also needed extensive evaluation on how vulnerable they are to the interruption due to failure from a risk, or perhaps due to malice from terrorists or those with malicious intent respectively (Gheorghe et al., 2006).

CIs, nowadays, are eventually not only exposed to multiple threats or catastrophic events, including climate change, natural disaster, institutional or regulatory changes, and terrorist attacks but also posed risks and vulnerability themselves. They are highly interconnected and interdependent, and embedded in a socio-technical system-of-systems, for this reason, it is even
more difficult to predict how a crisis might evolve or what systems would be affected (Gheorghe et al., 2006). As Rinaldi (2004) stated that “CIs have become increasingly interdependent,” in the meantime, human life quality and economic prosperity have also become more dependent on their functioning (Moteff, 2005; Gheorghe, 2005). Indeed, their reliability and safety level should come as the top priority and be high.

1.3 Future of Critical Infrastructure Resiliency

As was previously stated, CIs are networks of complex systems that provide essential services to a population or nation. The systems are complex by nature because they are widely distributed across large geographical regions and are becoming increasingly interconnected and interdependent as they evolve. Although, speaking about CIs in Engineering Management and Systems Engineering (EMSE) perspective, CIs can also be viewed as mega scale complex systems that include complex hardware and software components with sophisticated structures of operations and governance. To ensure the security of CI systems, several elements are needed to be addressed and verified, including addressing potential risks and vulnerabilities and sharing accurate information and analysis on existing and future threats (DHS, 2013).

Risks and vulnerability may seem to be separated, but they are fundamentally interrelated concepts that have broad implication for CIs. Risk, technically, refers to a measure of the probability and severity of undesirable outcomes (adverse effects) resulting from a threat, incident, event, or occurrence to the system. To be more specific, it is a combination of the likelihood of an event occurring and the events consequences. Probability is a measure of the uncertainty of occurrence of the event or scenario that initiates the event, while consequence is represented as levels of severity (Aven, 2010). Quantification of risk in this manner is intentionally used both as
an analysis and design tool. For an analysis tool, risk assessment can begin with presumed scenarios that are considered the threats against continued operation or system performance to discover the system weaknesses. As a design tool, reliability values can be applied to system functions based on their malfunctioning or a failure state where misleading data is generated from the system purposes without detection (Yuchnovicz, 2013). So much so that by developing risk analysis to set reliability design goals, the attempts would deliberately lead to the better design of resilient systems in which respectively make CIs less susceptible to threats. On the other hand, vulnerability is “a fault or weakness that reduces or limits a system’s ability to withstand a threat or to resume a new stable condition” (Aven, 2007). Based on this definition, a threat is an event or scenario with an associated uncertainty (probability of occurrence) and corresponding consequence (level of severity). As CIs are becoming so complex, they can be vulnerable to various events based on their system characteristics and intended functions. Vulnerability analysis and assessment can unveil the events that can be harmful to a system, and it must be conducted in all phases of operation and system configurations. Risk analysis and assessment of these events will allow further quantification of the events regarding uncertainty and the consequence of occurrence regarding severity. Overall knowledge of risk and vulnerability assessments will help to prioritize risk mitigation efforts.

More than a decade, CIs protection and resilience has been receiving serious attention from public and private sectors, including government, academic institutions, and both profit and non-profit research foundations. It has also been becoming a national top priority mission in most developed countries (DHS, 2013). Nevertheless, the sheer complexity of CIs has shifted the degree of investigation to a level that much more comprehensive research on the subject is significantly imperative. A profound study of CIs resilience framework is now moving toward the discipline of
modeling and simulation to determine system sustainment and future development direction of CIs when confronted the threats. For instance, Kroger (2008) strongly asserts that to be successful in developing the vulnerabilities reduction model for CIs; First, the risk management and risk governance strategies must be clearly defined. Second, advanced object-oriented programming and simulation tools are needed to perform an analysis and assessment.

1.4 The Need for New Approach

Decision-making is a fundamental part of human life. Decisions can be made quickly and easily when the objectives are clear, the information necessary to evaluate alternatives is available, and the outcomes of decisions can be accurately predicted. However, as the complexity of the decision increases, the decision-making process becomes more difficult because of the number of factors that have to be taken into consideration for the analysis. In other words, the decision is directly related to the value assigned to its consequences or results, especially when it involves large-scale complex systems and can create major impacts on the population or a nation. In this case, Risk-Informed Decision-Making Process (RIDMP) is a method that was designed to fulfill this gap. The intent of this technique is that whenever there is a significant decision between design alternatives, the process can be used as a way to inform the decision makers about the risk involved in each alternative (Zio & Pedroni, 2015).

According to National Aeronautics and Space Administration (NASA, 2010), “RIDMP is a fundamentally deliberative process that uses a diverse set of performance measures, along with other considerations, to inform decision making.” A process combines the input of stakeholders as well as cost and feasibility, and then focuses on informing the decision makers (NASA, 2010; Zio & Pedroni, 2015). With this applicability, a decision can be made with considerations beyond
just technical information. Unfortunately, one issue with RIDMP is that it is impossible to include or evaluate every risk for each alternative in all the decision-making situations. There are insufficient resources to evaluate all risks, especially for decisions involving complex interconnected and interdependent systems. Also, even if enough resources were available, there will always be unforeseen or unknown risks constantly emerging as a result of the operation and evolution of the systems and their environment. In recent years, the concept of resilient governance has rapidly received more attention and popularity in both academic and industrial societies. This paradigm is now shifting from the risk and vulnerability perspective to the view of resilience (Mitchell, 2013). For this reason, resilience should also be included as part of the decision-making process in what would be called “Resilience-Informed Decision-Making Process (ReIDMP).”

Some researchers may say that ReIDMP is simply an extended version of RIDMP; instead of looking at risks, the resilience is considered. This idea seems to be partially correct, because in the reality, they are explicitly differences. To put it another way, when discussing about both methods, it is indeed true that the purpose of both methods is to “inform” the stakeholders or decision makers. Although the core concept of ReIDMP may look the same as RIDMP, the implementation steps are not quite similar. To be more specific, while RIDMP is focused on identifying and understanding every risks and vulnerability in all possible aspects and then selecting the best alternative to prevent that potential risks and vulnerabilities. ReIDMP should be focused on a comprehensive study of the effectiveness of selected alternatives based on the concept of the ability to recover. So much so that an informed decision can be made in respect to striving for a resilient solution. To step further to analyze and assess the ability of the system to anticipate, absorb, restore, and adapt from the effects of the catastrophic and threatens events in a timely and efficient
manner (Mitchell & Harris, 2012). ReIDMP is required a completed analysis for all the alternatives evaluated during the decision-making process.

With resilience-based action approaches the decision-making process, it may be possible to reveal and select the most effective and viable solution. Meantime, the ReIDMP may also provide other benefits since it can enhance the analysis and deliberation results of alternatives. For instance, there may be some situation that an alternative can be selected if additional required actions are done to improve its resilience.

1.5 Research Scope and Objectives

As the world's population continues to grow and the demand for essential services and facilities tend to increase consistently, the future trend is expected to focus more and more on an ever-increasing need of sustainable development and resilience frameworks for present and next generations CI systems.

To be capable of making decisions on how to increase CIs resilience as well as drive down risk and vulnerability, in depth analysis needs to be performed to define the primary areas to invest resources. The fundamental resources are limited, therefore, the selection of knowledge to focus on should be carefully made to prevent expending the resources in a way that has a minimal effect on CIs. In particular, education and experience are keys to ensuring CIs resilience. A true meaning of resilience is one where engineering managers and systems engineers are correctly educated about the risks, vulnerability, and hazards that CIs may face, and what to do in the occurrence of catastrophic events. CIs that are better prepared to deal with events like natural disaster and terrorist attacks will have a better chance at a quicker recovery.
As shown in Figure 1, the primary purpose of this research is to develop a resilience quantification platform based informed decision-making process. The result of the effort is expected to provide a better understanding and guidance on sustainable development and resilience.
framework for existing and next generation CIs. On the other hand, the secondary goal is to introduce an idea of serious gaming concept as a teaching application in graduate level and the use of simulation computer game “SimCity 2013” as a teaching tool in a way that effectively enhances students’ learning experience on risks and vulnerability concepts.
CHAPTER 2
LITERATURE REVIEW

2.1 Norfolk Resilient City

In 2014, Rockefeller Foundation started a project, named 100 Resilient Cities (100RC). At that time, many cities, such as Bangkok, Barcelona, Glasgow, Lisbon, London, Melbourne, Milan, Montreal, Paris, Rio de Janeiro, Rome, Sydney, San Francisco, and other world-class cities, have been selected to join a program. Not to mention, the foundation selected the City of Norfolk as one among the first group of members of 100RC as well (Figure 2). 100RC is committed to supporting cities all over the globe to become more resilient under the challenging situations of physical sustainability, social complexity, and economic difficulty (City of Norfolk, 2015). These three major concerns are primarily a growing part of the 21st century, which need a direct partnership and close collaboration with member cities to understand resilience challenges and to seek viable solutions. A program promotes the adoption and incorporation in view of resilience that includes...
not only the shocks causing by natural disasters but also the stresses resulting from global situations or human errors. A vision of 100RC not just intends to help individual member cities to strive for resilient development. It also aims to facilitate the creative global practices of urban resilience planning among governments, private organizations, non-profit associations, and citizen groups (City of Norfolk, 2015).

Speaking about Norfolk, the city was established in August 1682 based on the British Act in 1680. The lower part of the county was surrounded by the Elizabeth River on the east, west, and south. For more than 300 years, this historic city on water has been serving as a key part of American's history, military, commerce, and innovation (City of Norfolk, 2015). Nowadays, Norfolk is a home of Naval Station Norfolk, the largest naval base in the world, and Port of Virginia’s Norfolk International Terminals, one of the most important economic assets on the East Coast of United States (Jeffers et al., 2016). It acts as an international city that drives the global trading activities and the main hub of Hampton Roads region that links national logistic nodes. According to these notable privileges, the water access is the greatest advantage of Norfolk. The shoreline and waterways are always and will be the most critical asset of a city, as they render the opportunities and additionalities to strengthen a foundation of transportation infrastructure. However, locating next to the water also causes a city with a huge drawback. Norfolk has been experiencing a number of flooding events throughout its history, but the frequency and severity of occurrences have dramatically increased over the last decades. Several factors are accelerating the risks of this natural hazard and forcing a city to invent the sustainable solutions for living in a beneficial way with water. Those concerns include:
- **Sea Level Rise:** With subsidence of local lands and coastal areas around the Norfolk's coastline, the city is now facing the highest rate of relative sea level rise on the East Coast (Jeffers et al., 2016). While the average rises of global sea-level are between 5 - 8 inches over the last century, the sea level at Norfolk has risen over 14 inches since 1930 (City of Norfolk, 2015).

- **Storm Incidences:** Regarding a statistical data on Water Level Elevations of Major Storms at Sewells Point Tide Gauge that affected Norfolk since 1933 by National Oceanic and Atmospheric Administration (NOAA), six out of the eleven occurred during the last twelve years (City of Norfolk, 2015). As a matter of fact, the percentage of tidal flooding areas around the city has increased by 3.25 times since 1960, and the sea level at Norfolk location is projected to rise between 1.5 - 7.5 feet in the next 85 – 100 years (Jeffers et al., 2016; City of Norfolk, 2015). Therefore, in order to help Norfolk withstanding this unavoidable circumstance, the direction is clear that the city will definitely need to plan ahead or even do something better for the near future.

- **Flood Risk:** While more frequent and more intense storms, as well as repeatedly routine flooding, keep threatening Norfolk's resident, some of the city's most commercially and industrially at-risk zones are openly vulnerable to floods and storms (City of Norfolk, 2015).

In summary, as risks of geographic condition around the city continue to shift, Norfolk is facing tough challenges in how to react for today and prepare for the future. With the unchangeable requirements, notably the Norfolk's likelihood and economy will continue to rely on the access to the water, the city must unmistakably adapt to the changing environment in effective ways. To build a resilient city as well as forming strong communities and societies, involved stakeholders
such as city leaders, the private sector, neighbor groups, and residents must collaborate with each other to develop solutions that lead to the flourishing of business and living quality.

2.2 Definitions of Resilience

According to the Definitions of Community Resilience: An Analysis by Community and Regional Resilience Institute (CARRI, 2013), it verifies that “Resilience” is a terminology that originally derived from the Latin “Resalire,” and means “To spring back.” It has been becoming a popular term in many fields of study and discipline and is considered one of the most important aspects in the context of achieving sustainable development in the last fifteen years (Folke, 2006; Robert, Parris, & Leiserowitz, 2005; Walker, Holling, Carpenter, Kinzig, 2004, & Westrum, 2006). In fact, the term of resilience was initially introduced and formally used by an ecologist in the 1970's and psychologist in the 1980's to develop somewhat distinct phenomena (CARRI, 2013; Rockefeller Foundation & ARUP, 2014). In an ecological community, the term was applied to describe the capability of an ecosystem to maintain and recover its functionality from the disruption or disturbance of catastrophic events (Folke et al., 2010; Gunderson, 2000; Holling, 1973). For a psychological society, the term was used to identify a group of test subjects with consistent behaviors in adversity or distress situation (Folke, 2006). Even though the conceptualization of resilience has noticeably gained widespread attention from various sectors, including government, academia, and industry and seriously apply to many areas of past, current, and possible future research and projects, unfortunately there is no agreement or approval on a universally accepted definition that is used across all fields of study. For this reason, the purpose of subject reviews is to present the diversity of developed definition based on a core concept of resilience.
After the 9/11 attacks in 2001, the term of resilience began being earnestly adopted by the government in developed countries to re-examine and re-evaluate their national security, especially the United States, and also systematically employed by engineering community to design the protection plans and security frameworks for CI systems. Since then the core concept was mostly related to the ability to absorb, recover from, and adapt to the hazards (CARRI, 2013). Nowadays, resilience has numerous definitions based on the applicability and suitability in the different domains of research communities. Some were derived by combining the definitions from an ecology with a psychology while some were obtained by merging certain part of meaning from an engineering with an economy. Likewise, most of them yet were carried the same core concept. In this dissertation, a variety of the most widely recognized definitions of resilience interrelated to specific fields of study are presented in Appendix A. Each of them basically reflects how the community responds to an adverse event. However, even though they are simply categorized regarding the intended domain of use, it is probably useful to review the themes among the core concepts within the definitions that can be appropriately applied to this research.

CARRI (2013) suggested that a second way to define the concept of resilience is the metaphorical meaning of “Resistibility and Adaptability.” Many ontological definitions begin with “The ability” or “The capability” of entities, organizations, or societies (see Appendix A) and then reflect the idea of “Resistance vs. Adaptation” to cope with shocks and stresses (Walker, et. al, 2004). That is to say, a system resists the threat to avoid change, and its resilience is determined by how much difficulty it can withstand and endure without collapsing. In contrast, a system adapts to great danger by altering its functionality or by spending resources in preservative ways (Anderies, Janssen, & Ostrom, 2004).
Another way to classify the definitions of resilience is the notion of “Predictability.” Due to the fact that some of the developed definitions partially lend from different fields of a research community, therefore, the definitions in this environment often can be referred to a prediction on how long and how well a system will be able to regain its intended functions compared to the others (CARRI, 2013; Holling, 1996). However, this type of classifications may be useful or appropriate for making predictions, either their ontological definitions indicate that resilience can only be applicable after an occurrence of the events (Butler, Morland, & Leskin, 2007), or the subjective nature of those definitions are clearly identified (Kimhi & Shamai, 2004).

Additionally, the definitions can also be classified regarding the term of “Trajectory.” As has been noted, since a terminology was firstly utilized by ecologists, most of the derived definitions in an ecological domain are typically focused on whether or not a system evolves in the difficult circumstances, and do not try to evaluate whether the change is an innovation or deterioration (Folke et al., 2010). This type of definition clusters more straightforward rather than complicated that if a system can survive stressful situations, it is resilient, but if it does not, it is not resilient (CARRI, 2013).

All in all, it seems to be difficult to choose one as the best from above exemplified definitions. While some depict resilience as an emergent property that appears only in the wake of a crisis (Butler et al., 2007), the others view resilience as a process of dealing with adversity (CARRI, 2013). Therefore, since each of them contains value and evidence which can lead to positive contributions or potential success within its relative research domain, a selection of ones should be more or less relevant in the way to support the study. As for this research, an underlying implication of resilience, for instance, in the context of CIs in the view of EMSE mainly refers to
the capability of a system – systems as a whole – to withstand, absorb, recover from, or adapt to a change in environment or conditions (Moteff, 2012).

2.3 Qualities of Resilient Systems

In the context of CIs, the notion of resilience becomes conceptually pertinent when either an extensive range of sudden shocks and chronic stresses or the collapses of physical and social systems dangerously threaten the national security. Considering this experience, Rockefeller Foundation & ARUP (2014) asserts with a clarification that resilience has fulfilled the gap between disaster risk reduction and natural hazards adaptation by moving away from traditional disaster risk management, which is usually recognized in conventional risk assessments related to specific events. In other words, “Instead of accepting the possibility that a wide range of threatening incidents – both tensions and collapses – may occur but are not necessarily predictable. Resilience focuses on enhancing the performance of a system in the face of multiple hazards, rather than preventing or mitigating the loss of assets due to specific events” (Rockefeller Foundation & ARUP, 2014). Nevertheless, one conceptual limitation of this evidence is that resilience does not account for the power dynamics that are integrated with the way CI function and cope with disruptions and disturbances.

Assigning the qualities to infrastructure systems will enhance an overall performance of resilience to CIs. In this manner, extensive research and studies have indicated that there are at least seven distinctive qualities in which truly resilient systems should demonstrate. Each of them can be identified and characterized in term of the followings:
2.3.1 Flexibility

This characteristic refers to the ability or capability of systems to react, adjust, evolve, and adapt by spending allocated alternative strategies in corresponding to the needs of changing circumstances or sudden crises (Rockefeller Foundation & ARUP, 2014). It is directly related to the decentralized and modular approaches to infrastructure management. Rockefeller Foundation & ARUP (2015) suggested that a successful development of flexible systems can be achieved through the introduction of new knowledge and innovative technologies, as well as the additional combination of local experiences and management in new ways.

2.3.2 Inclusion

A strategy of inclusion underlines a completeness of communication, including comprehensive consultation, commitment, and especially engagement of all decision makers and stakeholders. Addressing and monitoring the potential risks, hazards, and events related to one sector or set of CI systems in isolation of the others is an obstruction to reach the core concept of resilience (Rockefeller Foundation & ARUP, 2014, 2015). Hence, an inclusive approach is needed to create a sense of shared ownership or joint vision and then to produce an effective leadership or attentive governance on systems resilience.

2.3.3 Integration

This attribute emphasizes an integrated process and alignment between the interrelated or interconnected set of CIs and systems to maintain and promote consistency in decision-making among decision makers and stakeholders. Integration must be evident within systems and across different scales of their operation. It helps to ensure that investments and actions are mutually and
appropriately address the common needs or outcomes. Exchanging the data and information between systems and sub-systems allows them to function collectively and respond rapidly in shorter periods or loops throughout the whole system (Rockefeller Foundation & ARUP, 2014).

2.3.4 Redundancy

This feature refers to a spare capacity or secondary alternative within systems, which purposely designated to accommodate disruption due to extreme pressures or external interferences (Rockefeller Foundation & ARUP, 2014). The intent of redundant systems must be diversified in a way that there are multiple selections to obtain a given objective or to fulfill a particular function. An example of existing systems in the real world that incorporates redundancy is power distribution networks and multiple delivery pathways of energy infrastructures (Rockefeller Foundation & ARUP, 2015). Redundancies should be well considered, cost effective, and prioritized at a large-scale implementation.

2.3.5 Reflectiveness

Reflective systems signify an acceptance of inherent uncertainties and necessary changes in the real world. Rather than seeking permanent solutions based on theoretical beliefs, individuals and institutions must continuously evolve, modify their norms, and adjust their behaviors based on emerging evidence (Rockefeller Foundation & ARUP, 2014). Thus, reflective or thoughtful people are always enthusiastic to systematically look, listen, and learn from their past experiences, and then to leverage those learning and understanding to inform future decision-making (Rockefeller Foundation & ARUP, 2015).
2.3.6 Resourcefulness

This qualification implies that individuals, groups, and organizations are the key to success in finding and discovering the different ways to accomplish their goals or satisfy their needs during difficult times or challenging moments (Rockefeller Foundation & ARUP, 2014). It is more like a personal trait of persons rather than being a qualification of systems. Resourceful manpower may include decision-makers, stakeholders, and any other associated personnel who are responsible for or involved in the investment and development processes, such as future state forecast, set priorities ranking, and financial and physical resources allocation and management (Rockefeller Foundation & ARUP, 2014). Resourcefulness is considered an essential instrument of CI systems' ability to maintain and restore their functionality under critical conditions or severe constraints at times of crisis.

2.3.7 Robustness

Robust systems are a reflection of robust design. They represent how well systems are conceived, constructed, and particularly managed physical assets (Rockefeller Foundation & ARUP, 2015). As a result, the systems will be able to resist the outcomes or impacts of catastrophic events without significant damage or loss of functionality. Robust design of CI systems should focus on scanning potential internal failures and making precaution to ensure failure is predictable, safe, and not deviant from the root causes (Rockefeller Foundation & ARUP, 2014). That is to say, when the design thresholds of robustness are exceeded, the protective systems will not easily or suddenly fail.
2.4 Applicability of Gaming in Education

Games have been created with the purpose of entertainment for a long time. They have always attracted people because they provide fun and excitement. For this reason, game developers have tried very hard to invent and introduce the new ways of enjoyment. Thanks to the rapid advancement and extensive expansion in computer hardware and visualization technologies, each and every time, the graphical detail and definition of games have become more realistic and accurate to the player. With the ability to mimic or simulate reality, some game designers started to adopt a purpose of playfulness to develop another kind of games, a more serious one. Those applications can be used for research, education, and training as if they are seen fit or compatible with the study and finding objectives (Squire & Jenkins, 2003). When discussing the concept of gaming in education, there are at least four categories of existing idea emerging in the literature (Susi, Johannesson, and Backlund, 2007).

- **Serious Gaming:** The term represents the use of games for specific purposes or other benefits, such as learning, researching, and training, instead of entertainment value only. It may look just like playing digital games, but its objective is to achieve something extraordinary.

- **Simulations:** Simulation technologies are quite similar to serious games unless they have an ability to replicate and visualize the real-world objects or environment for real-life training.

- **Game-Based Learning:** The concept refers to a use of games in the traditional classroom to strengthen the course objectives and to enhance the learning and teaching experience. Game-Based Learning is considered a branch of serious gaming that designed to deal with designated learning outcomes (Corti, 2006).
- **Gamification**: Gamification advertises the use of game design elements in non-game contexts to motivate or influence desired behaviors. Those attributes include elements, such as leaderboards, badges, levels, trophies, or any other rewards. A concept is a considerably new to scholarly society but a substantially developed in the business world (see Appendix B\(^1\)).

During the past 20 years, there have been numerous research and studies on the effectiveness and productiveness of using serious games as a learning tool or gaming concept as a teaching technique. For example, Griffiths (2002) quotes that one investigation from a psychological association dating back in the early 1980s has logically revealed that playing digital games, both video-based or computer-based, develops the reduction in responsive times, improvement in hand-eye coordination, and encouragement in players’ self-esteem and self-respect. Considering this found evidence, Griffiths (2002) also concludes that video games or computer games have great benefits and positive potentials not only for their entertainment value but also non-entertainment purposes, and a future success of this initiative can be achieved when appropriate games selection and playing requirements are designed to address a particular problem clearly or to teach a certain skill specifically. With this in mind, a literature review in the following sub-section will focus on a conceptual framework of specific technique, notably serious gaming, in term of educational benefits.

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\(^1\) Appendix B presents additional details on the definition, distinctiveness, and core values of Gamification. The purpose of studying the gamified application in this research is to understand the nature and differentiate the requirements of using the technique in educational environment.
2.4.1 Serious Gaming

Digital games always have outstanding motivational potentiality. They manipulate a set of design elements to encourage players to interact with them willingly without any rewards, but just for the satisfaction of playing and the opportunity to win, so much so that playing video games or computer games undoubtedly consume the attention of players. By watching students or participants play the video games or computer games, indeed it becomes apparent that they prefer this way of learning approach rather than traditional ones (Griffiths, 1996, 1997, 2002). However, it is unquestionably relevant to investigate the extent that the technologies of serious games had a positive impact on education.

As serious games have the capability to acquire concentration and to stimulate motivation of players in learning experiences and outcomes, consequently, they have led to an emergence of gaming terminologies in education, such as edutainment, serious gaming, and gamification respectively. Serious gaming can be viewed as a redefined version of the first fundamental gaming concept in education “edutainment”, which was considerably popular during the 1990s. Unfortunately, due to a growing interest on the Internet and the poor quality of the games themselves, edutainment has finally failed to mark itself as the first milestone in the history of gaming in the academic world (Michael & Chen, 2006; Van Eck, 2006). Yet, the development of digital games for non-entertainment purposes was begun and evolved longer before a flourishing era of edutainment. As edutainment failed to prove its applicability and practicality, the concept of serious gaming was subsequently re-examined during the late 1990s. In 2002, with a released campaign of the video game, America’s Army, by U.S. Army and founded institution of the

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2 At that time, edutainment - educating through entertainment - became well-known due to the booming growth of personal computer market (Michael & Chen, 2006). The term was usually used to describe any types of education that are concurrently knowledgeable and enjoyable. The primary target group was young children in elementary school and junior high school with the focuses on reading, mathematic, and science.
Serious game Initiative by Woodrow Wilson Center for International Scholar in Washington, DC, a journey of serious gaming has started (Susi et al., 2007).

In general term, serious gaming usually refers to the uses of video games and computer games for informing, educating, and training at all genders and ages. The concept itself inherits the same primary goals as edutainment but extend far beyond teaching facts and routine memorization (Michael & Chen, 2006). By way of example, Corti (2006, p.1) simplifies the term of serious gaming that:

Serious gaming is all about leveraging the power of computer games to captivate and engage end-users for a specific purpose, such as to develop new knowledge and skills.\(^3\)

During the last decade, serious gaming has been applying to a broad spectrum of applications areas and research domains, including military, government, education, corporate, and healthcare, and also earning a widespread recognition of distinctive features and intrinsic capability from both public and private organizations. Nowadays, a concept of serious gaming is becoming even more and more popular in the global education and training market. The term itself is already established, but there is still no universal accepted definition (Susi et al., 2007). Many sources or references either describe the concept vaguely or do not define it clearly.\(^4\) They just clarify serious gaming as an intention of using digital games to achieve something greater than an entertainment purpose. Moreover, it also interestingly appears that there are not many commercial digital games in the market that carry such those educational value. Hence, when discussing the serious gaming, the key question is, “What the fundamental concept itself means actually?”

\(^3\) Today’s “serious games” is serious business; as stated by Ben Sawyer, co-founder of the Serious Games Initiative (Susi et al., 2007). In 2006, digital gaming sector was estimated with a value of $10 billion per year industry and the market of serious games only was roughly worth $20 million, however, it is expected to grow continuously over the next decade (Van Eck, 2006).

\(^4\) As of November 2018, a Google-search on “serious games” and “serious gaming” renders about 670 million and 159 million hits in the results.
Speaking about the term of serious gaming in academic society, the Department of Technology, Policy, and Management, Delft University of Technology (TU Delft), a leading institution in serious gaming research and development, provides the definition that:

Serious gaming involves the use of concepts and technologies derived from (computer) entertainment games for non-entertainment purposes such as for research, policy and decision-making, training and learning. Serious gaming often combines analog techniques (pen and paper) and social interaction with state-of-the-art game and simulation technology (immersive 3D virtual game worlds) (TU Delft, 2016).

According to above definition, CIs, as has been noted in section 1.2, can be characterized as complex systems; their behaviors, functions, activities, relationships, and interactions can be modeled and simulated in different ways for decision-making, research, and especially learning experiences. Furthermore, many research and experimentations also suggest that some critical or unique skills may be developed or strengthened by playing serious games (Griffiths, 2002; Squire & Jenkins, 2003; Michael & Chen, 2006; van Eck, 2006; Susi et al., 2007). For instance, the abilities of spatial planning and visualization, such as creative and critical thinking, data allocation and management, and three-dimensional objects rotation and manipulation gradually can be evolved along with gaming experiences (Mitchell & Savill-Smith, 2004; Subrahmanyam & Greenfield, 1994). Given that serious games may seem to be more effective and advantageous for young people, like children and teenagers who started out with relatively beginner skills (Griffiths, 1996, 1997), consequently, researchers, educators, and corporates are now using video games and computer games as an application or a tool for studying individuals, teaching students, and training personnel and staff.
Regarding the studies and results from various literature conducted by Griffiths (2002), there are many reasons that have provided insights as to why serious gaming may be useful for educational purposes. Those potentials benefits can be listed as follows:

- Serious games can be used as measurement tools or applications for research. As investigation and study tools, their potentials are diversity.
- Serious games attract participation across different demographic boundaries, including age, gender, ethnicity, and educational level.
- Serious games can aid students in establishing objective, ensuring goal rehearsal, providing feedback and support, and maintaining records of behavioral change.
- Serious games are productive instrument since they help researchers to measure performance on a set of various tasks and can be easily applied, standardized, and perceived.
- Serious games can be utilized to examine individual characteristics, like self-esteem, self-dignity, and self-respect.
- Serious games can be playful, fanciful, and purposeful to participators in the same time. As a consequence, it seems simpler to receive and maintain the attention of participants for longer periods of time (Donchin, 1995). Also, due to the fact that they are amusement and excitement, they may also promote a learning experience in innovative ways.
- Serious games can create an element of interactive thinking, which may stimulate learning.
- Serious games allow players to encounter novelty, curiosity, and difficulty, these aspects may motivate learning as well.
- Serious games interact with players through state-of-the-art technology. This implicit interaction may help participants to overcome the fear of advanced technology or complex devices (Technophobia), notably computers (Griffiths, 2002).
- Serious games can be a computer-based simulation. This innovation enables participants and players to engage extraordinary events or unusual activities in the form of complex computer models and to interact with each other without real consequences.

In the meantime, using serious games as applications or tools in educational context also have some disadvantages. For instance:

- Serious games may cause young participants, especially children and teenagers, to become excessive excitement. Under this condition, those players can produce unpleasant emotion or inappropriate behavior, such as competitiveness or aggressiveness.
- Serious game technologies have unceasingly developed from time to time. As a result, they are frequently being upgraded, which in turn, it is even harder for researchers or educator to test and evaluate the impacts across studies in an academic environment.
- Serious game exercises may enhance a few certain skills and experiences on some participants, which can lead to the inconsistent or incompatible evaluation results. To put it another way, it is not an absolute principle that all serious games are always good for all learning experiences and outcomes (Van Eck, 2006).
academic context would influence positive educational purposes in any case. Inevitably, it is imperative that researchers and educators must examine and evaluate the use benefits and positive potentials of serious games while remaining aware of possible unintended negative effects. Given all these points, most people would probably support the use of serious gaming if they were confident that those digital games were appropriately selected to help them learn about difficult topics or complicated problems.

2.5 Urban Planning Simulation Computer Game “SimCity 2013”

SimCity 2013 is an opened-ended and simulation computer game for city building and urban planning, which originally designed and formally introduced by American video game designer named “Will Wright,” a co-founder of the game development company “Maxis.” Regarding a massive and ongoing success of all five previous editions during the past two decades, a whole new redesign of SimCity 2013 edition was officially introduced and released once again in early of March 2013.

SimCity 2013 is considered to be a reboot and reprogram of game functionality and advanced features from all previous SimCity series. In 2013 version, players will have the ability to construct a settlement that can consistently grow into a city by zoning land, including residential, commercial, and industrial development, as well as essential service facilities, as shown in Figures 3, 4, and 5. Cities in a region will be interconnected and interdependent to each other via predefined regional networks, such as highways, railways, and waterways. The major infrastructures, like

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5 The game was firstly published in 1989 as SimCity Classic, renamed later as SimCity Classic, and then was continually spawned its first original version to several different editions later, including SimCity 2000 in 1994, SimCity 3000 in 1999, SimCity 4 in 2003, and SimCity Society in 2007 (Bereitschaft, 2015; Bos, 2001).

6 This latest version is a successor that supposes to continue a story of legendary simulation game from its predecessors and to succeed the next level of achievement of all-time best city building and urban planning simulation computer game.
economic, energy, transportation, and pollution systems will visibly flow between cities. Moreover, cities will also trade resources or share public services with their neighbors, like garbage collection or healthcare service. Cities can pool their collective wealth and resources to build a greater and larger system network and to provide benefits for the entire region, such as a massive solar power plant or an international airport as same as a concept “the larger in the size of region, the higher in the number of cities and great works that can be built.”

Figure 3. Simulated City Using SimCity 2013 – Residential Zone

In term of game planning, operation, and management strategies, players will need to specialize their cities into particular industries, such as manufacturing, education, tourism and gambling, and others. Each of them will require distinctive urban planning, simulation behavior, and economic strategies. Players will have either option to heavily specialize a single industry in each city or to assign multiple specializations in any given city for diversification. The game will also feature a simulated global price and economy. For instance, prices of key resources, including coal, ore, and crude oil will fluctuate depending on the game global supply and demand. In other words, if players all over the world are predominantly selling specific resource on the global
market (in the game) during the same period, this will drive the price for that resource down. Conversely, a resource that experiences very little exposure in the world market will be considered as a scarce resource, which driving the price up.

Consequently, besides the fact that SimCity has been surprising commercial success based on an advancement of complex simulation, it is still remarkable and peculiar because of what it does not have. To be more specific, SimCity is missing a couple of common elements that are considered most counter-productive by motivational theorists. First, there is no competitive element; it is impossible to play SimCity either against another person or the computer. Second, there is no external imposition of goal structure. It is impossible to win at SimCity, unless by fulfilling self-chosen and self-defined goals. Regarding SimCity's designer, Will Wright claimed “as a matter of fact that SimCity’s lack of goals, it makes SimCity not a game, but just a toy” (Bos, 2001; Minnery & Searle, 2014). Whatever goal players have chosen, they have turned it into a game. Bos (2001) also annotated that self-defined goals are potentially superior from a motivational theorist's point of view, since they avoid or, in some case, replace the intrinsic

![Figure 4. Simulated City Using SimCity 2013 – Commercial Zone](image-url)
motivation of killing pitfall with extrinsic motivation of self-defined goals, which most likely as same as inspiring players to develop their habits of goal setting and goal monitoring. For a classroom environment, as an example, teachers may need to assign specific goals for students using the simulation, or at least help the students to define their self-chosen goals. But in any case, those goals must not be set against the imposed external goals of the game.

Last but not least, SimCity 2013 also offers a unique style of learning experience by increasing its challenge level. In early stages of building a new city, players can ignore some minor rules, policies, or constraints, and their city will still grow (Bos, 2001). However, players must progressively learn how to manage tax rates, land values, crime rate, air and ground pollution, waste disposal, mass transit, and other factors, as they expand the city to become a metropolis. These conditions are not required to be dealt within a given period, but all of them must be taken into account for the continuous growth of a city (Bereitschaft, 2015). This is a natural but remarkable way to introduce the complexity of a large-scale system. Comparing this primary characteristic of a learning experience “organic scaffolding” from SimCity 2013 to arcade-style
games, it would not only provide players the ability to control how fast they approach and react to the new challenges but also generate an actively responsive system to keep them engaged (Bos, 2001).
CHAPTER 3
ReIDMP PLATFORM FRAMEWORK

3.1 Norfolk’s Resilient Framework

Making Norfolk as a resilient city is driven by the achievement of three primary goals. Each goal consists of strategies and actions, in which some are ongoing projects, and others are in the middle of outlining processes. Overall, they are a collective agreement to a new way of collaboration and engagement. According to the Norfolk Resilient Strategy (NRS) documented by City of Norfolk (2015), the strategic resilience framework can be identified as follows:

3.1.1 Goal I: Design the coastal community of the future

In the face of rising sea level, Norfolk, as one of the international hubs of a global trading system, is committed to maintaining the greatest responsibility in ensuring seamless movements through its port and to supporting the readiness of U.S. Navy Forces. To achieve this goal, City Manager's Office of Resilience acknowledges that in order to sustain the economic vitality and social cohesion, a physical transformation of the city is most needed. Over the decades, the city has worked very hard to design and build a number of protective systems for preserving Norfolk's coastline and keeping itself safe and dry. Those constructions include seawalls, sophisticated dune landscape, and other types of gray and green infrastructure. Notwithstanding, it is the time that all of ideas and solutions must be expanded in the direction of developing new creative infrastructure systems. With success in transforming to a new kind of coastal community, Norfolk's achievement can be used as an implementation model to demonstrate that how other coastal cities around the world can learn to live, adapt, and thrive along with the water.
3.1.2 Goal II: Create economic opportunity by advancing efforts to grow existing and new sectors

Naval Station Norfolk and Port of Virginia are central pillars of Norfolk’s economy. Unfortunately, with an uncertain future of government policy and geopolitical context as well as the declining trend in consumer spending and job investments, it is unlikely that just traditional naval activities alone will support the economic growth in a region. Indeed, it is true that the Port of Virginia is expected to grow gradually, but if a city is still unable to maximize its advantageous position as an international hub, all input efforts would be worthless. Instead of only creating the opportunity for living-wage employment in the area to revitalize the economy, the city will also direct its development attention on expanding existing businesses, assisting potential investors, and promoting local workforces to strengthen and attract more industrial enterprises.
3.1.3 Goal III: Advance initiatives to connect communities, deconcentrate poverty, and strengthen neighborhoods

As the directions of change point to the new ways of living and working, the City of Norfolk commits to be a place where all residents are connected to available resources they need to be successful. Connecting people together means to create stronger neighborhoods. They will communicate and support each other to make the city safer, to elevate a higher quality of life, and to protect themselves better in emergency situations or times. For this reason, the city has initiated a program, called Neighbors Building Neighborhoods. This initiative was built based on the fundamental belief that people are the most influential catalyst for their community changes. A campaign seeks to complement and support the missions that already accomplished and the tasks
that still underway, and then aims to strengthen and help the communities becoming more resilient at the individual, neighborhood, and city level.

![Diagram showing strategies for Goal III]

**Figure 8. Norfolk’s Resilient Strategy – Goal III**

### 3.2 Development of Resilient Informed Decision-Making Process Platform

In order to ensure the sustainment and resilience of existing and next generation CIs, decision makers and stakeholders must be well informed of past and current problems. They also need the knowledge and tools to help them analyze, assess, and design a viable implementation plan for long term development. The result or output of studies and research must be able to apply to the decision-making process and resource allocation for solving the real-world problems. Figure 9 shows that the structured methodology in this project consists of constructing a platform that capable of analyzing technical strategies and actions required for CIs resilience. This platform is aimed to serve as a standard practice when developing resilient city systems.
Figure 9. Framework of Resilient Informed Decision Process Platform
3.3 Phase I: Project Planning and Management

Project Management (PM) is a systemic process of planned and organized endeavor to meet a certain requirement, achieve a particular objective, or accomplish a specific goal. A body of knowledge is usually referred to the development of critical phases under the domain of management science, including initiating, planning, executing, controlling, and closing. PM is not a trivial thing, but it is a set of activities that are focused on completion of expected results in an effective way for individual, organization, or society. With this in mind, a successful project planning and management are another two key components to the success.

Either it is a plain project or a unique one, like launching a new product or constructing a megastructure; whether decision maker, stakeholders, project manager, or team members, all need a clear direction, organized operational procedures, consistently streamlined process, and user-friendly approach to maximize their full potential. Oftentimes, many projects have suffered from inadequate planning, inaccurate information, and unclear roles and responsibilities due to a lack of decent starting framework. The consequences of those poor performances can be serious or unacceptable. So that, to be successful in PM has never been easy, however, to be better prepared for “what will be coming next?” is not always impossible as well. Project KickStart Pro 5 (PKS) is a PM based software incorporated an intuitive planning and managing processes that offers users a smooth sequence of functions to develop a project plan with precise descriptions and deeper understandings on goals, obstructions, risks, and solutions. With its features and capabilities, a user should be able to define roles and responsibilities and to assign each team members' tasks accordingly. Then, a planner is also allowed to perform integral project management tasks, such as assignment tracking, project costs, deadlines, or even personalized objectives. In a short-time effort, the whole team will have the key milestones and well execution plan to a great project.
All in all, PKS will help a project manager to create a smart, efficient, and organized plan from start to finish. The software can be useful in one way or another, but in particular, it will obviously get project teams on board and unmistakably keep all members on the same page without leaving confusion about roles, responsibilities, expectations, and deadlines.

3.4 Phase II: Learning by Doing Through Gaming Strategic

According to the EMSE Department at Old Dominion University, Engineering Management (ENMA) 771/871: Risk and Vulnerability Management of Complex Interdependent Systems focuses on understanding the risks and vulnerabilities that affect CI systems and learning methods to mitigate such risks. The coursework primarily consists of three learning activities: lectures, assigned readings, and case studies. These methods tend to emphasize discursive and declarative knowledge at the expense of functioning and practical knowledge. However, since the course objectives and requirements seek to enhance overall concepts and skills by allowing students the opportunity to conduct a variety of risk and vulnerability assessments, it has become clear that such an approach does not maximize the students’ engagement with the complexity of the topic.

As a subject matter of this course concerns large-scale infrastructure systems like energy generation and distribution or public transportation systems, a learning goal of risk and vulnerability assessment materials is to be able to analyze potential risks and their impacts due to the occurrence of adverse events or pollution activities. By fully reviewing and understanding those presented activities within a city or region, students should be possible to determine the societal risks and asset vulnerabilities for the individuals who live in that specific area. As shown in Figure 10, Phase II proposes an idea of using computer game technology to enhance classroom engagements and practical experiences of students in quantifying resiliency of CIs. The following
proposed procedures utilize a combination of serious gaming concept in conjunction with risk analysis and vulnerability assessment techniques. Three specific documents are included as follows:

- Manual for the Classification and Prioritization of Risks Due to Major Accidents in Process and Related Industries\(^7\) (Figure 11).
- A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection\(^8\) (Figure 12).
- Guidelines for Integrated Risk Assessment and Management in Large Industrial Areas\(^9\) (Figure 13).

SimCity 2013 is a simulation game of organized play, a game has a set of stated rules and purposes to guide players to the goals, and the goals can be either fanciful or purposeful. If the requirements are specified and supervised to focus on learning outcome, then while preserving playfulness, a serious learning experience is possible. With this intention, a simulation will allow players to play with complex computer models, interact with each other, and experience revolutionary or evolutionary changes. This approach can be done before a decision or policy has

\(^7\) This manual is aimed to introduce methods and procedures to classify hazardous activities in region or city of interest through the categorizing of consequences and probabilities of occurrence. An assessment applies to the risks due to major accidents with off-site consequence in fixed installations handling, storing, and processing dangerous substances, and in transport of hazardous materials by road, rail, pipeline, and inland waterway (International Atomic Energy Agency, 1996).

\(^8\) The adoption of this guidebook is to present the standard procedures for assessing the vulnerabilities of physical assets, such as roadways, highways, tunnels, bridges, and inspection and traffic operation facilities among others. It provides a holistic set of steps to identify and mitigate the consequences to transportation routes from terrorist threats or attacks (Science Applications International Corporation, 2002).

\(^9\) The purpose of using this document is to provide a practical guidance and a technical reference for the proceeding of integrated health and environmental risk assessment studies and environmental management strategies in large industrial areas. The methodologies and techniques best suited with geographical areas that accommodate numbers of industrial and related activities of a hazardous and/or polluting nature (International Atomic Energy Agency, 1998).
been implemented without damaging effects to the real world. It also intends to provide benefits for students in better understanding and management of CI resilience. Ultimately, an idea envisions the establishment of a gaming laboratory for EMSE education in which an implementation approval was obtained through a submission of 2016 Faculty Innovator Grant Proposal\textsuperscript{10} (Appendix C).

\textsuperscript{10} The experimental design has been prepared for one year before actual implementation in ENMA 771/871 class. SimCity was firstly included in the course syllabus as a required tool along with other course materials in Spring 2015. During each experimental session, students were provided with the instructions detailed above and short demonstration at the beginning of the semester. They were directed to develop the city under the foundational concepts of sustainable development and infrastructure resiliency. By Fall 2015, the original version of the experimental design was revised and upgraded to a proposal for Faculty Innovator Grant 2016 Program, Center for Teaching and Learning at ODU. The submission won the award.
Figure 10. Depiction of Phase II – Deployment of SimCity Application
Figure 11. Procedural Steps of Rapid Risk Assessment
Figure 12. Procedural Steps of Vulnerability Assessment
Figure 13. Procedural Steps of Integrated Regional Risk Assessment
3.5 Phase III: Multi-Criteria Decision Analysis

Decision making, theoretically, can be considered a logical thinking process of suitable alternatives selection under different criteria or factors. In the process of decision analysis, decision makers and stakeholders must assess all possible positive and negative impacts and must also be able to judge the consequences of that decision. Multi-Criteria Decision Analysis (MCDA) or Multi-Criteria Decision-Making (MCDM) is a framework of analytical techniques that helps decision maker choosing between multiple options when multiple objectives have to be pursued. It is a systematic process and pragmatic approach, which involves multiple criteria in making a rational decision. MCDA allows the users to determine a selection as valuable and efficient as possible, to preserve a degree of consistency within the search, or at least to provide the inconsistencies, if they occur, without imposing unnecessary variable and unjustifiable structure in the decision analysis process. (Stewart,1992) With this in mind, a primary purpose of using MCDA is to assist the decision maker in discovering the most preferred solution to a problem. The application has been widely used to support a broad range of complex decision dilemmas.

There are many methods to solve the MCDM problem, but depending on the nature of the problem, different methods can be applied to address the problem efficiently. In this research, the decision models of multiple criteria, attributes, and alternatives will be structuring and be presenting with the implementation of two distinct MCDA methods through Decision Support System (DSS) tools.
3.5.1 Multi-Attribute Utility Theory

To make a decision on complex problems in the real world, the decision makers oftentimes have been challenging with multiple objectives, various stakeholders, future or long-term consequences, and risk and adverse effects (Nikou, 2011). In particular, when the problems are bound with the constraint, namely uncertainty, one of the most effective form of approach for dealing with this type of problems is a use of “Expected Utility.” In MCDA, this technique is formally called Multi-Attribute Utility Theory (MAUT). It was invented to ease the difficulty in solving the problem under the condition of uncertainty and is aimed to answer the question that “Which alternative is the best option?”. The method offers users the steps to assign scores and to compare possible alternatives in which afterward all of them can be identified and analyzed. It also allows a group of stakeholders to search and examine the consequences in the different ways for evaluating the options.

In essence, a core concept of MAUT is based on the theoretical foundation that the decision maker's preferences can be transformed and represented by a function, called the utility “U” (Ishizaka & Nemery, 2013). This utility function is being used to replace the value associated with each criterion for providing a degree of satisfaction to the decision maker. MAUT method works best when a decision maker consciously tries to optimize the performance of alternatives under a set of conditions and point of views (Ishizaka & Nemery, 2013), to put it another way, the preferred desirability of a particular alternative depends on how its associated attributes are being considered and judged. Similar to other MCDA methods, MAUT methodology consists of four key steps:

1. Constructing a decision problem by specifying the objectives and identifying the attributes needed to be measured.
2. Setting up the alternatives and exploring the potential consequences caused by each of them in term of the attributes identified.

3. Determining the preferences of the decision maker and stakeholders and assigning the weight of attributes reflecting their importance to the decision.

4. Synthesizing the results by assessing the impact of a certain criterion of the decision and lastly comparing the alternatives.

In this research, a DSS tool, called Logical Decision for Window (LDW), will be utilized to assist the processes of problem modeling, calculation, and analysis. LDW is the MAUT based decision support software package that helps a decision maker and stakeholders to evaluate and select the best option under difficult circumstances and restricted constraints. A package combines features between spreadsheet and database programs that allow a user to organize data and information for all possible prospects at the same time.

The followings are the basic required steps in completing the decision model and decision analysis with LDW:

- A decision maker can initialize the process by either manually inputting both hard (number) and soft (detail or explanation) data, or electronically importing prepared spreadsheets and database files. The software will convert an ordinary data table into a sophisticated hierarchical structure and links all those detailed information and specific preferences to overall goals. It can simply turn a set of incomprehensible numbers into a detailed roadmap in which guides a decision maker the right way to achieve the best outcome.
- Using the MAUT, the value judgments are a crucial stage of the whole process. Nonetheless, LDW makes this phase easier by providing a variety of methods, such as Smarter (easy-to-use), Tradeoff (sophisticated), and AHP (popular) for making the judgments and assigning the weights. The user can select and use one based on the appropriateness of the decision model.

- For a final step, the presentation of analysis results is designed to provide insights with interactive displays. A decision maker can rank the alternatives from the best to the worst associating any goal or evaluation measures and compare a particular option against the others to understand the differences.

- Importantly, A group of stakeholders can also revise the weight of importance to assume the effect of changes in the overall ranking results and conduct a sensitivity analysis to see the effects on the ranking results due to uncertainty.

Last but not least, MAUT method is usually adopted in a group situation, frequently, a necessary level of detail and specification during a discussion on the determination of attributes and their weights can turn into conflicts or arguments rather than moving toward a common ground. This restriction may result in time-consuming or even worst. So much so that to implement MAUT through LDW effectively, a decision maker and all stakeholders must be able to achieve a consensus on a set of attributes and a range of weights to be used in a model.

### 3.5.2 Evidential Reasoning

On the topic of MCDA problem under fuzzy weights and utilities, Zhou, Liu, & Yang (2010) suggested that “various types of criteria must be taken into account, which may be quantitative,
measured by numerical values with certain units, or qualitative, assessed using subjective judgments with uncertainties.” According to this quotation, the Evidential Reasoning (ER) will be the second MCDA method in this research for tackling problems with uncertainties and subjectivity. The technique is the latest development and a technical breakthrough in handling hybrid MCDA problems, which can be either hierarchical or non-hierarchical conditions (Xu & Yang, 2001). Essentially, ER approach is different from other conventional MCDA methods. Its algorithm was developed based on the fundamental principle of decision theory and the combination rule of Dempster-Shafer's evidence theory (Xu & Yang, 2001; Yang, 2001; Zhou, et al., 2010). When solving a problem with this method, the weights of importance are not necessary for assembling attributes in the model. Instead of aggregating average scores, it uses a belief structure, formally called the “degrees of belief,” to represent an assessment and to reach a conclusion as a distribution. This belief degree is served as the level of expectation in which can be purposely managed to obtain a decision maker's preferences.

Speaking about the basic characteristics, properties, and requirements of ER algorithm, Prof. Dong-Ling Xu and Prof. Jian-Bo Yang have contributed a significant amount of works in its area, which also covered a use of DSS tool, called Intelligent Decision System (IDS) (Xu & Yang, 2001; Xu & Yang, 2003; Xu, McCarthy, & Yang, 2006; Yang & Xu, 2003; Yang & Xu, 2004). IDS is an ER based decision support software designed to assist large-scale MCDA problems. The application has a unique capacity in handling thousands of attributes, which other tools do not. A package is also considered a flexible and versatile tool, since it can be applied to various types of information, like deterministic numbers, random numbers, and subjective judgments in different formats (Xu & Yang, 2003; Xu, et al., 2006).
To support a decision-making process with standard ER approach through IDS, Xu, Yang, Carlé, Hardeman, & Ruan, (2008) recommend that there are five required basic steps, which a user must complete, including model implementation, data collection, group information and opinion, assessment aggregation, and analysis results presentation. Each of them can be briefly described following by:

**Problem Modeling**

A model implementation in IDS implies to the process of identifying the alternative courses of action, or simply choices, criterion weights, and evaluation scales for assessing selections on criteria (Xu et al., 2008). Using the software, yet, the construction of an assessment criterion tree is straightforward. After a tree is structured, a user needs to define each criterion accordingly. At this point, it is so important to note that the IDS software was designed to use the 5-point scale as a standard estimation for assessment procedures, which mean, all criteria are being assessed as qualitative measurements, and the number of highest grades is 5. For this reason, whether it is a quantitative criterion or a qualitative criterion, the descriptions are required on both types of criterion. Meanwhile, the number of grades or points must be included as well. In addition to a default setting in IDS, relative weights of attributes can be assigned through either pairwise comparison or interactive chart, where the bars can be instantly dragged up and down to adjust the desirable weight of criteria. A function is considered a useful feature since a user can early observe the differentiation of individual viewpoints or group-decision standpoints on criterion importance. At the end of this step, a user may administer an assessment model to individual participants for initiating the next phase.
**Data Collection**

Practically, the assessment in this step normally involves activities, such as evidence collections, evidence comparisons, judgment resolution, and scoring determination (Xu et al., 2008). With a completed problem structure in model implementation, individual participants can start to assess each option and to record their scores and opinions. Each of them just needs to check appropriate grades, and then ER algorithm will automatically generate a belief degree next to each answer. This belief degree represents an appropriate strength level for describing an alternative on the criterion. Yet, in the events that there was not enough detail or information for participant group to make accurate judgments. They may select only a grade in which it is the most appropriate based on their knowledge without worrying about the distribution of the belief degrees (Xu et al., 2008). IDS will handle a process by equally dividing 100 percent of belief degree and automatically distributing them to the checked items itself.

**Group Decision Support**

When utilizing IDS, individual participants may independently record and anonymously register their assessments of each alternative to prevent the risks of potential disagreement among them. As a consequence, individual lists can be either separately reviewed or privately imported as a single file. After importing all inputs, a user will have options to select between comparing assessment data via a function of graphical representations or generating a collective assessment information for each alternative (Xu et al., 2008).

**Assessment Aggregation**

As has been explained, the aggregation process of assessment information from lower-level to higher-level criteria is analyzed through the ER algorithm. With IDS functionality, this
According to the field of computer science engineering, a concept of object-oriented programming (OOP), some may call “structured programming,” is a set of procedural programming that administers a logical structure in the program being written to allow it greater efficiency while being easier to understand and modify. An idea is also simplified and described

3.6 Phase IV: Object Oriented Programming

Assessment Results Presentation

IDS can generate different types of analysis results in graphical formats to support decision communication, such as performance ranking, performance score range, and performance distribution. However, while the ranking and score graphs present general pieces of result information, the distribution chart is the one provided more insight than the others. The selected alternatives can be compared to each other through all those diagrams and distinguished from any preferred areas in different levels of the assessment hierarchy (Xu et al., 2008). Moreover, the properties and appearances of those graphs can be configured and then be exported to MS-Word documents or MS-PowerPoint files. The software also provides a search function to help a decision maker in identifying strengths and weaknesses, which afterward a model can be used to study the effect of action plans when simulating various improvement scenarios.

compilation is automatic and update real-time in the background, whenever either an initial assessment data is modified, or an additional detail is entered for any criterion (Xu et al., 2008). Thus, a user should be able to obtain the original outcomes promptly if nothing is changed or to see the updated reports at any stages of revisions even before the assessment on some criteria is finished.
by Eck (2014) as the approach of structured programming thus: “To solve a complex problem, break the problem into several pieces and work on each piece separately; to solve each piece, handle it as a new problem respectively which itself can be broken down into smaller piece of problems again; eventually, you will work your way down to problems that can be solved directly, without further decomposition.”

Considering OOP in the sense of EMSE perspective, the paradigm of OOP may be best addressed by corresponding alternate synonym with a domain of use as Object-Oriented Analysis and Design (OOAD). Given that the term of OOAD was derived from adopting the fundamental concept of OOP, it may be adequately concluded that OOAD is an analytic method that uses to illustrate an information system by identifying things called “objects.” In this case, an object represents a real person, place, event, or system. The end product of object-oriented analysis is an object model, which represents the information system regarding purpose and object-oriented concepts. It allows researchers to express or present the important pieces of information and essential features of the application to the stakeholders easier than any other approaches.

Booch et al. (2007) indicates that there are four main processes that necessary for characterizing the conceptual framework of an OO model, including abstraction, encapsulation, modularity, and hierarchy. Each of them can be exemplified following by:

- **Abstraction/Discovery:** The first technique refers to a simplified representation of a system, capturing only those relevant characteristics or essential aspects with regard to the perspective of the researchers.

- **Encapsulation/Visualization:** This component refers to the hiding details in the internal composition and work of an object. Encapsulation acts as a protector or keeper to limit user
access to an object’s internal data. Also, it offers a means to reduce system complexity (Booch et al., 2007; Pulfer & Schmid, 2006).

- **Modularity/Mapping:** This process refers to the concept of partitioning an object into a set of sub-objects called modules. Especially for complex and large-scale system design, thus modularity helps in managing complexity by disintegrating a huge intractable solution into smaller and more manageable ones which are interconnected and can be composed of the required large-scale solution.

- **Hierarchy/Model and Analysis:** The last step refers to the allocation of rank to encapsulation. As mentioned, since encapsulation manages the hiding of detail or otherwise prioritizing the relevant details for the purpose of problem at hand; this, however, would make an imperative need for hierarchy as different levels of detail may be required in solving problems (Booch et al., 2007).

OOP can be applied and used through the form of a tool, called TopEase® Designer. TopEase® is a software product, which was designed to allow organizations to model the impact of adverse events on every dimension of their business, understand which elements need to be restored within which timeframe, create and maintain organization disaster response plans, and identify any gaps where response plans do not yet exist. In the same way, all its capabilities including discovery, visualization, mapping, and particularly model and analysis would enable the researchers to design and model a structure of a complex or large system and then to perform a comprehensive system analysis.
CHAPTER 4

PLATFORM DEVELOPMENT: THE CITY OF NORFOLK AS AN EXAMPLE

4.1 Project Execution Plan

In order to tackle a sophisticated project, such resilient city development, in a professional manner, PKS is selected to render essential study and extensive examination in Phase I. The information presented in the NRS report will be utilized as an input data to develop and evaluate an ideal platform framework introduced in Chapter 3.

PKS is equipped with nine wizard functions, while its planning process requires seven major steps. The user interface and operating procedure of the software itself are considerably simple and straightforward (Figure 14). The software features not only provide a more convenient way to administer the work structure but also increase the management efficiency to monitor the ongoing progresses and resource requirements until the project completion. To generate a comprehensive list of phases, tasks, responsibilities, and timeframe as a standard based approach for any resilient city development projects, the following sub-sections will concisely describe how to outline and detail an execution plan of Norfolk Resilient City (NRC) as a development project with PKS implementation.

4.1.1 Project Name

Each project has a name, therefore, naming a project is the very first mandatory step for planning with PKS. As shown in Figure 14, since the project objective is to create a resilience development plan for The City of Norfolk, the name of this project is given as “Norfolk Resilient City Development.”
4.1.2 Project Phases and Tasks

Major grouping sub-tasks, known as project phases, can be identified, and then tasks can be associated with each phase with this wizard function. A planner can begin a process by either using predefined phase library shortcut or entering specific details manually. As a result, by linking and integrating inputs from NRS document with pre-designed methodologies in a proposed ReIDMP framework, the extracted information can be grouped into six project phases as illustrated in Figure 15.

With a completed list of phasing determination, PKS will move to the next sub-procedure, which is “task identification.” The software wizard will cycle through those six phases, one at a time, asking a planner to enter tasks for each phase. Nevertheless, it is important to note that phases will be organized respectively to an initial entering sequence of a planner, but it is not always necessary that a planner must register tasks to the phases by following that sequence. To be more
specific, PSK was also designed with a feature of non-linear thinking about the project tasks list. Meaning that if a planner was thinking about or has come up with the tasks on the different phase, the drop-down feature would allow the planner to go to that phase, add the tasks, and then return. In this study, most of the listing tasks were concisely determined and precisely associated with each phase based on the obtained information from NRS report and the methodological approaches in the proposed ReIDMP platform framework. Altogether, a completed list of phases and tasks is presented in Figure 16. Noted that some additional listing tasks in Analysis and Assessment of Risk, Vulnerability, and Integrated Risk, including assessment of infrastructure performance, regional performance, and resilience-enhancing investment were itemized and included intentionally as predefined extension works for potential future study. Neither analysis nor assessment of these three tasks will be performed for final evaluation and incorporated with the result representation of ReIDMP platform framework development.

Figure 15. Norfolk Resilient City Development: Project Phases
### Figure 16. Norfolk Resilient City Development: Project Phases and Tasks

<table>
<thead>
<tr>
<th>Task Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Norfolk's Resilient Project Definition, Scope, and Milestone</strong></td>
</tr>
<tr>
<td>1. Stakeholder Engagement</td>
</tr>
<tr>
<td>2. Identification of Shocks, Stresses, and Key Infrastructures</td>
</tr>
<tr>
<td>3. Selection of Tools, Assessment Methodology, and Data Collection</td>
</tr>
<tr>
<td><strong>Design and Development of Simulation City Based Serious Gaming Concept</strong></td>
</tr>
<tr>
<td>5. Outline of Case Studies and Scenarios</td>
</tr>
<tr>
<td>6. Evaluation of Case Studies and Scenarios</td>
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<tr>
<td>7. Prioritization of Case Studies and Scenarios</td>
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<td>8. Selection of Case Studies and Scenarios</td>
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<td>9. Review and Revision of Case Studies and Scenarios</td>
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<tr>
<td>10. Approval of Case Studies and Scenarios</td>
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<tr>
<td>11. Planning and Design of Simulated Norfolk City Areas Using SimCity Application</td>
</tr>
<tr>
<td>12. Modeling and Development of Simulated Norfolk City Areas Using SimCity Application</td>
</tr>
<tr>
<td>13. Evaluation and Verification of Simulated City</td>
</tr>
<tr>
<td><strong>Analysis and Assessment of City's Risk, Vulnerability, and Integrated Risk</strong></td>
</tr>
<tr>
<td>16. Probabilistic Resilience Quantification &amp; Visualization Building Performance to Hurricane Wind Speeds</td>
</tr>
<tr>
<td>19. Assessment of Vulnerability</td>
</tr>
<tr>
<td>22. Integrated Risk Assessment &amp; Management in Large Industrial Areas</td>
</tr>
<tr>
<td>23. Assessment of Infrastructure Performance</td>
</tr>
<tr>
<td>24. Assessment of Regional Performance</td>
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<tr>
<td>25. Assessment of Resilience Enhancing Investments</td>
</tr>
<tr>
<td>26. Evaluation, Verification, and Validation of Results</td>
</tr>
<tr>
<td><strong>Development of Resilient City Strategies and Action Plans</strong></td>
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<tr>
<td>27. Goal I: Design the Coastal Community for the Future</td>
</tr>
<tr>
<td>29. Collectively Create A Vision for the City's Future</td>
</tr>
<tr>
<td>31. Access, Identify, and Implement Innovative Infrastructure for Water Management</td>
</tr>
<tr>
<td>37. Create A Place Where People Want to Live, Work, and Play</td>
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<tr>
<td>41. Redesign Tools and Regulations to Achieve Our Vision for the Future</td>
</tr>
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<td>47. Goal II: Create Economic Opportunity by Advancing Effort to Grow Existing and New Sectors</td>
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<td>48. Create A Multi-Pronged Economic Development Strategy</td>
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<td>53. Nurture the City's Entrepreneurial Ecosystem</td>
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<td>56. Strengthen the Workforce Development Pipeline</td>
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<td>60. Reinvest In and Revitalize Neighborhoods</td>
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<td>66. Explore Innovative Financing Methods</td>
</tr>
<tr>
<td><strong>Goal III: Advance Initiatives to Connect Communities, Deconcentrate Poverty, and Strengthen Neighborhood</strong></td>
</tr>
<tr>
<td>71. Improve Citizen Access to Information and Services</td>
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<td>76. Support Community-Building Efforts Through Technology</td>
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<td>80. Connect the Community Through Conversation</td>
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<tr>
<td><strong>Multi-Criteria Decision Analysis</strong></td>
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<td>86. Multi Attributes Utility Theory</td>
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<td>87. Evidential Reasoning</td>
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<td><strong>Object Oriented Analysis and Design</strong></td>
</tr>
<tr>
<td>88. Representation of Analysis and Results</td>
</tr>
</tbody>
</table>
4.1.3 Project Goals

Entering project goals is essentially the same as it was in entering project phases. This wizard functions as a 1st-level verification for a more profound understanding of the project phases and tasks structuring. The milestones, goals, and targeted accomplishments of a project can be identified in this step to suggest any necessary phases or tasks that the planner has not been thought off yet. As was previously clarified in Section 3.1, The City of Norfolk strives to accomplish three primary goals. Each of those goals comprises of a set of strategies, and then each of strategies encompasses with a set of actions. The three primary goals of Norfolk Resilient City, however, have been mapped and detailed in a previous step as one of the major phases and a set of grouping tasks. Consequently, there are no additional phases or tasks needed at this time.

4.1.4 Project Obstacles

PKS also offers a feature, which allows a planner to identify the potential risks or issues in project planning stage. In this wizard, the planner can key in a list of obstacles that may occur during the project timeframe, and then prepare the encounter plans as additional phases or tasks to overcome those problems if ones happen. Unfortunately, with provided input from NRS report, none of such information have been addressed or discussed obviously. For the purpose of ReIDMP platform development, a few obstacles were assumed and added to the list, so much so that merely to make a project execution plan more elaborate.

4.1.5 Task Assignment

Assigning the tasks or responsibilities to team members and stakeholders in PKS is simplistic and direct. A planner can either manually key in the resource names, such as team members, individuals, and organizations to the main window or use an automated resource list wizard
“People Library” to store the resources information by registering them one-by-one or importing those data from Microsoft Outlook. The distinction between these two options is that if selecting an option 2, the software will save all information in its resource list. Then the planner can reuse that stored information when similar resources are required for planning a new project.

The option 2 was implemented in this study since it has been seen to provide more flexibility during the process of planning reviews, and faster access in case the resource revisions are needed later on. As illustrated in Figure 17, being that ReIDMP platform framework was developed under the supervision of a group of five committee members, thus all of them have been added to the “People Library” and assumed the role as the project consultants. Likewise, due to the fact that the NRS report was prepared by The City of Norfolk, City Manager's Office of Resilience, hence the staff members have been inputted to the list of resources and specified the different roles based on verified information from a staff homepage of City Manager's Office of Resilience website.
Figure 17. Norfolk Resilient City Development: Project Resources
<table>
<thead>
<tr>
<th>Task Name</th>
<th>Assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norfolk Resilient City Development, Scope, and Milestones</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Christine Morris, Dr. Susan Perry, Scott Smith, Dr. Zubin Adhamana, Kyle Spencer</td>
</tr>
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<td>Development and Planning of Norfolk City Areas Using SmCity Application</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Kyle Spencer, Dr. Zubin Adhamana, Dr. Susan Perry</td>
</tr>
<tr>
<td>Development of Regional Risk Assessment</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Dr. Zubin Adhamana, Dr. Susan Perry</td>
</tr>
<tr>
<td>Development of Resilient City Strategies and Action Plan</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Dr. Zubin Adhamana, Dr. Susan Perry</td>
</tr>
<tr>
<td>Goal I: Design the Coastal Community for the Future</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Dr. Zubin Adhamana, Dr. Susan Perry</td>
</tr>
<tr>
<td>Goal II: Create Economic Opportunity by Advancing Efforts to Grow Existing and New Sectors</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Dr. Zubin Adhamana, Dr. Susan Perry</td>
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<tr>
<td>Goal III: Advance Initiatives to Connect Communities, Diversify the Economy, and Strengthen Neighborhoods</td>
<td>Dr. Adrian Ghesori, Dr. Rostie Ulud, Dr. Mamoudou Sack, Dr. Slava Timashov, Dr. Roland Puffer, Dr. Zubin Adhamana, Dr. Susan Perry</td>
</tr>
</tbody>
</table>

Figure 18. Norfolk Resilient City Development: Task Assignment
Once the project task list is constructed, and the project team members are identified, the planner can start assigning the tasks to each resource that supposes to responsible for that task. Basically, on the condition that the task requires more than one resource to finish, the planner must select each person, one at a time, on the list of resources to assign that task to those people. On the other hand, if one resource, especially consultants, is needed by multiple tasks, the planner can choose those tasks as a group and then assign them all at once to that person. The representation of task assignment step for NRC development project is displayed in Figure 18.

4.1.6 Task Management

The step six in PKS is not only about reorganizing and editing the project phases and tasks, but it can be seen as a 2nd-level verification of phase determination and task identification as well. This wizard contains the features that allow the planner to:

- Move up and down any task or any phase and its tasks
- Promote a sub-task to a task and demote a task to a sub-task
- Add a new task and add a new sub-task under existing task
- Delete any task and sub-task or any phase and its tasks

During the implementation of this step, after reviewing the existing structure of project phases and tasks, a minor modification was made to avoid the potential confusion of listing tasks in the Development of Resilient Strategies and Actions Plan. By way of example, three primary goals were inserted into the list as the three sub-phases, and the associated strategies of each goal were demoted under sub-phase as the individual task. Then again, the proposed actions of each strategy were demoted under the task as the individual sub-tasks. The same correction concept was also
applied to the Analysis and Assessment of Risk, Vulnerability, and Integrated Regional Risk. Three analysis and assessment areas were promoted from the main tasks to the sub-phases, and the analysis and assessment methods of each domain were re-associated to their sub-phase as the individual tasks.

4.1.7 Project Timeline

The main purpose of the final wizard is to present the project timeline visually. The software uses the feature of Gantt Chart, which allows the planner to editing start/finish dates and durations, to working with weekends and holidays, and to adjusting tasks according to resource availability. In PSK, the default duration of tasks is set at one day. The planner can either key-in the exact number of days or select the date in the calendar of start/finish date fields for indicating the duration of each task.

In this planning, due to the fact that NSR document was released on October 2015, it was assumed that most of the predefined actions are ready to be implemented around that time as well. Hence, fall 2015 was adopted as the set-point to complement the estimation of task durations in prior or later phases. As presented in Figure 19, by merging the information in NRS report as one of the project phases with the methodological approaches in proposed ReIDMP platform framework, it has been estimated that it would require at least seven months in advance for the preparation and development of strategies and actions.
Figure 19. Norfolk Resilient City Development: Project Timeline and Task Duration
4.2 Analysis and Assessment of Risk and Vulnerability via Serious Gaming

The development of Phase II in proposed ReIDMP platform framework consists of two practical approaches. The first component is a deployment of simulation computer game, SimCity 2013, under the concept of serious gaming. The second element is the analysis and assessment of risk, vulnerability, and integrate regional risk using the guidelines and methodologies provided by International Atomic Energy Agency (IAEA) and Science Applications International Corporation (SAIC). The studies have been experimented within one of the graduate level courses, ENMA 771/871: Risk and Vulnerability Management of Complex Interdependent Systems. To understand the simulation mechanism of SimCity and the productive application of its visualization for sophisticated investigation, the following two sub-sections will explain and clarify more detail about how those approaches were proceeded.

4.2.1 Design and Development of Simulation City by Using SimCity 2013

The fundamental goal of playing SimCity is to build a city. It may sound like a simple task, but in fact, it is quite challenging. When starting a new city, there are neither best strategy nor specific technique that can be used as a routinely based approach. The game provides a lot of freedom in what the player can build, so that many people tend to construct essential infrastructures and service facilities without the pre-design of city layout. In this study, to use the application of simulation urban planning game for the non-entertainment purpose, especially at higher education level, the systematic urban planning is definitely inevitable.

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1 A primary focus of this initiative has involved enabling students to conduct a variety of risk and vulnerability assessments in a simulated city based on students’ own design. The experimental tests have been consecutively executed during the spring semester of the last four academic years, starting from 2015 to 2018. The test subjects are students in master and doctoral programs who register for the class. This combination was not only designed to support the development of ReIDMP platform, but it also aims to enhance the efficacy of learning experiences relating the knowledge of risk and vulnerability.
In SimCity 2013, the player will assume the role and duties as a city mayor. The central aspect of this character is all about construction and zoning, which comprise a wide range of responsibilities, including laying down the roads, manipulating the land areas, providing the essential facilities, maximizing the service capacities, and otherwise balancing between demand and supply of resources. Most of the time, the player will work with the main menu bar across the lower end of the interface. This menu bar contains fourteen buttons with fourteen different options. Each of them is distinguished by the symbols, such as lightning bolt, plumbing, trash can, firefighter helmet, and police badge, as depicted in Figure 20. The following twelve sub-sections are overview detail of what options are, what each option does, and how they can facilitate the development of simulation city.

Note that forasmuch as the purpose of experimentation is to examine and verify the potential use of simulation computer game in combination with technical high-level analysis and assessment method, the gameplay mode in four experimental tests was set as a gentler version, called “Sandbox.” Further, the scope of evaluation covers only the existing technological inventions in the real world. Nonexistent innovations and fancy features in a couple of options of the game, particularly government and disaster, are not included in this discussion.

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12 By clicking each button, the interface will display the features in its particular category. When playing the game, the color of icons will remain in dark blue in case all services and systems in the city are operationally functional. On the other hand, if there is any concern, incident, or disruption in the city, the icon will switch its color to yellow, which indicates a minor issue, or red, which indicates a major problem.

13 It is an ideal option especially for easing the players with no experience to SimCity’s mechanism or trying out the creative management strategies. By applying this setting, the game unlocks most of the features and disable all disasters since start building a new city.
Figure 20. SimCity 2013: In-Game Main Menu Bar
1. **Roads**

The most important aspect of city planning is the roads. They play the most significant role and are considered a heart of SimCity. In the game, roads are differentiated by using two properties, the number of lanes and the level of supported densities.

![SimCity 2013: Traffic Density](image)

Roads in SimCity can be difficult. They are the blood vessels that connect the city to the other cities, provide access to the buildings, distribute power, water, and sewage to Sims, and allow Sims to travel from one to another location. Designing them wrong or with too many flaws will waste money, limit the building sizes and densities, and undoubtedly cause unfavorable traffic conditions (Figure 21). In a case of traffic, the congestion is an unavoidable problem that naturally occurs when having an increased number of populations. The events will cause many indirect effects in the city. For instance, if emergency services, like ambulances or fire engines, cannot get to the location or scene on-time, the Sims will die, or the buildings will burn down. For these reason, an effective road pattern is a real key to overall success. Finding the right proportion of street connections and avenue intersections are a vital part of keeping the traffic condition as smooth as
it flows into, out of, and around the city. Then, with the combination between the adequate planning of road network and intuitive management of mass transit infrastructures, the player can minimize the traffic congestion to practically nothing, even with the population over 100,000 Sims.

2. Zones

The zoning administration is the second most important task of being the SimCity mayor. After finishing up with the construction of the roads, the player has to determine that which areas will be reserved for what purposes. By selecting Zones button, the menu bar will expand-up and display the zoning tools, which only contain four options, including residential zone, commercial zone, industrial zone, and dezone. In this version of SimCity, zones are extremely simplified. The residential zone is the area of residences and apartments where Sims live. The commercial zone is the place of shopping arcades or business centers where Sims shop. The industrial zone is the site of manufacturing factories or processing plants where Sims work. Lastly, the dezone is a tool that use to unmark zones. With those three assigned zones, Sims will start populating their buildings based on three factors, including road type, available space, and land value. However, it should be noted that in the early stage of starting a new city, all buildings will normally be simulated under the rudimentary principles of low-density and low-wealth. To make the buildings developed, they need to be supplied with basic resources, such as power, water, sewage, and parks.

3. Power

Nearly every building in SimCity needs electric power to function. Energy is the first critical infrastructure and essential service that the mayor has to provide to run the city. So that without a power plant, the city will not grow. The third option on the toolbar is power production tool. In
this latest edition, there are several types of power plant. Each is radically distinct in term of technological advancements, which can be arranged from, an old-fashion dirty generator like coal power plant, to a modern clean reactor such as nuclear power plant. Each of them has advantages and disadvantages. However, most are undoubtedly expensive, and some are unquestionably polluted.

![Figure 22. SimCity 2013: Electric Power Distribution](image)

Note that when the player builds the power plant, all roads automatically serve as the power lines that distribute and deliver the electricity to the buildings throughout the city, as displayed in Figure 22. This concept applies to all types of roads without any exception. Furthermore, since the electric power moves along the road network in real-time, it means that the buildings closer to the power station will gain the service before the buildings farther down the plant.

4. Water

Even in real life, clean water is another basic need for living. It is a prerequisite to maintain public health and to support life activities. Human in the real world considers it as one of critical
infrastructure sectors. In a like manner to SimCity, water is an essential resource, and clean water production plant is the second vital service facility. Sims cannot survive without it as well.

Figure 23. SimCity 2013: Water Supply Distribution

By clicking the fourth button on the menu bar and selecting either water tower or water pumping station, the map will switch to the data mode and display entire water table directly underneath the land area. To maximize the production of fresh water in the long-term, the mayor needs to place the building on the groundwater sources with the deeper blue color on the map. In a matter of providing the services, the idea is similar to the electric power distribution. Roads also act as the underground water pipes that deliver water to the buildings in the city (Figure 23). Nevertheless, one potential issue with the water infrastructure is the ground pollution. If the buildings nearby the water station pollute the area, the groundwater source will be contaminated. The incident will probably cause the water contamination, and then consequently lead to the indirect problem of Sims sickness. To eliminate this concern, the player must construct the water pumping plant in a clean place or far away from polluters.
5. Sewage

The third utility service is a wastewater treatment system. As same as living human, all Sims consume clean water and then produce wastewater. In the game, if sewage is not properly dealt, it will turn to the ground pollution and cause nearby area with a germ problem, which can lead to other consequences, particularly Sims sickness.

![Figure 24. SimCity 2013: Wastewater Management](image)

In the fifth option, there are two simple solutions to handle the sewage. First is the sewage outflow pipe and second is the sewage treatment plant. Both function the same purpose of service, which is to collect the sewage, but not the same in the way of processing it. The difference between them is that the outflow pipe accumulates the sewage and later dumps it to the ground with the significant amount of pollution. In contrast, the treatment plant stores the wastewater and slowly cleans it before replenishing the surrounding groundwater table with clean water. Figure 24 shows how the sewage service in SimCity works when either one of facilities was in operation. However, it does not mean that the option 2 is a feasible plan in the long-term, that is to say, the sewage treatment station can also cause its own ground pollution footprint in case its overcapacity,
understaffed, or underpowered. Thus, as being SimCity mayor, the player must keep an eye on the plant from time-to-time.

6. Waste Disposal

The next option, notably the seventh button on the toolbar, in this evaluation is waste disposal. Besides the management of sewage treatment system, another two categories of waste collection service that the mayor must take into account are garbage and recycles. In SimCity, both are grouped in the same category, but in fact, they are different things in which necessitate a specific service facility to manage. Garbage is the wastes that need a garbage dump to consolidate and dispose of it. The dump station is the only solution to the city's trash disposal problem. Recycles are materials that require a recycling center to claim and process, and then produce the valuable commodities, such as plastic, metal, and alloy for making extra profit. The recycling plant should be built to reduce the accumulated amount of waste in the city without any pollution as well as to augment the expansion and prosperity of the city.

By having at least one facility for both services, the garbage dump trucks and recycling collection trucks will leave the garages at their stations every day in the morning and circle around the city to collect trash and materials, as depicted in Figure 25. The trucks will head back to their locations and drop all collections at the end of the day. In addition to the collection performance of garbage dump trucks, traffic condition is the most important variable that can create the direct effect to its service capacity. In other words, if the garbage trucks cannot get to the place on-time and any garbage goes uncollected, the remaining amount of trash will be converted into the soil pollution at the site of the buildings that produced it. To prevent an issue, the player can either
build the garbage dump in the location that its trucks can easily journey to populated areas or dispatch sufficient numbers of the resources to all neighborhoods.

![Figure 25. SimCity 2013: Garbage and Recycle Collection](image)

7. **Fire**

According to simulation experiences, when the populations in the city are over 400 Sims, a variety of problems, including garbage, fires, health, and crimes will be triggered. Fire can be a nightmare that burns just a block of the buildings down or turns even a half of the city into the ashes if the mayor does not pay enough attention. Single fire or multiple events can start in any buildings and any zones in the city, but in most cases, they usually happen in the industrial zone. As a matter of fact, the normal fires will require a basic fire truck, and the hazmat truck will be suited for the hazmat fires. Without the hazmat truck, hazmat fires will be unstoppable. They will indefinitely spread until all nearby buildings are burned down.
A fire station is a cheap but effective solution in the early stage of developing a new city. It comes with a fire engine, which can service normal fire protection. Up to four fire trucks can be added to improve service performance or to cover multiple fire incidents. One distinctive advantage of the fire station is the size of building itself. A small physical footprint makes it a perfect support station, which can be used in the areas with limited space. However, the risk of fire will grow exponentially as the city expands (Figure 26). To control the situations across the city, the large fire station needs to be commissioned. This one can provide the same service as the small one can, not only better but also more comprehensive. The large fire station comes with handful tools that can fight all types of the fire incident, namely normal, hazmat, single, and multiple events. The station also offers the extra additional modules, such as fire marshal and fire helipad, which allow it to lower the fire risk and to expand the coverage area of service.
8. Health

Sims can get sick, injured, and die as same as human beings. When Sims get sick, it will trigger the risks of injury, and when Sims get injured, it will activate the risks of death. Injured Sims need ambulances to pick them up. Otherwise, they will die. Therefore, sick Sims must receive medical attention as soon as possible. In the ninth option, two simple alternatives in providing healthcare service are a clinic and hospital.

The service concept and building configuration of the clinic are quite similar to the fire station in many aspects. It is cheap and small, but a worthy investment for a solid starting point and undeveloped city. Clinic comes with one ambulance bay and ten patient rooms. Both modules can be additionally upgraded to reduce response time for injury emergencies and to increase room capacity for patient treatments. A hospital is a large medical center with the extensive ranges of medical equipment and specialized facilities. The extra additional modules at the hospital, including wellness centers, emergency center, diagnostic lab, and surgical center, can significantly improve the sickness causes, recovery times, and survival rate of Sims across the city.

9. Police

As the city mayor, another important responsibility to citizens is to protect them from harm and violence. Law and order must be upheld to retain the community safety and happiness. In SimCity, criminals are automatically simulated based on various factors, but mainly education background and unemployment rate. They will randomly appear in the residential zone or travel into the city by personal vehicles. Criminals have their own patterns and routines to follow. They will leave their place at night and head to the targeted zone or building that they intend to commit the crimes. A list of offenses and violence can be ranged from simple shoplifting to attempted
murder. With each successful process of criminal acts, they will gain more experiences level, which lead to the higher chances of succeeding in the next illegal activities. As a consequence, a series of crime events can deteriorate the city's image and value. To fight criminals and keep Sims safe, the police station and police precinct are the only two answers in this option.

![Figure 27. SimCity 2013: Law Enforcement and Safety Service Coverage](image)

In fact, both stations are identical in a case of functionality but different in terms of building scale, upgradeability, and serviceability. Similar to the technical qualifications of fire station and clinic, the police station is a smaller and less upgradable facility that works for a new city within initial development stage. It suppresses crimes and arrests criminals by dispatching the patrol cars to watch out and secure its coverage area. If there are any crimes in progress, the patrol officers will respond to the report and try to catch criminals as fast as they can. Then, arrested criminals will be transported back to the police station and imprisoned in the jail. To expand the police force on the street as well as to support the growing number of prisoners, additional patrol car lots can be authorized to boost the number of police cars, and the prison blocks can be renovated to raise the number of jail cells. Nevertheless, the true fighting against crimes will begin when the police
precinct is founded. This station can cover an extensive area of patrol parameters, as illustrated in Figure 27. It also comes with unique modules, notably detective wing and crime prevention center, that allow the mayor to track down criminals actively and reduce the crime rate passively. For one thing, detectives can be commissioned to investigate criminals' hiding location and then arrest them before they have started committing crimes. For another, crime prevention agents can be assigned with a proactive approach to teaching kids in education system about the value of being a good citizen.

10. Education

![Figure 28. SimCity 2013: Educated Sims in the City](image)

If the road network is the primary component in attaining an overall success, education is a secondary element for breaking through the next level of accomplishment. Schooling practically makes life quality of Sims better in many ways. It reduces the crime rate, health issues, fire risk, garbage amount, and water and electricity consumptions. As a result, educated Sims are likely to save resources, more likely to produce recycles, less likely to cause fires and get sick, and unlikely
to become criminals. Although all educational facilities generate no income, they promote the happiness and knowledge levels of residents in the city (Figure 28) as well as the technology level of manufacturers in the industrial zone. By building any of them in the residential zone, they also raise land value of the nearby area to the medium wealth level. In the eleventh option on the toolbar, there are five educational facilities. A completed list of each type can be described as follows:

- **Grade School:** A grade school is an ideal educational facility, which provides basic education to young Sims. It increases the education level of city's residents and the overall number of skilled workers in the city.

- **High School:** This type of school functions the same purpose as the grade school, albeit larger and more expensive. High School favors the community by helping kids stay off the street, keeping them out of trouble, and especially educating them. So much so that they will not become criminals.

- **Community College:** The exclusive benefit of a community college is that it intentionally boosts up the technology level of industrial buildings to level 2 (medium-tech), or occasionally even level 3 (high-tech) in some cases. Industrial factories with these two tech levels pay the higher number of tax and produce the lesser amount of air pollution. In SimCity, a community college is not accredited. However, its operational cost and building size are much cheaper and a lot smaller when comparing to a university.

- **University:** The university provides Sims with the highest level of education. It is a facility that allows the industrial buildings to advance and maintain the level 3 technology faster. Most of the research projects can be initiated and performed to unlock high-tech modules at this place, but the completion time will depend on the number of enrolled students.
- **Public Library**: When Sims cannot afford to go shopping, they spend time at the library instead. Hence, the education level of city's residents will slightly increase as Sims become more educated. Unlike previous four educational facilities, a public library can be accessible by Sims of all ages.

In the game, even though each academic institution can offer education degree at a certain level, it does not mean that all of them are necessary to be constructed in one city. In other words, Sims will travel between neighboring cities to attend schools by school buses if there are not enough desks in their city. In a case of higher education, Sims will drive or use public transportations to visit college or university in nearby cities.

11. **Mass Transit**

As was previously alluded in Roads section, the mass transit is an indispensable critical infrastructure that allows the mayor to improve traffic flow and prevents traffic congestion. It helps Sims to move around the city and connects them to other cities in the region. The following are five primary transportation systems in the Mass Transit option, the button with bus icon.

- **Buses**: Buses are the most basic public transportation infrastructure in SimCity. As displayed in Figure 29, the system can operate as long as the road network is completed, and the bus stops are assigned. In this option, there are two types of the bus station. First is a shuttle bus depot and second is a bus terminal. They perform the same service, which is to transport low and medium wealth Sims. A noticeable difference between them is that the shuttle bus depot provides a service for local only while the bus terminal responsible for both local and regional.
Streetcars: To build the streetcar depot, it requires high-density streetcar avenues. With this specific condition, some mayors may not look at the streetcars as a practical solution since the investment is costly. However, this type of public transportation is indispensable when the population is over 100,000 Sims. The streetcars not only loosen the traffic density by lessening the number of cars on the roads, but they also enhance the service performance of a whole mass transit system by sharing the number of low and medium wealth commuters from the buses system. An example of functional streetcars service is present in Figure 30.

Trains: Unfortunately, trains are not a serviceable transit system in all cities, to put it another way, the station requires regional heavy rail track network to connect. Passenger trains are carriers that allow regional commuters and shoppers to travel into or out of the city. It is also ideal public transportation for low and medium wealth tourists.

Boats: Quite similar to the construction requirement of train stations, the ferry terminal needs a specific geographical condition to be constructed, especially along a shoreline.
Thus, the water transportation is an inapplicable option in some cities. Notwithstanding, if available, the passenger ferry dock and cruise ship dock can transport low and medium wealth workers from other cities in the region as well as bring in medium and high wealth tourists to the city.

- **Planes:** A municipal airport is the only air transportation infrastructure and last type of mass transit system in the game. It is a second alternative solution in transporting more medium and high wealth tourists into the city. The airport can be built and operate in any flat terrain. It is not expensive but just requires a large area to build. One extra benefit of having the airport is that it boosts the happiness of nearby factories by shipping the industrial freight out on cargo planes.

![Figure 30. SimCity 2013: Mass Transit System (Streetcars)](image)

**12. Parks**

The final option in this evaluation is the thirteenth button on the main menu bar, Parks tool. Parks come with three levels of wealth but in a variety of sizes. They purposely function as the
spaces for relaxation experiences and leisure activities. Sims visit parks to enjoy their times and return home with the happiness.

![Figure 31. SimCity 2013: Land Values and Wealthy Level](image)

Besides being the comfort zones for residents, kids, and tourists, parks are the attribute that specifies the land value. In the game, land value is a standard that characterizes the wealthy level of areas, as exhibited in Figure 31. Then, the wealthy level of areas is a measure that determines the social class of Sims, mainly residential and commercial zones. Thus, the idea of building parks is not only to provide the places for relieving Sims' stress, but it is also to designate the wealthy levels of residents, workers, and merchants in the city. Sims will play their role based on their associated social class. For instance, low wealth workers will fill the positions at the manufacturing factories and medium wealth employee will get the jobs in the business offices.
4.2.2 Visualization of Risk and Vulnerability Assessments

Risk and vulnerability assessments are performed in many areas of engineering and technology. The goal of evaluating them is to be able to analyze potential impacts that can result in occurring of adverse events. In this research, the second part of the experiment in Phase II entails the utilization of a product from SimCity as an applied visualization for technical analysis of risk and vulnerability. The specific techniques and procedures adopted in this investigation include assessments on potential accident of hazmat processing at fixed installations and during transport activities, assessments on potential transportation routes regarding the critical assets, and assessments on health and environmental impacts from polluted byproducts generated by industrial sector within the city and region. Altogether, these analysis efforts would improve the conceptual understanding of risks and vulnerabilities that present in everyday society and how those exposures may affect the larger society as a whole. Then, an informed decision-making process can be formalized to initiate and supervise a comprehensive plan that promotes the level of resilience within the city.

4.2.2.1 Rapid Risk Assessment

For reviewing the Rapid Risk Assessments (RRA) concurrently with the modeled environment in SimCity application, the method applied in this process was derived from the “Manual for the Classification and Prioritization of Risks due to Major Accidents in Process and Related Industries” published by IAEA in 1996. A document is also known as “IAEA-TECDOC-727 (Rev.1)”. It represents the means to manage the risk of accidents regarding hazardous activities either fixed installations or transportation in the city or region of interest. The assessment method relies heavily on tables that have been developed based on historical information and input from
subject matter experts (IAEA, 1996). By completing methodological procedures, the assessment results can render decision makers with a holistic view of incentive information about the major risks within the selected region.

**Applications and Algorithm of RRA Methodology**

According to IAEA-TECDOC-727 (Rev.1), the assessment process of each activity requires two calculating approaches to estimate the casualties per incident (Consequence) and probabilities of occurrence (Frequency) (IAEA, 1996). In a case of consequences, the estimation is defined by the number of fatalities, which can be calculated by using the equation (1) and tables in IAEA-TECDOC-727 (Rev.1) document, as presented in Figure 32.

\[ C_{AS} = A \times D \times \prod_{i=1}^{3} CF_i \]  \hspace{1cm} (1)

Where:

- \( A \) = Affected area by the incident (circle area)
- \( D \) = Population density within the affected area
- \( CF_1 \) = Correction factor for populated area (part of circle area)
- \( CF_2 \) = Correction factor for the distance of effect category (radius of circle)
- \( CF_3 \) = Correction factor for mitigation at the selected facility.

The following set of procedures is the sequential steps to obtain the constant of each variable in the equation of consequence estimation:

1. Classify the activity using Table II and indicate reference numbers for Table IV(a) or IV(b).
2. Determine the hazardous substance in each activity. Note that if multiple-hazmat are presented in one location, both cannot be considered simultaneously. Alternatively, if hazardous materials are different in term of effect area categories, such as flammable and toxic, they must be analyzed separately.

3. Estimate the quantity of substances in each hazardous activity.

4. Indicate the effect category code (related to the letters A-H and Roman numerals I-III) using Table IV.

5. Indicate the maximum effect distance in meters, the effect area in hectares “A”, and shape of the effect area category using Table V.

6. Estimate the population density “D” within the affected area using Table VI.

7. Estimate the distribution percentage of existing population in the circular area in which radius is the maximum distance of effect. Then, obtain the correction factor “CF1” using Table VII.

8. Estimate the distance area correction factor “CF2” based on the fraction distance (length or depth) in which populations exist within the effect radius of the circular area.

9. Estimate the mitigation correction factor “CF3” using Table VIII.

10. Calculate the external Consequences “CA,S” using the equation (1).
**TABLE II. Checklist of Reference No.**

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<th>Activity</th>
<th>Most important substances</th>
<th>Reference numbers (Table IV)</th>
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<tr>
<td>Fuel storage</td>
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<td>Delivery station</td>
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<td>Car station</td>
<td>Petrol and LPG</td>
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<tr>
<td>Intermediate depot</td>
<td>Petrol</td>
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<td>Gas cylinder storage</td>
<td>Oil</td>
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<td>Processing and storage of fuel</td>
<td>Natural gas</td>
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<td>Refinery</td>
<td>LPG</td>
<td>7, 9, 10, 11</td>
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<tr>
<td>Alkylation process</td>
<td>Various gases</td>
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**TABLE IV(a) and VI(b). Classification of Substances by Effect Category**

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</tr>
<tr>
<td>2</td>
<td></td>
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<td>3</td>
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<td>4</td>
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<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Flammable liquid
- Vapour pressure at 20°C < 0.3 bar
- >0.2
- A I

- Flammable gas
- Vapour pressure at 20°C ≥0.3 bar
- <0.1
- 0.2-0.4
- >0.4
- A I

- Under pressure
- <0.2
- >0.2
- A I

**TABLE V. Maximum Distance & Effect Area Category**

<table>
<thead>
<tr>
<th>Effect distance (m)</th>
<th>Effect area category (ha^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>A</td>
<td>6-25</td>
</tr>
<tr>
<td>B</td>
<td>25-50</td>
</tr>
<tr>
<td>C</td>
<td>50-100</td>
</tr>
<tr>
<td>D</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

Figure 32A. Example of Information from Table Used in the Process of Consequence Estimation of Major Accidents
Figure 32B. Example of Information from Table Used in the Process of Consequence Estimation of Major Accidents (Continued)
The estimation of frequency is different from the estimation of consequence. The probability of occurrences is calculated based on the type of hazmat activities. Both cannot be assessed by the same generic equation and estimated procedures. For fixed installations or processing plants, the probability number of a major accident is computed by using equation (2A). The constant of each variable can be obtained by evaluating the information disclosed in tables in IAEA-TECDOC-727 (Rev.1) document, as illustrated in Figure 3.

\[
N_{\text{Fixed}} = N'_{\text{Fixed}} + \sum_{i=1}^{4} CP_i \quad (2A)
\]

Where:

- \(N'_{\text{Fixed}}\) = Average probability number for the facility and the substance
- \(CP_i\) = Correction parameter for the frequency of loading/unloading operations
- \(CP_2\) = Correction parameter for safety systems in cases of flammable substance
- \(CP_3\) = Correction parameter for the safety level at the facility
- \(CP_4\) = Correction parameter for wind direction towards a populated area

To proceed further in calculating the probability number of accidents at the fixed facilities with the equation (2A), the guidance on how to determine the constant of each variable can be described as follows:

1. Estimate the average probability number of an accident \(N'_{\text{Fixed}}\) using Table IX.
2. Estimate the probability number correction parameter for loading/unloading operations “\(CP_i\)” using Table X.
3. Estimate the probability number correction parameter for safety systems for flammable substances “CP₂” using Table XI.

4. Estimate the probability number correction parameter for organizational and safety management aspects “CP₃” using Table XII.

5. Estimate the probability number correction parameter for the wind direction toward populated areas “CP₄” using Table XIII.

6. Calculate the probability number “N_{Fixed}” using the equation (2A).

7. Convert the probability number “N_{Fixed}” into the frequency value “P_{i,s}” for the number of accidents per year using Table XIV.

In the cases of hazmat transportation, the probability number of a major accident is calculated by using equation (2B) and tables in IAEA-TECDOC-727 (Rev.1) document, as exhibited in Figure 34.

\[
N_{\text{Transport}} = N^{*}_{\text{Trans}} + \sum_{i=5}^{7} CP_i \quad (2B)
\]

Where:

\( N^{*}_{\text{Trans}} \) = Average probability number for the transportation of substance

\( CP_3 \) = Correction parameter for the safety conditions of substance transportation

\( CP_6 \) = Correction parameter for traffic density of the transportation route

\( CP_7 \) = Correction parameter for wind direction towards a populated area
The steps in defining numerical values in equation (2B) are quite similar to equation (2A). They are simple and straightforward. The following are the instructions on how to assign the constant of each variable.

1. Estimate the average probability number of transport category \( N^{\text{Trans}} \) using Table XV or XVI.
2. Estimate the probability number correction parameter for the safety of transport system \( CP_5 \) using Table XVII.
3. Estimate the probability number correction parameter for traffic density \( CP_6 \) using Table XVIII.
4. Estimate the probability number correction parameter for the wind direction toward populated areas \( CP_7 \) using Table XIX.
5. Calculate the probability number \( N_{\text{Transport}} \) using the equation (2B).
6. Convert the probability number \( N_{\text{Transport}} \) into the frequency value \( P_{i,s} \) for the number of accidents per year using Table XX.

Once the consequence value and frequency number of all potential accidents are calculated, the outputs of each activity need to be plotted on the chart to represent and quantify the state of risks. For this RRA manual, the samples of assessing information, diagram drawing, calculation procedure, and result representation from classroom experimentation are shown in Figure 35\textsuperscript{14}.

\textsuperscript{14} In contribution of Shelly Jules-Plag, 2017
Figure 33. Example of Information from Table Used in the Process of Probability Estimation of Major Accidents for Fixed Installations of HAZMAT or Dangerous Goods
Figure 34. Example of Information from Table Used in the Process of Probability Estimation of Major Accidents for Transportations of HAZMAT or Dangerous Goods
Rapid Risk Assessment (continued)

Estimate of Consequences

1. Asset 6 – Trade Port

Figure 3.1: Trade Port Risk Diagram (approx. 0% of CH affected area is populated)

<table>
<thead>
<tr>
<th>Description</th>
<th>Location</th>
<th>Ref. No. (Table I)</th>
<th>Amount (tonnes)</th>
<th>Effect Category (Table IV)</th>
<th>Physical Effect (Table V)</th>
<th>Population Density (Table VI)</th>
<th>Correction Factor (Table VII)</th>
<th>Correction Factors (Table VIII)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trade Port</td>
<td>Asset 6</td>
<td>Oil storage Ref 3</td>
<td>6000 Barrels (approx. 80 tonnes)</td>
<td>CI Wind direction not considered</td>
<td>50-100 m</td>
<td>3</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>Coal storage (coal ash)</td>
<td></td>
<td>Ref 30</td>
<td>100</td>
<td>CI Wind direction considered</td>
<td>100-200 m</td>
<td>1.5</td>
<td>0.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Consequence 1: 3 [ha] x 40 [persons/ha] x 1 x 0 x 1 = 0 fatalities (good placement limits fatalities)
Consequence 2: 1.5 [ha] x 80 [persons/ha] x 0.2 x 0 x 0.1 = 0 fatalities (good placement limits fatalities)

Figure 35A. Sample of Experimental Results on Incorporating RRA with SimCity 2013
Figure 35B. Sample of Experimental Results on Incorporating RRA with SimCity 2013
Figure 35C. Sample of Experimental Results on Incorporating RRA with SimCity 2013
2. Rapid Risk Assessment

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Ref. Name</th>
<th>Activity</th>
<th>Substance</th>
<th>Ref. No. (Table IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Asset 6</td>
<td>Trade Port (Harbor)</td>
<td>Fuel (storage)</td>
<td>Depot/main station</td>
<td>3</td>
</tr>
<tr>
<td>2 Asset 20</td>
<td>Chemical Manufacturing</td>
<td>Coal (storage)</td>
<td>Intermediate depot</td>
<td>30</td>
</tr>
<tr>
<td>3 Asset 12</td>
<td>Coal Mining/Power Plant</td>
<td>Coal (processing)</td>
<td>Furnaces</td>
<td>31</td>
</tr>
<tr>
<td>4 Asset 13</td>
<td>Water Treat/Pumping Station (1)</td>
<td>Public Utility (processing)</td>
<td>Waterworks</td>
<td>32</td>
</tr>
<tr>
<td>5 Asset 14</td>
<td>Sewage Plant</td>
<td>Public Utility (processing)</td>
<td>Sewage treatment</td>
<td>9</td>
</tr>
<tr>
<td>6 Asset 15</td>
<td>Ore Mining/Smelting (1)</td>
<td>Metallurgical (processing)</td>
<td>Furnace</td>
<td>31</td>
</tr>
<tr>
<td>7 Asset 8</td>
<td>Omega Production</td>
<td>Metallurgical (processing)</td>
<td>Furnace</td>
<td>31</td>
</tr>
<tr>
<td>8 Asset 21</td>
<td>Ferry Port</td>
<td>Harbor Facilities (storage)</td>
<td>Tanks</td>
<td>4</td>
</tr>
<tr>
<td>9 Asset 20</td>
<td>Chemical Manufacturing</td>
<td>Specific Chemicals (transport)</td>
<td>Drugs/Pharmaceuticals</td>
<td>6</td>
</tr>
<tr>
<td>10 Asset 12</td>
<td>Coal Mining/Power Plant</td>
<td>Coal (transport)</td>
<td>Coal product</td>
<td>6</td>
</tr>
</tbody>
</table>
**4.2.2.2 Vulnerability Assessment**

The second process of the analysis portion is the vulnerability of transportation corridors relating physical assets such as bridges, tunnels, storages, complexes, and headquarters. The assessment technique utilized in the experiment was developed from the original instructions in “A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection” prepared by SAIC in 2002. The development of this handbook was funded and commissioned as a joint research, called Project 20-07/Task 151B, under the supervisions of National Cooperative Highway Research Program and American Association of State Highway and Transportation Officials. The method involves multiple steps to conducting a Vulnerability Assessment (VA) and identifying cost-effective countermeasures to deter or compromise the vulnerability of dangerous goods and potential threats. The guidelines reference recommended approaches that apply to a wide range of assets in general, and to any state Department of Transportation (DOT) in particular.

**Applications and Algorithm of VA Methodology**

As has been proposed in Section 3.4, Figure 12, the assessment process for the vulnerability of highway transportations originally consists of six primary steps. However, the one delineated in this ReIDMP platform development is a slightly modified version. To be more specific, the process has been redefined to accommodate the limited availabilities of data parameter in SimCity. One additional sub-procedure was incorporated as a supplementary approach at the beginning of the whole process for complementing any number of alternate routes analysis. Further, the critical assets chosen in this process was focused on essential infrastructures and service facilities, instead of road elements. The purpose of this adaptation was due to the homogeneous nature of the streets and avenues within the simulation model. There are just a few variations in types of road, bridges,
and tunnels. Therefore, concentrating on roadway elements may not provide enough information to generate and differentiate the accurate results of vulnerability assessment between routes. In contrast, focusing on facilities along routes would render a more considerable degree of disparity between routes, such that the significant differences between the vulnerability of each route could be identified. The following contents are the detail of each of the assessment steps as it applies to transportation routes within the simulated city.

1. Identification of Routes and Critical Assets

The goal of this step is to create an inclusive list of critical assets. Those assets can be infrastructures, facilities, equipment, and personnel that deem vital to the transportation system. To develop a comprehensive list of critical assets, the assessor must first determine which routes will be analyzed, as illustrated in Figure 36\textsuperscript{15}. Then, when the potential routes have been verified and selected, one can proceed further in locating the prominent assets along each route, as depicted in Figure 37\textsuperscript{15}.

\textsuperscript{15} In contribution of Justin Mathews, 2015
Figure 36. Determination of Potential Routes Using Simulation City from SimCity 2013

Figure 37. Identification of Critical Assets Using Simulation City from SimCity 2013
2. Assessments of Critical Asset Scoring and Criticality Coordinate

The next task of the assessment process is to identify and prioritize critical assets. In this step, fourteen critical asset factors will be used as the criterion to determine the assigned value of each asset on the list. The factors are the conditions, scenarios, and consequences that may result in the loss of the asset. The values are the number ranged from “less” (1) to “extremely” (5), which indicate the degree of importance. Nonetheless, it should be noted that the scoring assignment of these factors is binary. The values of (1) to (5) can be assigned just in case the factor applies to the asset. Otherwise, the number must be replaced with the value of (0). A hypothetical example of assigning values to the critical asset factors is presented in Table 1.
Table 1. Example of Assigning Values to Critical Asset Factor (SAIC, 2002)

<table>
<thead>
<tr>
<th>Critical Asset Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deter and Defense</strong></td>
<td>****</td>
</tr>
<tr>
<td>A. Protection Providing Ability</td>
<td>1</td>
</tr>
<tr>
<td>B. Relative Attack Vulnerability</td>
<td>2</td>
</tr>
<tr>
<td><strong>Loss and Damage</strong></td>
<td>****</td>
</tr>
<tr>
<td>C. Casualty Risk</td>
<td>5</td>
</tr>
<tr>
<td>D. Environmental Impact</td>
<td>1</td>
</tr>
<tr>
<td>E. Replacement Cost</td>
<td>3</td>
</tr>
<tr>
<td>F. Replacement/Down Time</td>
<td>3</td>
</tr>
<tr>
<td><strong>Consequence to Public Service</strong></td>
<td>****</td>
</tr>
<tr>
<td>G. Emergency Response Function</td>
<td>5</td>
</tr>
<tr>
<td>H. Government Continuity</td>
<td>5</td>
</tr>
<tr>
<td>I. Military Importance</td>
<td>5</td>
</tr>
<tr>
<td><strong>Consequences to General Public</strong></td>
<td>****</td>
</tr>
<tr>
<td>J. Alternative Availability</td>
<td>4</td>
</tr>
<tr>
<td>K. Communication Dependency</td>
<td>1</td>
</tr>
<tr>
<td>L. Economic Impact</td>
<td>5</td>
</tr>
<tr>
<td>M. Functional Importance</td>
<td>2</td>
</tr>
<tr>
<td>N. Symbolic Importance</td>
<td>2</td>
</tr>
</tbody>
</table>

After the scoring assignment of all listing critical assets is completed, now that it is the time to fulfill the core requirements of this procedure. First is the calculation of the total score, and second is the computation of criticality coordinate. These two estimations can be implemented by using
Table 2, Matrix of Critical Asset Scoring and Criticality Coordinate. As can be seen in Table 2, the assigned critical asset factor values have been entered in corresponding with the critical asset factors recorded in Table 1. The sum of these values represents the total score \( x \) for that asset. The highest number among the ranking of critical asset total scores is the maximum possible criticality value \( C_{\text{max}} \). Then, both values, \( x \) and \( C_{\text{max}} \), are substituted as the constants in criticality equation to calculate the coordinate \( X \).

Table 2. Matrix of Critical Asset Scoring and Criticality Coordinate

<table>
<thead>
<tr>
<th>Critical Asset</th>
<th>Critical Asset Factor</th>
<th>Total Score ( (x) )</th>
<th>Criticality ( \frac{x}{C_{\text{max}}} \times 100 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset 1</td>
<td>A 1 2 5 B 1 3 3 C 5 5 5 D 5 4 E 1 5 F 2 1</td>
<td>43</td>
<td>100</td>
</tr>
<tr>
<td>Asset 2</td>
<td>A 1 2 5 B 0 3 3 C 0 0 5 4 D 1 5 E 2 1</td>
<td>27</td>
<td>63</td>
</tr>
<tr>
<td>Asset 3</td>
<td>A 1 2 5 B 1 3 3 C 0 5 0 4 D 1 5 E 2 0</td>
<td>32</td>
<td>74</td>
</tr>
<tr>
<td>Asset 4</td>
<td>A 0 2 5 B 0 3 3 C 5 5 5 D 4 1 5 E 2 1</td>
<td>41</td>
<td>95</td>
</tr>
<tr>
<td>Asset 5</td>
<td>A 1 2 5 B 0 3 3 C 0 0 4 0 D 5 2 1</td>
<td>26</td>
<td>60</td>
</tr>
<tr>
<td>Asset 6</td>
<td>A 0 2 5 B 0 3 3 C 5 5 5 D 0 1 5 E 2 0</td>
<td>36</td>
<td>84</td>
</tr>
<tr>
<td>Asset 7</td>
<td>A 0 2 5 B 1 3 3 C 0 0 5 4 D 0 5 2 0</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>Asset 8</td>
<td>A 0 2 5 B 1 3 3 C 0 0 4 0 D 5 2 0</td>
<td>25</td>
<td>58</td>
</tr>
<tr>
<td>Asset 9</td>
<td>A 1 2 5 B 1 3 3 C 5 5 5 D 4 0 5 2 1</td>
<td>42</td>
<td>98</td>
</tr>
<tr>
<td>Asset 10</td>
<td>A 1 0 5 B 0 3 3 C 0 5 0 4 D 1 5 E 2 1</td>
<td>30</td>
<td>70</td>
</tr>
</tbody>
</table>

3. Assessments of Vulnerability Factor Scoring and Vulnerability Coordinate

The third approach in the VA process is the calculations of vulnerability. This procedure particularly involves applying the vulnerability factors to analyze the inherent vulnerabilities of critical assets. The factors are classified into three categories, including visibility and attendance, accessibility, and susceptibility. Each of them is comprised of two sub-elements, which will be utilized to evaluate the default value and later on to calculate the vulnerability score and coordinate in the end. In the case of the vulnerability factor default values, the scoring scale is quite essentially the same as it was used in determining the critical asset factors. The values range from (1) to (5).
They indicate the degree of importance associated with the specific definition for that factor. At this time, a hypothetical example of assigning values to the vulnerability factor is shown in Table 3.

Table 3. Example of Assigning Values to Vulnerability Factor (SAIC, 2002)

<table>
<thead>
<tr>
<th>Vulnerability Factor</th>
<th>Definition</th>
</tr>
</thead>
</table>
| (A) Recognition Level | - Largely invisible in the community  
- Visible by the community  
- Visible Statewide  
4 Visible Nationwide  
- Visible Worldwide |
| (B) Attendance & Users | - Less Than 10  
- 10 to 100  
3 100 to 1,000  
- 1,000 to 3,000  
- Greater Than 3,000 |
| (C) Access Proximity | - No vehicle traffic & no parking within 50 feet  
- No unauthorized vehicle traffic & no parking within 50 feet  
- With vehicle traffic but no parking within 50 feet  
4 With vehicle traffic but no unauthorized parking within 50 feet  
- With open access for vehicle traffic and parking within 50 feet |
| (D) Security Level | - Controlled & protected security access with a response force  
2 Controlled & protected security access without a response force  
- Controlled security access but not protected  
- Protected but not controlled security access  
- Unprotected & uncontrolled security access |
| (E) Receptor Impacts | - No environmental or human receptor effects  
- Acute or chronic toxic effects to environmental receptor(s)  
3 Acute & chronic effects to environmental receptor(s)  
- Acute or chronic effects to human receptor(s)  
- Acute & chronic effects to environmental & human receptor(s) |
| (F) Volume | - No materials present  
- Small quantities of a single material present  
- Small quantities of multiple material present  
4 Large quantities of a single material present  
- Large quantities of multiple material present |
When the default values of vulnerability factor on all selected critical assets are assigned, those recorded numbers can be transferred into one table by using the Matrix of Vulnerability Factor Scoring and Vulnerability Coordinate (Table 4). Similar to the implementation developed in the Matrix of Critical Asset Scoring and Criticality Coordinate, the assigned vulnerability factor values must be organized in corresponding to the vulnerability factor registered in Table 3. To calculate the total score (y) for each critical asset, the sub-element scores in the same category are multiplied by each other, like visibility and attendance (A1 x A2), accessibility (B1 x B2), and susceptibility (C1 x C2). Then, the three resulting numbers are summed. Finally, the value of factor (y) is used as the constant in vulnerability equation to calculate the coordinate (Y) for that asset respectively.

<table>
<thead>
<tr>
<th>Critical Asset</th>
<th>Vulnerability Factor</th>
<th>Total Score (y)</th>
<th>Vulnerability Y = (y/75)100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A x B) + (C x D) + (E x F)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A B C D E F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5 1-5 1-5 1-5 1-5 1-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asset 1</td>
<td>4 3 4 2 3 4</td>
<td>32</td>
<td>43</td>
</tr>
<tr>
<td>Asset 2</td>
<td>4 3 4 2 3 4</td>
<td>35</td>
<td>47</td>
</tr>
<tr>
<td>Asset 3</td>
<td>3 3 4 3 5 5</td>
<td>46</td>
<td>61</td>
</tr>
<tr>
<td>Asset 4</td>
<td>2 3 4 1 2 3</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Asset 5</td>
<td>2 3 4 3 1 1</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Asset 6</td>
<td>2 2 5 5 1 1</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Asset 7</td>
<td>2 1 3 5 1 1</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Asset 8</td>
<td>3 3 5 5 1 3</td>
<td>37</td>
<td>49</td>
</tr>
<tr>
<td>Asset 9</td>
<td>2 3 5 4 3 5</td>
<td>41</td>
<td>55</td>
</tr>
<tr>
<td>Asset 10</td>
<td>1 2 4 3 4 3</td>
<td>26</td>
<td>35</td>
</tr>
</tbody>
</table>

4. **Representation of Consequence Results**

The purpose of result representation, in fact, basically refers to the reviewing of consequence assessment. This step will help to identify that which assets possess the most significant concerns in term of their criticality to a specific set of circumstances and conditions and their vulnerability
to undesirable outcomes. For the real-world projects or case studies, this assessment must also be performed in conjunction with the pieces of advice from subject matter experts, such as the reliability of data collection, the credibility of threats, or specifically identified vulnerabilities.

Once the coordinate of criticality (X) and vulnerability (Y) for each asset are calculated, they are adopted as defined points and plotted on a scatter diagram, called the Matrix of Criticality versus Vulnerability, as presented in Figure 38. The matrix is split up into four quadrants (I, II, III, or IV). The chart analyzes the critical assets by prioritizing the level of consequence based on the critical asset factors and vulnerabilities default values estimated in step 2 and 3. Any assets that
fall into Quadrant I (high criticality and high vulnerability) are considered to be critical to the city or region and judged to be vulnerable to the identified hazards and potential threats. Notwithstanding, the consequences of disruptions on these assets will depend on the nature of the intervention and the impact of the loss of the asset. The possible damages may vary from the loss of life and property to the loss of transportation infrastructures or even completed shutdown of transporting system functionality.

5. Development of Potential Countermeasures

While assessing the critical assets along the routes and their susceptibility to potential threats provide a reduction in the vulnerability of those assets, designing the typical countermeasures would render the enhancement of security and the improvement of resilience for the community at the core. For this reason, the development of these protection protocols ideally requires effective collaboration between stakeholders, subject matter experts, and regional governance bodies. Assembling the proper team and tasking with the right job will ensure that the challenges are correctly identified and precisely addressed within the scope of the assessment process.

Theoretically, countermeasures must be developed based on the focus of three primary attributes, including deterrence, detection, and defense. The definitions of these terminologies are used as the relative terms to identify a collection of countermeasures considered applicable to protecting physical assets and their functionalities. Each of them can be defined as follows:

- **Deterrence:** The protective measures deter an attacker either by making it difficult for the aggressor to access the facility or causing the aggressor to perceive a risk of being caught.
- **Detection:** The surveillance measures discover the potential attack and alert the security response team or emergency response units.
- **Defense:** The defensive measures protect the asset by delaying the attacker's movement toward the asset, keeping the attacker away from gaining access to the facility, and mitigating damage from the attacks, especially weapons and explosives.

By finalizing the representation of assessment results from Step 4 under the implication of three terminologies annotated above, the items presented in Table 5 are examples of potential countermeasures. It should be noted that the effectiveness of those listed countermeasures is subjectively measured by considering how well the strategies reduce either the probability of occurrences or consequences of attacks on assets with specific threats and vulnerabilities.

**Table 5. Potential Countermeasure Identifications (SAIC, 2002)**

<table>
<thead>
<tr>
<th>Potential Countermeasures</th>
<th>Deter</th>
<th>Detect</th>
<th>Defend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install motion detected cameras with infrared technology. Cameras should include an automatic alarming trigger to notify response team.</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Place active barriers at vehicle entry point. Barriers should be able to be rapidly deployed and be capable of stopping large commercial vehicles.</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Construct fences or gates to block bystanders from instantly accessing the buildings.</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Replace external windows with safety glass to prevent broken glass from explosions or shrapnel.</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Hire a private security force to continually monitor the facility and surrounding area.</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Build a reinforced, well ventilated area for facility residents to take refuge in the event of an attack.</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Restrict all parking and vehicle traffic in close proximity to the facility to authorized vehicles only.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install redundant power systems (e.g., emergency generators) to maintain critical systems and communication networks.</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Upgrade exterior lighting and emergency phone stations at walkways, entrances, exits, and parking lots.</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Limit access to restricted buildings or area through the issuance of a security badge with specific access identification and key card.</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
6. Estimation of Countermeasure Costs

The idea of cost estimation in VA process is to calculate the range of aggregate expenditures for implementing the countermeasures identified in Step 5. The investment plan must be drafted to package countermeasures in the ways that operationally rational and strategically cost-effective. With these intentions, the productive countermeasure packaging will allow the assessment team to review all possible alternative solutions, namely equipment, technologies, and structures, for maximizing vulnerability reduction. Nevertheless, the expenses of countermeasure implementation, such as capital investment, annual operation, maintenance costs, and life-cycle cost can be varied. The relative cost ranges for each transportation agency are very subjective and depend on many variables. Table 6 displays an example of sample values as a general guideline to estimate the countermeasure costs in each category. These figures, when applying to the countermeasures, are described as high (H), medium (M), or low (L) as shown in Table 7.

**Table 6. Countermeasure Relative Cost Range (SAIC, 2002)**

<table>
<thead>
<tr>
<th></th>
<th>Sample Countermeasure Relative Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capital Investment</td>
</tr>
<tr>
<td>Low</td>
<td>&lt; $150K</td>
</tr>
<tr>
<td>Medium</td>
<td>$150K - $500K</td>
</tr>
<tr>
<td>High</td>
<td>&gt; $500K</td>
</tr>
</tbody>
</table>

All in all, this step practically refers to balancing the unit price of the countermeasure packages to the critical assets. The team can group the assets into categories and then adjust the appropriate budget and cost per unit for countermeasures to the number of critical assets in each category. For one thing, a single asset might be seen fit with multiple countermeasures. For another, several
assets could be considered applicable to just a particular countermeasure. The nature of these circumstances will frequently require cost-benefit analyses and trade-off studies.

Table 7. Matrix of Countermeasure Cost Estimation (SAIC, 2002)

<table>
<thead>
<tr>
<th>Countermeasure Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install motion detected cameras with infrared technology. Cameras should include an automatic alarming trigger to notify response team.</td>
<td>X</td>
</tr>
<tr>
<td>Place active barriers at vehicle entry point. Barriers should be able to be rapidly deployed and be capable of stopping large commercial vehicles.</td>
<td>X</td>
</tr>
<tr>
<td>Construct fences or gates to block bystanders from instantly accessing the buildings.</td>
<td></td>
</tr>
<tr>
<td>Replace external windows with safety glass to prevent broken glass from explosions or shrapnel.</td>
<td>X</td>
</tr>
<tr>
<td>Hire a private security force to continually monitor the facility and surrounding area.</td>
<td>X</td>
</tr>
<tr>
<td>Build a reinforced, well ventilated area for facility residents to take refuge in the event of an attack.</td>
<td>X</td>
</tr>
<tr>
<td>Restrict all parking and vehicle traffic in close proximity to the facility to authorized vehicles only.</td>
<td>X</td>
</tr>
<tr>
<td>Install redundant power systems (e.g., emergency generators) to maintain critical systems and communication networks.</td>
<td>X</td>
</tr>
<tr>
<td>Upgrade exterior lighting and emergency phone stations at walkways, entrances, exits, and parking lots.</td>
<td>X</td>
</tr>
<tr>
<td>Limit access to restricted buildings or area through the issuance of a security badge with specific access identification and key card.</td>
<td>X</td>
</tr>
</tbody>
</table>

7. Development of Security Operational Planning

Security operational scope, objectives and management are final vital part of VA. The awareness and preparedness must begin with comprehensive plans, standard policies, and stringent
regulations. The smart initiatives will help to improve the security of critical assets against the imminent threats and potential consequences. Unfortunately, there is no example of completed security operational plan provided at this time since it is considered beyond the scope of ReIDMP platform development. However, to establish the roles and responsibilities as well as to maximize the supports and services in crisis or emergency situations, the substantial resources and mandatory requirements can be developed by using the general outline of operational security planning located in Appendix D.

For the development of this guideline, the experimental results are presented in Figure 39\textsuperscript{16}. These figures are samples of assessment result from in-class experimentation.

\textsuperscript{16} In contribution of Douglass Farrar, 2017
Figure 39A. Sample of Experimental Results on Incorporating VA with SimCity 2013
Vulnerability Assessment – Routes

Figure 39B. Sample of Experimental Results on Incorporating VA with SimCity 2013
Vulnerability Assessment – Routes

Figure 39C. Sample of Experimental Results on Incorporating VA with SimCity 2013
Figure 39D. Sample of Experimental Results on Incorporating VA with SimCity 2013
Figure 39E. Sample of Experimental Results on Incorporating VA with SimCity 2013
Vulnerability Results – Select Route 1

Summary:

• Routes 2 through 5 each have at least one critical asset that is identified in Quadrant I. These assets are as follows:
  • Route 2: Quadrant I Critical Assets 3 (Hospital) and 12 (Trade Depot)
  • Route 3: Quadrant I Critical Asset 12 (Trade Depot)
  • Route 4: Quadrant I Critical Asset 12 (Trade Depot)
  • Route 5: Quadrant I Critical Assets 11 (Trade Port) and 12 (Trade Depot)

• The only route without critical assets in Quadrant I is Route 1.
  • Route 1 still passes Critical Assets 1 (Police Station), 2 (Fire Station), and 4 (Big Ben).

• Recommended that hazardous materials transported along Route 1 to the greatest extent possible.

(Ref SAIC Manual, 2002.)

Figure 39F. Sample of Experimental Results on Incorporating VA with SimCity 2013
4.2.2.3 Integrated Regional Risk Assessment

Besides RRA application, another method of risk assessment utilized in this analysis portion of the ReIDMP platform development is Integrated Regional Risk Assessment (IRRA). This method was adapted from the “Guidelines for Integrated Risk Assessment and Management in Large Industrial Areas.” The document was a collaborative product of Inter-Agency Program on the Assessment and Management of Health and Environmental Risks from Energy and Other Complex Industrial Systems. It was the jointly sponsored project, which issued under the supervision of IAEA in 1998, and is also known as “IAEA-TECDOC-994” (IAEA, 1998). The manual introduces the compilation of procedures and techniques to assist in planning and conducting the integrated health and environmental risk assessment at the regional level. The guidelines also include a reference framework for developing and evaluating the formulation of appropriate risk management strategies. Overall, IRRA method focuses on the assessment of the risk due to continuous emissions instead of risk due to major accidents. These concerns usually do not pose an immediate effect or loss of life, but they often lead to high morbidity rates in long-term. In other words, the individuals may not experience sudden death, yet their life expectancy will slowly be shortened because of the severe sickness propensity or chronic health condition caused by the duration of exposure to emissions.

Applications and Algorithm of IRRA Methodology

By summarizing the contents in Chapter 4 of IAEA-TECDOC-994 within the research scope of ReIDMP platform development, the IRRA process incorporates three main areas of study, namely air emissions, soil contamination, and water pollution, and consists of six primarily methodological steps.
1. Identification of Continuous Emission Sources

The initial step of the assessment process is to identify the sources of emissions. The estimations of sources, types, and quantities on any emission categories, including solid, liquid, and gas, are needed in evaluating their risks and adverse effects on the human health and environmental hazards. An example list of possible sources of information is presented Table 8.

### Table 8. List of Possible Sources of Information (IAEA, 1998)

<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Activity</td>
<td>Ministry of Industry or Commerce</td>
</tr>
<tr>
<td></td>
<td>National Planning/Economic Development Agencies</td>
</tr>
<tr>
<td>Electronic Energy Minister, Authority, or Company</td>
<td>Internal Revenue Agencies</td>
</tr>
<tr>
<td></td>
<td>Local Governments</td>
</tr>
<tr>
<td></td>
<td>Industry Associations</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>Ministry of Energy</td>
</tr>
<tr>
<td></td>
<td>Ministry of Industry</td>
</tr>
<tr>
<td>Rail and Road Traffic Activity</td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Air Traffic Activity</td>
<td>Airport Authorities</td>
</tr>
<tr>
<td></td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Shipping Activity</td>
<td>Port of Authorities</td>
</tr>
<tr>
<td></td>
<td>Ministry of Transportation</td>
</tr>
<tr>
<td>Air Emissions</td>
<td>Ministry of Health or Environment</td>
</tr>
<tr>
<td></td>
<td>Air Pollution Control Authorities</td>
</tr>
<tr>
<td>Water Emission</td>
<td>Ministry of Health or Environment</td>
</tr>
<tr>
<td></td>
<td>Water Pollution Control Authorities</td>
</tr>
</tbody>
</table>

2. Characterization of Emission Source Inventory

Data collection of emission sources must be characterized and are compared with relevant emission standards. By all means, the correct numbers of emission quantities and physical or
chemical properties are relatively essential to increase the accuracy of risk assessment efforts. IAEA (1998) suggested that there are four fundamental approaches, which can be implemented to initiate the process as follows:

- **1st Approach:** If monitoring is available, then estimate all required emission data from operational sources by direct measurement.

- **2nd Approach:** If monitoring is not available or not technically feasible, then calculate the emission quantities and other associated input values from pollutants using theoretical or empirical equations correlating operating parameters.

- **3rd Approach:** If direct measurement is unavailable and input constants are not calculable, then utilize the compilation of comparative data and values from similar situations or existing literature to estimate the emission values.

- **4th Approach:** If none of above approaches are applicable, the only last option left is to rely on advice and judgment from experts.

In this ReIDMP platform development, owing to the fact that the application capability of SimCity environment still possesses the limitations in simulating some specific information required as input data. Consequently, the 2nd approach is selected to overcome those constraints and to proceed further in the investigation process. All in all, the calculation in this second option converts estimated emission quantity into input values by using emission coefficients. An example list of conversion factors and specific information of five conventional air pollutants in U.S. required to practice this step are displayed in Table 9. Also, in order to get a better understanding in characterizing emission sources inventory, an example of how to calculate input values can be found in Figure 40.
Table 9. Emission Coefficients of Five Conventional Air Pollutants (IAEA, 1998)

<table>
<thead>
<tr>
<th>Energy Industry</th>
<th>SO\textsubscript{x}</th>
<th>NO\textsubscript{x}</th>
<th>CO</th>
<th>HC</th>
<th>TSP</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluidized Bed, Bituminous</td>
<td>1440.0</td>
<td>366.00</td>
<td>56.00</td>
<td>15.00</td>
<td>138.00</td>
<td>Steam plant with emission controls</td>
</tr>
<tr>
<td>Fluidized Bed, Subbitumen</td>
<td>1700.0</td>
<td>582.00</td>
<td>90.00</td>
<td>30.00</td>
<td>146.00</td>
<td>Steam plant with emission controls</td>
</tr>
<tr>
<td>Coal-Oil Power Plant</td>
<td>1297.0</td>
<td>648.00</td>
<td>40.00</td>
<td>18.00</td>
<td>144.00</td>
<td>40/60 mixed by weight of coal/oil</td>
</tr>
<tr>
<td>Petroleum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Oil Extraction</td>
<td>13.60</td>
<td>18.60</td>
<td>0.50</td>
<td>10.60</td>
<td>3.50</td>
<td>Emission from drilling/production</td>
</tr>
<tr>
<td>Enhanced Oil Recovery</td>
<td>207.00</td>
<td>71.00</td>
<td>4.00</td>
<td>2.00</td>
<td>24.00</td>
<td>Recovery via Steam injection</td>
</tr>
<tr>
<td>Oil-Fired Power Plant</td>
<td>3720.0</td>
<td>432.00</td>
<td>49.30</td>
<td>9.80</td>
<td>410.00</td>
<td>Steam plant with emission controls</td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offshore Gas Extraction</td>
<td>1425.0</td>
<td>84.70</td>
<td>1.90</td>
<td>0.60</td>
<td>1.90</td>
<td>120 gas wells</td>
</tr>
<tr>
<td>Natural Gas Purification</td>
<td>0.01</td>
<td>40.90</td>
<td>0.00</td>
<td>0.36</td>
<td>0.16</td>
<td>Treatment prior to transmission</td>
</tr>
<tr>
<td>Liquified Nat. Gas Tanker</td>
<td>7.42</td>
<td>5.84</td>
<td>0.41</td>
<td>0.52</td>
<td>2.44</td>
<td>63,460 DWT ton tanker</td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Pit Uranium Mining</td>
<td>0.43</td>
<td>0.25</td>
<td>0.00</td>
<td>0.02</td>
<td>0.27</td>
<td>Mining of ore for fuel</td>
</tr>
<tr>
<td>Underground Uranium Mining</td>
<td>0.02</td>
<td>0.32</td>
<td>0.19</td>
<td>0.03</td>
<td>0.01</td>
<td>Mining of ore for fuel</td>
</tr>
<tr>
<td>Solar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential Wood Stoves</td>
<td>32.30</td>
<td>134.65</td>
<td>29.10</td>
<td>28.15</td>
<td>565.00</td>
<td>Steam boiler with emission controls</td>
</tr>
<tr>
<td>Industrial Wood-Fired Boiler</td>
<td>70.00</td>
<td>162.00</td>
<td>1300.0</td>
<td>325.00</td>
<td>79.60</td>
<td>Steam boiler with emission controls</td>
</tr>
</tbody>
</table>
To recalculate input data into metric ton/GW * Year

\[
\frac{n}{10^{12} BTU} = \frac{MT}{GW \times a}
\]

Where: \(MT = 1000 \text{ kg, } a = 365 \text{ days}\)

**Case 1: Oil-Fired Power Plant – Sulphur Oxide (SO}_2\)**

\[
27 \times 3720 \times \left( \frac{1}{GW} \right) \times \left( \frac{1}{365 \text{ days}} \right) \times \left( \frac{1,000,000 \text{ kg}}{1 MT} \right) = 275,178.2 \text{ kg/GW}
\]

**Case 2: Coal-Oil Power Plant – Sulphur Oxide (SO}_2\)**

\[
27 \times 1297 \times \left( \frac{1}{GW} \right) \times \left( \frac{1}{365 \text{ days}} \right) \times \left( \frac{1,000,000 \text{ kg}}{1 MT} \right) = 95,942.5 \text{ kg/GW days}
\]

**Figure 40. Sample Recalculation to Develop Input Value Using Emission Coefficient**

3. **Determination of Pathway for Analysis**

The investigation of human exposure to hazardous materials and substances frequently concentrates on four following factors (IAEA, 1998):

- The sources and mechanisms of releasing pollutants to the environment
- The transfer amounts and rates of pollutants through the environment
- The exposed duration of human subjects to the contaminated particles or polluting substances
- The moving directions of the pollutant
When analyzing continuous emissions, as far as the release mechanisms have existed and the human activities are concerned, the moving path of the pollutants from the source to the receptors (dermal, inhalation, eating, and drinking) is needed to be determined and evaluated. Pathways are the condition that indicates the numbers of population average exposures and maximum individual exposures. Each of them also represents a unique mechanism of exposure.

4. Selection of Model for Dispersion Value Calculations

In the case that the direct measurements of pollution exposures from continuous emission and hazardous wastes are absent, the quantification of the pollutant concentrations must be performed by using analytical models that roughly simulate passage, distribution, and transformation of materials in the environment. These models can range from simple hand-on calculations with the graphical calculator to the complex computerized systems or software that solve coupled partial differential equations. IAEA-TECDOC-994 recommended that IRRA requires a decent selection of appropriate mathematical models for establishing the description of natural phenomena and effects of pollution exposure (IAEA, 1998). The selection of models perhaps must depend heavily on the availability of information and the purpose of the study. Combining highly sophisticated models with inadequate data is unquestionably the worst decision. Last but not least, it is crucial to keep in mind that the final product of IRRA is supposed to be a list of corrective measures, which is rational, practical, and favorable with social and economic objectives (IAEA, 1998).

A. Atmospheric Dispersion Models

The idea of applying atmospheric dispersion modeling within IRRA process is to estimate the pollutant concentrations as a function of time since release and to construct the dispersal pattern
of hazardous emissions concerning the source (IAEA, 1998). Some models can be developed in the form of simple mathematical formulas. The uncomplicated ones can be exercised with an intermediate level of calculation proficiency, but the advanced models will need considerable levels of skill and experience. A variety of meteorological dispersion models, such as Gaussian Plume model, physical models, or regional air quality models could be employed but must be adopted with appropriate judgment (IAEA, 1998).

- **Gaussian Plume Models:** The Gaussian plume modeling is one of the simplest ways to calculate the dispersion if air is the medium. It is commonly used and relatively suitable for evaluating the concentration of pollutants as a time function with the dispersion distances between 50-80 km from a large point of emission sources (IAEA, 1998). This technique simulates an estimated concentration distribution in the form of the plume model as a function of a few sources and meteorological characteristics. The input data of its mathematical descriptions require only a source term, an atmospheric stability category, wind speed, and wind direction. However, to conduct the analysis of a simple air pollution model with Gaussian plume modeling, one of the most convenient approaches is the implementation through online-based atmospheric dispersion model calculator. As shown in Figure 41, the mathematical formula and physical characteristics of dispersion in wandering plumes have been programmed as a calculator application package. The user just enters the value of all required input variables in the fields of section 1. Then, the program will automatically work by itself and instantly generate the sigma values in section 2, and then the results in section 3 respectively.

- **Physical Models:** Physical models are choices of meteorological dispersion concept, which can simulate the wind and temperature patterns as well as predict the exact
behavior of single or several plumes. They are capable of providing qualitative results comparable with other sophisticated plume computerization methods (IAEA, 1998). Nonetheless, this type of models can only be used if a precise representation of topography is available.

- **Regional Air Quality Models:** The air quality models require simple data and easy to use. They adopt a concept of a linear relationship between regional average emissions and regional average concentrations, which is, however, only helpful when the changes happen in the smaller range from the observations and for pollutants with uncomplicated atmospheric chemistry condition. The mechanisms of this type of model implementation are pretty strict and cannot be adjusted for new case requirements.

---

**Gaussian Equation:** The highest concentration is the center of the plume at ground level ($y=0$, $z=0$, $h=0$), where the equation is:

$$\chi = \frac{Q}{2\pi \nu \sigma_y \sigma_z}$$

**Step 1. Enter the input variables:**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$ (emission rate)</td>
<td>0 grams/sec</td>
</tr>
<tr>
<td>$\pi$</td>
<td>3.14159...</td>
</tr>
<tr>
<td>$u$ (average wind speed)</td>
<td>0 meters/sec</td>
</tr>
<tr>
<td>$x$ (downwind distance)</td>
<td>0 meters</td>
</tr>
<tr>
<td>Atmospheric Stability (A-F)</td>
<td></td>
</tr>
</tbody>
</table>

Calculate  Clear

**Step 2. Record sigma values (note: ^ means "to the power of"):**

$$\sigma_y = \left[ \begin{array}{c} \sigma_y \end{array} \right]^{0.894} = \left[ \begin{array}{c} \sigma_y^{0.894} \end{array} \right]$$

$$\sigma_z = \left[ \begin{array}{c} \sigma_z \end{array} \right] - \left[ \begin{array}{c} \sigma_z \end{array} \right] = \left[ \begin{array}{c} \sigma_z - \sigma_z \end{array} \right]$$

**Step 3. Results**

$$\text{Conc.} = 0 \left[ \begin{array}{c} 2 \times 3.14159 \times 0 \times 0 \times 0 \end{array} \right] = 0 \text{ micrograms/m}^3$$

Figure 41. Gaussian Plume Calculator by California State University Northridge (CSUN, 2018)
B. Aquatic Dispersion Models

The aquatic environment can be sorted into various kinds of media, such as lakes, rivers, bays, oceans, and rain and flood water. All have different characteristics, and each requires a particular way of approaches. The aquatic dispersion models are considered moderately to extremely complicated. They are usually analyzed by using a computer software package that can be configured for modeling specific bodies of water, complex structures of aquifers and intricate patterns of flow (IAEA, 1998).

- **Surface Models:** Surface models deal with the contamination of surface water. Choices of models are mainly either steady state or time-dependent. Both are distinct in the term of complexity, namely two or three dimensions, with or without convection, and with or without sinks (IAEA, 1998). Many water quality models tend to be highly site-specific. They were designed to prohibit real-time condition changes and to not deviate from its intended functional purposes. Thus, the simple and straightforward models are as good as solutions for estimating the pollutant concentrations in streams and rivers. In contrast, the complex ones are more appropriate for computerizing dispersion patterns in lakes, reservoirs, and any other bodies of water with complicated situations.

- **Subsurface Models:** Subsurface models deal with the pollutant concentrations deep in the water level. They are simple in concept but quite challenge in execution compared to surface models. The contamination modeling procedures consist of two phases and usually involve the potential complexity of the subsurface structures. The first stage is an investigation of a vertical movement of pollutants through the unsaturated zone above an aquifer. The second stage is the examination of plume formation and flow rate
of pollutants through the aquifer. On the whole, the modeling implementation of subsurface aquifer contamination requires a comprehensive collection of data and needs to be done by using advanced computer software packages.

C. Food Chain Models

The evaluation of food chain pathways is typically determined from examination of diets, sources of products, and potential pathways of exposure (IAEA, 1998). Many conceptual frameworks and computerized models have been developed for investigating this kind of the pollutant dispersions and contamination activities. Food chain models are categorized as both terrestrial and aquatic. They are distinguished in term of ecosystems but do not differ in concept (IAEA, 1998). These models were primarily appropriated for assessment of long-term releases. However, they can also be applied to the cases of accidental releases, yet the result may possess considerable degrees of uncertainty.

5. Evaluation of Health Impact to Population

The necessity of estimating dose-response relationship is tied directly to quantitative risk assessment. IAEA (1998) recommended that it is a mandatory requirement that aids the assessment team and stakeholders to avoid irrational planning and decision making. The conventional method of approach usually consists of hazard identification, then followed by parallel steps of exposure quantification and dose-response assessment. This procedure is purposely concerned with the evaluation and quantitative characterization of the relationship between the exposure level and health impact.
A. Elements of Exposure

As was previously stated, IRRA deals with multiple intermediaries of exposure, including air, water, and soil. The exposure in different environmental mediums, even with the same concentration of pollutants, could result in an extremely different dose at the tissue level. By all means, the exposure-response function will highly depend on how the subject was exposed.

- **Exposure and Dose:** A clear distinction between exposure and dose is a significant element in the understanding of the dose-response relationship and the use of it in risk assessment. Exposure is the amount of pollutant or state of harmful condition in the environment to which an individual is exposed. Dose is the concentration of the pollutant that causes the impacts or problems to the organ, tissue, or specific cell in the human body. These two technical terms are bound under a principle of causality (cause and effect). Even so, the connection between them is interposed by simple factors, such as breathing rate, complex metabolism, and pharmacokinetic processes. These systems in the human body can intervene between the initial point of exposure and the issue of interest. They were quite difficult to understand and can be involved in substantial interspecies variation.

- **Averaging time:** In short, the average duration of exposure measurement ranges from seconds to a day or even longer, and also varies depending on the environmental conditions. For one thing, people who stand in one spot for a certain period will be endangered from a continually varying exposure. For another, a person who moves around on their daily activities will be exposed to even more extensive variations of exposure.
- **Exposure Time-Regimen:** In assessing the risk of health impact on the population, the duration of exposure was perceived as uncertain variables. They were often introduced in the assessment processes by applying dose-response functions based on two forms of the examination. First is the epidemiological and occupational studies on humans, which daily workers were exposed 8-hours a day, 5-days a week, and normal persons with continued exposure. Second is toxicological experiments on whole mammals in which the animals were exposed 5-days a week.

- **Complex Mixtures:** Nobody is exposed to a single substance or pure chemical. Even in the specific time and place, both human and animal are habitually under the risk of exposure to multiple compounds of pollutant. Nevertheless, it should be remembered that dose-response functions are always represented the effects in term of either a single pure state or an index of a mixture only.

- **Measurement Techniques:** Technically, the considerations in measuring exposure, dose, and effect are usually unnecessary in most cases.

### B. Elements of Effects

There are many conclusions on health impacts or issues, which are available for dose-response functions and applicable for risk assessment. Most of the end-points regularly focus on diseases with significant concern, such as cancer, heart disease, reproductive toxicity, and even genetic disorders in future generations. These potential effects are a serious matter in term of human wellness in which can be understood easily by decision makers.
### C. Sources and Implication of Data

In principle, there are three basic ways to compile the data for analyzing dose-response functions, including:

- **Epidemiological and clinical studies of human populations**
- **Toxicological studies on whole mammals**
- **Laboratory studies on either cells or tissues of human or mammals.**
All studies from those sources that mean to provide the basis of the dose-response function must include information on both exposure activities and immune responses. They also need to be verified with reliable literature before applying to determine an effective dose-response relationship.

D. Interpretation of Dose-Response Relationship

A dose-response relationship is a factor that signifies an increase in a particular health effect as well as an increase in exposure to a pollutant. The result of this interaction may be concluded in absolute terms (number of increasing cases per 1,000 people per unit of exposure) or relative terms (number of increasing percentages in background rate per unit of exposure). Dose-response relationships are usually developed through the application of a mathematical model in combination with data from epidemiological, toxicological, and clinical studies. However, it is important to remember that the mathematical model was only used to simplify the underlying biological mechanisms and to provide theoretical assumptions, which are experimentally unverifiable.

E. Level of Aggregation

Individual responds differently when exposing to environmental pollution. Thus, the collectible population data must be sorted out into groups with similar characteristics. The degree of detail in each group should also be primarily relying on available information from exposure and dose-response. That is to say, the more detail available in the dose-response function, the more flexibility and higher reliability are possible in the assessment process and result. The three-basic criterion of grouping are as follows:
- **Demographic factors**: age, gender, and ethnicity
- **Constitutional factor**: genetic predispositions, pre-existing disease, immune deficiency, and health conditions
- **Intermediary factors**: exposure level, specific agent, and other additional conditions (e.g., diet, smoking, and concurrent occupational or environmental exposures).

Some of the above factors, especially age, gender, diet, and smoking, are considered extremely useful in a risk assessment, and strongly recommended to include in a dose-response function. On the other hand, some information, such as genetic disorders or chromosomal abnormalities, might be difficult to obtain due to the privacy right.

**F. Uncertainty**

Discussing the dose-response functions, particularly at low-level exposures, it is an unavoidable situation that the cases may possess a considerable degree of uncertainty. This concern is a sensitive subject since the uncertainties can cause misleading in results and conclusions derived from using the dose-response function. Therefore, anytime that a model is put into practice, analysts must take two critical aspects of uncertainty into account, including:

- Uncertainty in the appropriate form functionality of the dose-response model
- Uncertainty in the parameter setting validity of that model

Moreover, since IRRA relies heavily on knowledge from the field of science and the use of 95% confidence levels is widely accepted in the scientific community, 95% is thus the standard value that often adopts as the confidence level in risk assessment. In practical term, this recommended approach will also help in providing sufficient information on uncertainty in the
dose-response function. With such supplemental details, the decision makers would have a better understanding in particular analysis and should be able to draw conclusions by their own judgment.

6. Evaluation of Continuous Emission Impact to Environment

Assessment of environmental impacts is much more complex and requires extensive knowledge than human health impacts. The details involve a large variety of living organisms and physical entities, the availability of toxicological data, and maintainability of other ecological relationships and interactions. In general, the assessment usually focuses on four specific areas of key ecological issues. Additional information is delineated in Appendix E.

Finally, by integrating the redefined version of applications and algorithms developed from IRRA assessment documents with the visualizations of the simulated city, the depictions in a set of Figure 4217 are samples of assessment result representations from in-class experimentation.

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17 In contribution of Stephen Fehr, 2015
Integrated Regional Risk Assessment

Ground pollution map:

Figure 42A. Sample of Experimental Results on Incorporating IRRA with SimCity 2013
Integrated Regional Risk Assessment

Figure 42B. Sample of Experimental Results on Incorporating IRRA with SimCity 2013
Integrated Regional Risk Assessment

Air pollution map:

Figure 42C. Sample of Experimental Results on Incorporating IRRA with SimCity 2013
## Integrated Regional Risk Assessment

<table>
<thead>
<tr>
<th>Activity</th>
<th>Pollutant</th>
<th>Soil pollutant emissions (PPB)</th>
<th>Air pollutant emissions (PPM)</th>
<th>Local Impact</th>
<th>Regional Impact</th>
<th>Global Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>150MW Coal Power Plant</td>
<td>Sulfur dioxide, carbon dioxide, mercury compounds, others</td>
<td>6.7</td>
<td>1.8</td>
<td>Moderate</td>
<td>Low</td>
<td>Contributor</td>
</tr>
<tr>
<td>Coal Mine</td>
<td>Hydrocarbons, sulfur dioxide, carbon dioxide, mercury compounds, others</td>
<td>15.1</td>
<td>0.1</td>
<td>Moderate</td>
<td>Low</td>
<td>Contributor</td>
</tr>
<tr>
<td>Garbage Dump</td>
<td>Residual chlorides, nitrates, phosphates, dissolved solids, heavy metals, others</td>
<td>0</td>
<td>0</td>
<td>Low</td>
<td>0</td>
<td>Contributor</td>
</tr>
<tr>
<td>Industrial Manufacturing</td>
<td>Brown ooze, black smoke</td>
<td>158.2</td>
<td>4.7</td>
<td>Moderate</td>
<td>Low</td>
<td>Contributor</td>
</tr>
<tr>
<td>Streetcars</td>
<td>Smugness</td>
<td>0</td>
<td>Oppressive</td>
<td>Moderate</td>
<td>Low</td>
<td>Contributor</td>
</tr>
</tbody>
</table>

Figure 42D. Sample of Experimental Results on Incorporating IRRA with SimCity 2013
4.3 MCDA Application via DSS Software

Whilst MCDA is a series of systematic approaches intended to support the analysis process of decision-making involving multiple criteria and alternatives, often conflicting objectives, DSS is a collection of decision support software products that use those analytical techniques in MCDA framework to aid decision makers and stakeholders in solving the complex decision problem with much better and more comprehensive way. They conventionally are interactive computer-based systems in which can be applied to various contexts of complex decision scenarios. The tools work by adopting models or algorithms from disciplines such as data processing, mathematical programming, and logic modeling. Some DSS applications even incorporate a multitude of MCDA methods and come with a preliminary preference setting that allows users to break down a problem into a set of more manageable components; to define and structure individual components in systematic ways; to weight and measure each component; and then to combine all evaluated results to identify the preferable solutions. When applying MCDA in group decision-making, the framework will help people in expressing their thought, judgment, and decision opportunity in a way that the values of each view are as important as the others.

In Phase III of ReIDMP platform development, the details from the NRS document have once again been utilized as input data for designing and evaluating the decision models. Specific pieces of information, particularly “NRS: Framework,” were synthesized to fit appropriately with two selected MCDA methods, which are MAUT and ER. For this decision model testing, three key goals of the NRC project are transformed into three primary areas of interest, including environment, economy, and society. Each goal consists of a set of its associated strategies and corresponding proposed actions, which will serve as attributes and alternatives respectively. In the case of proposed actions, the original propositions of each strategy in the NRS document have
been intentionally revised and clustered into a single item at this time to comply with the MCDA framework requirement. The following table (Table 10) and insight are a completed list of detailed data summary.
**Table 10. List of Redefined Norfolk Resilient Goals, Strategies, and Actions (City of Norfolk, 2015)**

<table>
<thead>
<tr>
<th>Aspects (Goals)</th>
<th>Selective Strategies (Criteria/Attributes)</th>
<th>Proposed Actions (Alternatives)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental Aspect: Design the Coastal Community of the Future</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVS1</td>
<td>Creative Vision for Norfolk City’s Future</td>
<td>EVA1</td>
</tr>
<tr>
<td>EVS2</td>
<td>Innovative Infrastructure for Water Management</td>
<td>EVA2</td>
</tr>
<tr>
<td>EVS3</td>
<td>Ideal Place for Living and Working</td>
<td>EVA3</td>
</tr>
<tr>
<td>EVS4</td>
<td>Tools and Regulations for Vision Accomplishment</td>
<td>EVA4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EVA5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EVA6</td>
</tr>
<tr>
<td><strong>Economic Aspect: Create Economic Opportunity by Advancing Efforts to Grow Existing and New Sectors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECS1</td>
<td>Multi-Pronged Economic Development Strategy</td>
<td>ECA1</td>
</tr>
<tr>
<td>ECS2</td>
<td>City’s Entrepreneurial Ecosystem</td>
<td>ECA2</td>
</tr>
<tr>
<td>ECS3</td>
<td>Workforce Development Initiative</td>
<td>ECA3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ECA4</td>
</tr>
<tr>
<td>ECS4</td>
<td>Neighborhood Revitalizations</td>
<td>ECA5</td>
</tr>
<tr>
<td>ECS5</td>
<td>Innovative Financing Methods</td>
<td>ECA6</td>
</tr>
<tr>
<td><strong>Societal Aspect: Advance Initiatives to Connect Communities, Deconcentrate Poverty, and Strengthen Neighborhoods</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCS1</td>
<td>Citizen's Information Access</td>
<td>SCA1</td>
</tr>
<tr>
<td>SCS2</td>
<td>Community-Building Support Through Technology</td>
<td>SCA2</td>
</tr>
<tr>
<td>SCS3</td>
<td>Community Connection Channels</td>
<td>SCA3</td>
</tr>
</tbody>
</table>
The Description of Selective Strategies and Proposed Actions

- **EVS1 – EVA1:** To create and preserve the coastal community, The City of Norfolk is committed to defining its future through a collaborative visioning process. A campaign focuses on facilitating a citizen-led discussion to address “what is important for Norfolk” and to identify “what principles should be adopted by or would be the best option for the city” (City of Norfolk, 2015). The goal of this idea is to generate an innovative plan for living with water and to make long-term investments for future growth.

- **EVS2 – EVA 2 and EVA3:** Securing the future of Norfolk's coastal community requires innovative water management approaches and infrastructures that can respond to both present and future risk events (City of Norfolk, 2015). The city intends to conduct a comprehensive study of flooding in partnership with U.S. Army Corps of Engineers and to create integrated flooding management solutions by combining human-made and natural systems, such as green infrastructure and seawall upgrades, to better control flooding. The City of Norfolk also teams up with a group of global experts to provide peer critiques and to explore how multiple benefits can be achieved successfully from flood mitigation investments.

- **EVS3 – EVA4:** Coastal access is a Norfolk’s key advantage. This fundamental value attracts people in terms of residential dwellings and business investments (City of Norfolk, 2015). Therefore, while protecting the coastline and core area through infrastructure investment, the City of Norfolk is strived to branding itself with a strong identity as a vibrant place for inhabitants and investors.

- **EVS4 – EVA5 and EVA6:** People are the beginning of a change, but to form a better change together, the city must redesign the government process and redefine the regulatory
environment that align with resilient actions (City of Norfolk, 2015). New tools and regulations, especially zoning code, land use, rapid housing model, and long-term recovery plan, should be user-friendly and must encourage future project developments in the way of sustainability and resiliency.

**ECS1 – ECA1:** To create more economic opportunity, Norfolk has investigated its economic situation and identified the potential disciplinary approaches and drivers for existing and new sectors to boost economic prosperity (City of Norfolk, 2015). The city is committed to incorporating knowledge into a new comprehensive economic development strategy for future growth. The development plan will include information, such as business recruitment, expansion, retention, and creation, with a focus on capturing markets outside of the region. The City of Norfolk also collaborates with U.S. Citizens and Immigration Service to establish an EB-5 regional center, where direct investments from foreign investors will be allowed to fund the regional projects.

**ECS2 – ECA2:** Norfolk has been becoming as a burgeoning center for entrepreneurs over the past few years. These small businesses and growing enterprises burst out energy and excitement into the city. With this in mind, the city believes that in order to accelerate and maintain the overall growth, Norfolk must address the key challenge of access to capital and access to talent. The need for these requirements is to invent a platform, called Resilience Lab/ Accelerator, that serves as a connector between problems, solutions, and products.

**ECS3 – ECA3 and ECA4:** Highly qualified human resources are another key to the future success of Norfolk’s economy. Thus, the strong workforce must be built starting with the youth (City of Norfolk, 2015). Providing the training opportunity to residents and nurturing
the skill sets needed to strengthen the future economic growth are an obvious answer to crafting resilience. The City of Norfolk intends to pave the pathways for the consistent growth and to ensure ongoing access on education and opportunity through adulthood. The city also plans to open the first regional career technical school and workforce development center, which will help students and transitioning workers in gaining more knowledge or technical competency for higher job position employment.

- **ECS4 – ECA5:** It is inevitable to admit that the expansion and prosperity of Norfolk's future economy are tied directly to the vitality of neighborhoods. The social disparities, like concentrated poverty, social isolation, and lack of educational or career training opportunities, limit economic growth rate in many areas of the city. To resolve these issues as well as secure the future resilience, the City of Norfolk means to collapse those disparities by launching the poverty support programs, called “Lots of Opportunity” and "Affordable Housing Trust Fund" (City of Norfolk, 2015). The former was invented to target households in a range from low to moderate of median income with a condition of first-time homebuyers. The latter was founded to establish the operating principles and long-term sustainable funding sources for the fund.

- **ECS5 – ECA6:** Funding is one of the primary challenges for NRC project. Resourcing resilience solutions require a tremendous amount of investment. The City of Norfolk not only intends to focus on existing resource allocations but also plans to develop new financing methods for the implementation of 45 proposed resilience actions. To raise more funding resources, however, Norfolk’s Departments of Budget and Strategic Planning and Finance have worked with its partner in seeking innovative ways to leverage the financial benefits from investments of risk reduction bond or social impact bonds.
**SCS1 – SCA1:** Accessing accurate information in a timely manner is a critical aspect to an individual in making an informed decision. So much so that all key data, such as buildings, permits, code violations, flood risks, storm damages, and calls for service, must be integrated into a single system and can also be disseminated into actionable information. The City of Norfolk has partnered with Palantir, a global data integration company, in developing the building blocks for information-based decision-making. This new resilience module will enhance the city’s ability to serve and respond to citizens.

**SCS2 – SCA2:** City of Norfolk (2015) claimed that a city with well-connected communities will withstand better and recover quicker from the disruptive events. Advancements in technology can help citizens to connect easier and allow them to build a larger network of people. The City of Norfolk aims to bring communities together and more attached with one another by engineering new smartphone applications and networking technologies that capable of connecting vulnerable populations with community and services.

**SCS3 – SCA3:** The City of Norfolk is strived to improving communication methods for connecting people with each other and their government. The city believes that when citizens are engaged in sharing the same vision, they will be an essential working part to fulfill that vision (City of Norfolk, 2015). The city’s Department of Neighborhood Development works closely with local communities and residents in mapping their neighborhood’s physical, social, and economic assets. This effort will help the city to understand those core values that make neighborhoods strong and to provide support in times of emergency.
With a provided data parameter above, the works will be administered by two DSS software, namely LDW and IDS, which were also briefly discussed already in Chapter 3, Section 3.5.1 and 3.5.2. Nevertheless, in order to represent well-defined decision modeling structures, the decision analysis will be implemented with a two-step approach. First, each aspect (environment, economy, and society) will be modeled individually to explore a ranking of proposed actions (alternatives) regarding their associated strategies (attributes) and targeted objective (goal). Second, the top-three priority of alternatives on each goal will be adopted and combined as a comprehensive version of the decision model to analyze the prioritization of alternatives concerning twelve attributes and three goals. Last but not least, it is crucial to inform that the purpose of implementing DSS in this study is to demonstrate the benefits of MCDA approach through DSS tools and especially to present examples of analysis results in the view of academic research. Any findings from either LDW or IDS are not the final product or absolute answer.

4.3.1 Logical Decision for Window

LDW is a DSS software designed for supporting the processes of decision-making analysis. It allows decision makers and stakeholders to address and solve difficult problems by considering many variables at once, separating facts from value judgments, and explaining the choice to others. The tool captures differences by evaluating each alternative on a set of attributes, called “measures” and analyzes the importance of those differences by incorporating value judgments, known as preferred levels, to the measures. Once the preferred levels have been assigned, LDW can apply the implications of those defined judgments to particular pieces of data and information and then provide the alternative ranking results based on preference settings. All in all, the software is capable of handling a large number of attributes and manipulation of multiple utility curves.
Adding objects, such as goal, sub-goal, attribute, sub-attribute, and alternative, require only a few keystrokes. The configuration of utility functions for those attributes is automated. The application also comes with a variety of methods for assessing attribute weights, has many results displays, and enhances users’ experiences with many sophisticated features. Perhaps the most useful element of LDW is its capability to support rapid changes in values, with results that can be immediately viewed.

Structuring decision models and specifying the data parameters are the most important aspect of using a DSS tool. LDW facilitates the beginning step by providing a pre-outlined hierarchical structure, which is ready-to-use for modeling a decision problem. This default hierarchy comprises of two levels. The 1st-level is a goal, and the 2nd-level is a measure. In LDW, a goal is a set of measures and other goals that form a hierarchy of decision problem. Each analysis always needs at least one goal, initially called “Overall Goal.” Additionally, in order to identify which objects are the goal component and which objects are the measure component, LDW distinguishes them by using basic shapes. The rectangular represents goals or sub-goals, and the oval depicts attributes or sub-attributes. Accordingly, by inputting the data listed in Section 4.3 into the LDW with its function wizard, the hierarchical structure of decision models regarding three individual goals can be constructed as represented in Figures 43, 44, and 45. Also, the integrated version of all three goals was modeled as depicted in Figure 46.
Figure 43. LDW Hierarchical Structure of Decision Model: Environmental Goal

Figure 44. LDW Hierarchical Structure of Decision Model: Economic Goal

Figure 45. LDW Hierarchical Structure of Decision Model: Societal Goal
Each goal has certain measures that are used to define how well an alternative meets the goal. Thus, adding measures is slightly more complicated than goals. Measures require the input of most preferred or least preferred levels and scale with units for each measure. The input of most and least preferred values is a significant characteristic since this is how the application detects that a goal is designed to maximize or minimize a certain value. LDW also allows the use of label scales.
for specific attributes in addition to numerical values. This function is a distinctive feature of the application as oftentimes many attributes cannot be characterized in term of numerical units. As for this decision analysis, the scale of five priority levels selected was the same for all attributes and every model. The labels are including lowest, low, moderate, high, and highest, as shown in Figures 47 and 48.

**Figure 47. Using Label Scales in LDW: Designation of Units**

**Figure 48. Using Label Scales in LDW: Nomination of Label Scales**
Alternatives are a collection of choices that decision makers and stakeholders expect to rank in the analysis and mean to select after obtaining the result. However, when implementing decision analysis with LDW, the set of proposed alternatives will not be included or illustrated graphically in the hierarchical structure of the decision model. It will be displayed separately in another window. The user can navigate oneself to reach that alternative registration window by clicking on the tab bar, namely “Matrix: Name of Overall Goal”, located at the top of LDW main activity window. As shown in Figures 49, 50, and 51, by entering the information redefined and clustered from NRS's proposed actions, the list of alternatives to be considered was incorporated into the scoring judgment matrix concerning the set of measures. Each of NRS's three primary goals was modeled individually to investigate the possible ranking of alternatives on each goal, recalling detail on the implementation plan and analysis scope stated at the end of a preface of Phase III development (Section 4.3). Later, the top-three alternatives in each ranking result will be adopted and put together to develop a comprehensive version of the decision model that all three goals are integrated. Noted that just two alternatives from the ranking result of a Goal III will be selected at this time since its original strategies and proposed actions are less in numbers than the activities listed in Goal I and Goal II. In this step, the determination of priority level on each alternative must be arranged in corresponding with each attribute to generate a certain amount of utility that will contribute to the overall goal. So much so that the assigned priority level must accurately indicate how the alternative performs with respect to that measure. Each pairwise would have different priority levels in which some might be more or less favorable than others. Eventually, it is important that each of these measures was mutually independent to each other, meaning that an increase in the value of one measure will not provide a change in the value of another.
The assessment of common units is a function wizard of LDW that was ideally designed to convert the level for each measure to common units of utility. In principle, this step is mandatory and always subjected to be evaluated if a set of measures utilizes different types of scale, either quantitative (numerical) or qualitative (label). In LDW, there are multiple conversion methods available to assess common units, such as Analytic Hierarchy Process (AHP), SUF, AHP SUF, Balance Beam SUF, Adjusted AHP, Ideal AHP, and Direct Assessment. By default setting, most are risk neutral and assumes that scales are equally distributed (i.e., 0, .25, .50, .75 and 1). The user can individually edit the utility of each scale using these conversion methods. The feature converts a measure’s level into utility, which can be linear or exponential. However, when any measure's levels in the decision model use labels as a unit, only four methods, including AHP, Adjusted AHP, Ideal AHP, and Direct Assessment, will be applicable to perform the conversion assessment.
This rule is applied to the current situation since all measures in the decision models were characterized to use the label scales of priority level. Hence, the Adjusted AHP was chosen at this time to accommodate the conversion process of common units. Theoretically, this method is essentially the same as the original AHP. Both versions define the relative performances by comparing performance ratio on each possible pair of alternatives or labels. The only difference between them is that the Adjusted AHP function wizard provides a simpler approach of assigning values, which the least preferred has a utility of 0.0 and the most preferred has a utility of 1.0. The adjustment of performance ratios using in this decision analysis is illustrated in Figure 52. The same set of values in the matrix was repeatedly assigned to each of the measures since all of them use the label scales.

The final aspect of any decision analysis with multiple attributes is the assessment of weights. The purpose of this step is to define how the utilities of an active set of goals and their members (measures) are combined into the utility for a higher-level goal or overall goal. The assessment is usually completed by using a weighted average of the utilities. Similar to the common unit assessment step, LDW provides several options of weight assessment for each of the measures. The available methods are, including AHP, Smart, Smarter, Tradeoffs, Balance Beam, Direct Entry, and Pairwise Weight Ratios. For this experimental evaluation, the option of Smart Method (swing weights) was adopted to determine the preferred level of importance on any attributes. This
method was selected as it is the simplest approach among other weight assessment options, which renders an easy understanding as well as flexible adjustment. By selecting swing weight function, the user can directly enter the value, ranging from the least preferred (0) to the most preferred (100), to adjust the relative weight of importance on each attribute. The swing weight values administered in each of three individual decision models are presented in Figures 53, 54, and 55.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Least Preferred Level</th>
<th>Most Preferred Level</th>
<th>Swing Weight (100 = most imp.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVS1 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>60</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVS2 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>80</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVS3 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>40</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVS4 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>75</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 53. LDW Weight Assessment: Weight Distribution on Environmental Attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Least Preferred Level</th>
<th>Most Preferred Level</th>
<th>Swing Weight (100 = most imp.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECS1 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>90</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECS2 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>50</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECS3 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>00</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECS4 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>30</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECS5 Measure</td>
<td>Lowest</td>
<td>Highest</td>
<td>80</td>
</tr>
<tr>
<td>Priority Level</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 54. LDW Weight Assessment: Weight Distribution on Economic Attributes**
Once the components of goals, attributes, and alternatives are correctly transformed to the decision models, the conversions of common unit on all of the measures are appropriately established, and the assessment of weight distribution on an active set of goals and their members is precisely verified, LDW will calculate the results based on those settings and configurations. Speaking about the result representations, LDW offers a variety of features to present the analysis results in different formats. However, the most common and simplistic one is the Rank Alternatives. With a selection of this function wizard, the application will generate a graphical chart, which displays the relative utility scores along with the stacked bar comparing each of the alternatives. The utility values are the determinant that indicates the length of the stacked bar. The higher in the number of total utilities means the longer in the length of the bar. Additionally, each stacked bar represents the accumulated ratios of utility obtained from each of the measures. As a result, each alternative could be compared to each other to see exactly how the utility for each measure factored into the final decision. Figures 56, 57, and 58 are the results of the alternative ranking on each of the three individual objectives.
Figure 56. LDW Alternative Ranking Result: Environmental Goal

Figure 57. LDW Alternative Ranking Result: Economic Goal
By modeling each of NRC's goals individually as the 1st-step approach to examine the alternative rankings based on their goal, the new screening sets of proposed actions include (EVA2, EVA3, EVA1), (ECA1, ECA4, ECA3), and (SCA1, SCA2). With the finding of eight selective proposed actions, an inclusive version of the decision model will be executed by using this set of alternatives. In the 2nd-step approach, three NRC's goals were incorporated into a larger-scale model with the condition of demoting to the sub-goals while the associated strategies of each goal have remained as the measures (Figure 46). The label scale judgments of priority levels previously determined for each pairwise (Figures 49, 50, and 51) were mapped and combined with any new possible pair of proposed actions and strategies, as shown in Figure 59. About the assessment of common units, neither custom configuration in the conversion method nor specific adjustment on the performance ratios were changed. The same set of values demonstrated earlier in the matrix of common unit conversion by Adjusted AHP (Figure 52) was still applied in the larger-scale modeling case. There is also no change on either the selection of weight assessment method or determination of swing weight values regarding any measures. However, the only additional correction in the setting at this time was the ratio of weight distributions on each of the NRC three primary goals. The adjustments of weight distribution and new utility ratios are exhibited in Figure 60.
Figure 59. LDW Matrix of Alternatives: Priority Level of Selected Proposed Actions

Figure 60. LDW Weight Assessment: Adjustment of Weight Distribution on Three Goals
According to the description of a stacked bar chart disclosed in Figure 61, the prioritization of proposed actions is ranked from (1) ECA1 - (2) EVA2 - (3) ECA3 - (4) EVA3 - (5) EVA1 - (6) ECA4 - (7) SCA1 - (8) SCA2. To sum up, ECA1, ECA3, and ECA4 were placed as the first, the third, and the sixth; EVA2, EVA3, and EVA1 were ranked as the second, the forth, and the fifth; and SCA1 and SCA2 somehow were outranked by the others and dropped to the seventh and the eight. This ranking of priority holds an implication in which could be interpreted that the priority level of proposed actions in economic and environmental aspects may appear to be distinguishable in term of scoring performance, but they are the critical element to achieve an overall goal of NRC. In a case of societal aspect, its proposed actions may seem to have less priority than the others, yet they are important and need to be accomplished as well. However, as Phase III of ReIDMP platform was purposely designed to be developed by using two different MCDA techniques through two specific DSS software packages, so much so that this prioritization list was not a final
answer at this point. The result merely provides an initial assumption and overall idea of the priority level on proposed alternatives. A summary of point based on the finding will be reviewed and finalized once after the implementation of the decision model with IDS is completed.

Incidentally, besides the Ranking Alternative function, additional options that also provide informative result representations are Dynamic Sensitivity and Compare Alternatives.
As shown in Figure 62, the sensitivity analysis graph renders good insight into how the ranking of alternatives could change if the weight of specific attributes has been altered. The user can adjust...
the weight by directly dragging the blue color bar or clicking on the current weight to enter the new value at the lower section of the LDW main activity window.

In LDW, the user is also allowed to compare each alternative's performance against one another. By selecting this function, the user simply chooses any two alternatives to create a pair that needs to be examined. Figures 63 and 64 are examples of Compare Alternative charts.

**Figure 63. LDW Comparison of Alternatives: ECA1 vs EVA2**

<table>
<thead>
<tr>
<th>Prioritization of NRC Proposed Actions Goal Utility for</th>
<th>ECA1</th>
<th>0.361</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA2</td>
<td>0.326</td>
<td></td>
</tr>
<tr>
<td>Total Difference</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Total Difference</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>ECS1</td>
<td>0.107</td>
<td></td>
</tr>
<tr>
<td>EVS2</td>
<td>-0.102</td>
<td></td>
</tr>
<tr>
<td>ECS3</td>
<td>0.051</td>
<td></td>
</tr>
<tr>
<td>ECS5</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>EVS4</td>
<td>-0.027</td>
<td></td>
</tr>
<tr>
<td>EVS3</td>
<td>-0.014</td>
<td></td>
</tr>
<tr>
<td>SCS2</td>
<td>-0.011</td>
<td></td>
</tr>
<tr>
<td>ECS4</td>
<td>-0.010</td>
<td></td>
</tr>
<tr>
<td>SCS3</td>
<td>-0.009</td>
<td></td>
</tr>
<tr>
<td>ECS2</td>
<td>0.009</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 64. LDW Comparison of Alternatives: ECA3 vs EVA1**

<table>
<thead>
<tr>
<th>Prioritization of NRC Proposed Actions Goal Utility for</th>
<th>ECA3</th>
<th>0.299</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA1</td>
<td>0.281</td>
<td></td>
</tr>
<tr>
<td>Total Difference</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Total Difference</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>ECS3</td>
<td>0.101</td>
<td></td>
</tr>
<tr>
<td>EVS2</td>
<td>-0.045</td>
<td></td>
</tr>
<tr>
<td>EVS1</td>
<td>-0.040</td>
<td></td>
</tr>
<tr>
<td>EVS4</td>
<td>-0.040</td>
<td></td>
</tr>
<tr>
<td>ECS1</td>
<td>0.031</td>
<td></td>
</tr>
<tr>
<td>SCS1</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>EVS3</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>SCS2</td>
<td>-0.011</td>
<td></td>
</tr>
<tr>
<td>ECS4</td>
<td>-0.010</td>
<td></td>
</tr>
<tr>
<td>SCS3</td>
<td>0.004</td>
<td></td>
</tr>
</tbody>
</table>
4.3.2 Intelligent Decision System

In a like manner to LDW, IDS is a DSS software that has been developed to assist decision makers and stakeholders in facing a complicated situation of the decision problem. However, while the other DSS(s) use traditional MCDA methods, like AHP or MAUT, IDS adopts a theory of ER approach, an evidence-based reasoning process, to deal with the complex decision problems, particularly for those comprising both quantitative and qualitative criteria with uncertainties (Xu & Yang 2001, 2003; Yang & Xu, 2002, 2003). In IDS, the MCDA problem is modeled and analyzed by using an extended decision matrix in which each pairwise of attribute and alternative is assessed with a two-dimensional variable, namely possible criteria referential values and their associated degree of belief (Yang & Xu, 2003, 2004). The tool has significant advantages over conventional methods in allowing the user to improve consistency, transparency, and objectivity during the execution process. On the whole, the software is considered a flexible application that is not only capable of handling the different types of data, such as probability uncertainty, incomplete information, subjective judgments, and interval data, but it also offers a wide range of informative analysis results, including alternatives' scores, performance diversity, strength and weakness, and profile and graphical representation.

Speaking about software implementation, once again, constructing decision models and defining the necessary data is the most important aspect of utilizing a DSS product. The interface and usability of IDS are quite similar to LDW, yet somewhat more user-friendly and straightforward. In IDS, the main menu bar and basic function shortcut bar are located at the top of the main application wizard, and below those two bars is the modeling activity window. This window consists of two sections in which the right side is the tree view window for illustrating a hierarchical structure of the decision problem, particularly goals and criteria, and the left side is
the list view window for displaying a set of possible alternatives that need to be assessed (Yang & Xu, 2004). For this decision model testing with IDS, the data parameter listed in Section 4.3 has remained unchanged. The two-steps approach used in LDW is still applied. Eventually, by mapping the same set of input data into the IDS with its function wizard, the hierarchical structure of decision models regarding three individual goals and the integrated version of all three goals are presented in Figures 65, 66, 67, and 68. However, in addition to representing the decision model in the tree and list view as described above, IDS also offers another viewing option in visualizing a holistic view of the decision model. This mode is called “Dialog Box View” in which can be found and operated by selecting the fifth icon on basic function shortcut bar. Within this mode, the yellow colored boxes represent the alternatives (proposed actions), while, the light blue colored boxes portray the attribute (strategies). Each also presents brief information about decision component. For alternative box, the name is at the top; the ranking is in the bottom left, and the utility value is in the bottom right. For attribute object, the name is at the top; the weight is in the bottom left, and the value (quantitative case) or average utility value (qualitative case) in the bottom right. Figures 69, 70, 71, and 72 are the matched example of each decision model in the dialog box version.
<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Environmental Aspect: Design the Coastal Community of the Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA1</td>
<td>EVS1 - Creative Vision for Norfolk City’s Future</td>
</tr>
<tr>
<td>EVA2</td>
<td>EVS2 - Innovative Infrastructure for Water Management</td>
</tr>
<tr>
<td>EVA3</td>
<td>EVS3 - Ideal Place for Living and Working</td>
</tr>
<tr>
<td>EVA4</td>
<td>EVS4 - New Tools &amp; Regulations for Vision Accomplishment</td>
</tr>
<tr>
<td>EVA5</td>
<td></td>
</tr>
<tr>
<td>EVA6</td>
<td></td>
</tr>
</tbody>
</table>

Figure 65. IDS Tree - List Views of Decision Model: Environmental Goal

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Economic Aspect: Create Economic Opportunity for Sustainable Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECA1</td>
<td>ECS1 - Multi-Pronged Economic Development Strategy</td>
</tr>
<tr>
<td>ECA2</td>
<td>ECS2 - City’s Entrepreneurial Ecosystem</td>
</tr>
<tr>
<td>ECA3</td>
<td>ECS3 - Workforce Development Initiative</td>
</tr>
<tr>
<td>ECA4</td>
<td>ECS4 - Neighborhood Revitalizations</td>
</tr>
<tr>
<td>ECA5</td>
<td>ECS5 - Innovative Financing Methods</td>
</tr>
<tr>
<td>ECA6</td>
<td></td>
</tr>
</tbody>
</table>

Figure 66. IDS Tree - List Views of Decision Model: Economic Goal

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Societal Aspect: Advance Initiatives for Community Prosperity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCA1</td>
<td>SCS1 - Citizen’s Information Accessibility</td>
</tr>
<tr>
<td>SCA2</td>
<td>SCS2 - Community Supports Through Technology</td>
</tr>
<tr>
<td>SCA3</td>
<td>SCS3 - Community Connection Channels</td>
</tr>
</tbody>
</table>

Figure 67. IDS Tree - List Views of Decision Model: Societal Goal

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Prioritization of Proposed Actions for Norfolk Resilient City</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA1</td>
<td>EVS1 - Creative Vision for Norfolk City’s Future</td>
</tr>
<tr>
<td>EVA2</td>
<td>EVS2 - Innovative Infrastructure for Water Management</td>
</tr>
<tr>
<td>EVA3</td>
<td>EVS3 - Ideal Place for Living and Working</td>
</tr>
<tr>
<td>ECA1</td>
<td>EVS4 - New Tools &amp; Regulations for Vision Accomplishment</td>
</tr>
<tr>
<td>ECA3</td>
<td>Economic Aspect: Create Economic Opportunity for Sustainable Growth</td>
</tr>
<tr>
<td>ECA4</td>
<td>ECS1 - Multi-Pronged Economic Development Strategy</td>
</tr>
<tr>
<td>SCA1</td>
<td>ECS2 - City’s Entrepreneurial Ecosystem</td>
</tr>
<tr>
<td>SCA2</td>
<td>ECS3 - Workforce Development Initiative</td>
</tr>
<tr>
<td>SCA3</td>
<td>ECS4 - Neighborhood Revitalizations</td>
</tr>
<tr>
<td>SCA4</td>
<td>ECS5 - Innovative Financing Methods</td>
</tr>
<tr>
<td>SCA5</td>
<td>Societal Aspect: Advance Initiatives to Connect Communities</td>
</tr>
<tr>
<td>SCA6</td>
<td>SCS1 - Citizen’s Information Accessibility</td>
</tr>
<tr>
<td>SCA7</td>
<td>SCS2 - Community Supports Through Technology</td>
</tr>
<tr>
<td>SCA8</td>
<td>SCS3 - Community Connection Channels</td>
</tr>
</tbody>
</table>

Figure 68. IDS Tree - List Views of Decision Model: Integration of Three Goals
Figure 69. IDS Dialog Box View of Decision Model: Environmental Goal

Figure 70. IDS Dialog Box View of Decision Model: Environmental Goal

Figure 71. IDS Dialog Box View of Decision Model: Environmental Goal
When using IDS to conduct a decision analysis on MCDA problem, defining a set of assessment grades for each attribute is imperative. Each grading set must be separately determined, so that the software would be able to understand how each attribute is being assessed. In the dialog
setting window, the attribute can be defined as qualitative or quantitative with whether the certain or uncertain conditions. As for a case of NRC decision model testing, since the selected strategies and proposed actions were meant to be assessed with the label scale of five priority levels, an option of the qualitative attribute was selected at this time. The number of five (5) evaluation grades and same label units, notably lowest, low, moderate, high, and highest, were recorded as assessment grades and applied to each of the attributes. The steps in programming specifications in the dialog window of attribute setting are exhibited in Figures 73 and 74. Furthermore, in order to keep the configuration settings of this model testing comparatively identical as well as relatively consistent with the previous modeling implementation in LDW, it is assumed that the utility values of five priority grades are linearly distributed, which are 0, .25, .50, .75, and 1 (Figure 75).

Figure 73. IDS Attribute Dialog Window: Attribute Type and Number of Grades
Figure 74. IDS Attribute Dialog Window: Qualitative Assessment Grades

Figure 75. IDS Attribute Utility Dialog Window: Utility Assignment of Evaluation Grades

Judging the score or assigning the grade for each of the alternatives in corresponding with each of the attributes in IDS is different from LDW and other DSS applications. In IDS, the software does not offer an option of visualizing all possible combinations between alternatives and attributes in a comparison table or a matrix format. Each alternative and each attribute must be manually paired and individually evaluated one-by-one at a time. Moreover, on the condition that ER
assesses the qualitative attributes by using both grades and a degree of belief. Consequently, instead of assigning just a single value of scores or determining one level of importance, the user can choose one or more preferred grades with different degrees of belief. The examples of how the grades have been assigned to some of each possible pair of the alternative and attribute are displayed in Figures 76, 77, and 78. One additional annotation to these three figures is the implication of a belief degree in the field on the right of a checkbox. Technically, this variable represents the strength in which an answer is believed to be true. The value can be less than or equal to one (1). Meaning that when only one answer was selected, a belief degree will be equal to (1). However, if two or more answers were chosen, the values of a belief degree either will be equally average based on the number of checked answers by IDS or can be instantly adjusted with an exact number by the user, which in the end the sum of all values must still be equal to (1) (Figures 77 and 78). At any rate, this distinctive feature is an outstanding benefit that sets IDS apart from other DSS tool. It possesses unique flexibility in handling MCDA problems with subjective information and judgmental uncertainty at the same time.

![IDS Dialog: EVA1](image)

**Figure 76. IDS Assessment Information Dialog Window: Preferred Grade (EVA1 – EVS1)**
Another mandatory requirement in developing the decision model with IDS is the determination of relative weights for each of the attributes. In IDS, the software provides a few options of the assessment method, notably visual scoring and pairwise comparisons, to assist the user in assigning weights to the attributes. The former seems to be a favorable method in this
decision analysis since the latter requires additional knowledge and opinions from subject matter experts. By selecting the visual scoring option, the function wizard allows the user to administer the weight distribution to each attribute by either dragging an interactive bar graph up and down to reach a preferred limit or entering an exact value in the weight edited field. Figures 79, 80, and 81 show the distribution of weight values assigned in each of three individual decision models. Nevertheless, it should be noted that the visual scoring approach for each decision model was performed with the normalized condition to ensure that the sum of the weights on all of the attributes is equal to 1.

![Figure 79. IDS Attribute Weight Dialog Window: Environmental Attributes](image1)

![Figure 80. IDS Attribute Weight Dialog Window: Economic Attributes](image2)
With the completed setting of three required modeling procedures, the software should be ready to analyze the decision model and produce the output information. In IDS, the most frequently used function in processing the result representation is the “Graph Ranking.” The user can reach the command by either selecting Report Graph Ranking on the main menu bar or directly clicking the twentieth icon on the basic shortcut bar within IDS window. By opting-in this function wizard, the software will generate a graphical chart, which displays the relative utility scores along with the vertical bar comparing each of the alternatives. Again, the utility values are the determinant that indicates the height of the bar. The greater in the number of utilities means the taller in the height of the bar.
Figure 82. IDS Alternative Ranking Graph: Environmental Goal

Figure 83. IDS Alternative Ranking Graph: Economic Goal
As illustrated in Figures 82, 83, and 84, the rankings of alternatives in the vertical bar charts from three individual decision models describe that a screening set of proposed actions comprises (EVA2, EVA3, EVA1), (ECA1, ECA4, ECA3), and (SCA1, SCA2). Likewise, this finding was intended to be utilized as a new set of alternatives in a comprehensive version of the decision model for the final prioritization. In proceeding the 2nd-step approach of modeling implementation, the components in each of three individual decision models (Figures 65, 66, and 67) were incorporated into a larger-scale model with the same condition as previously done in LDW (Figure 68). The grading assignment of priority levels for each pair of alternative and strategy, like provided example in Figures 76, 77, and 78, were characterized and consolidated with additional grading judgment of new possible combinations between proposed actions and strategies. In a case of attributes' weight, there is no change in either the selection of assessment method or evaluation of distribution ratios as well. The task was completed by applying the same
sets of weight values through a visual scoring function (Figures 79, 80, and 81). The only additional configuration in the setting at this time was the ratios of weight distribution on three NRC targeted objectives. The adjustments of weight distribution and new utility ratios are presented in Figure 85.

Figure 85. IDS Attribute Weight Dialog Window: Weight Distribution on Three Goals

Figure 86. IDS Alternative Ranking Graph: Integration of Three Goals
By integrating three primary goals and analyzing them as a comprehensive model, the final output in Figure 86 shows that the prioritization of proposed actions is ranked from (1) ECA1 - (2) EVA2 - (3) ECA3 - (4) EVA1 - (5) ECA4 - (6) EVA3 - (7) SCA1 - (8) SCA2. Considering this result in comparison with the one obtained from LDW, it appears that both are the same in term of top-three and the last two priorities, but slightly different in the fourth, the fifth, and the sixth ranks. With the application of the ER approach, ECA1, EVA2, ECA3 still receive the scores that were prioritized as the first, the second, and the third on the prioritization list. EVA1 and ECA4 obtain the higher scores than previous decision analysis and earned the places as the fourth and the fifth. On the contrary, as EVA1 and ECA4 have developed themselves one rank up, ECA4 has dropped down to the sixth. About the societal aspects, SCA1 and SCA2 indeed possessed a certain amount of utility scores. They somehow have been outranked by the others and fell to the seventh and eighth again.

At any rate, the prioritization could be summarized that in order to transform Norfolk into a resilient city, creating the economic opportunity in the city will need a development plan and job creation capital as well as career technical school and workforce development center that align with existing businesses and future directions. In the meantime, designing the coastal community for the future would require a comprehensive study on flood risk and flooding control before the development of integrated flood management solution and next-generation water management strategies. Both environmental preservation and economic development are correspondingly significant and must be arranged simultaneously. As for societal reformation, connecting the communities, deconcentrating the poverty, and strengthening the neighborhoods are considered small pieces of the essential element that intend to fulfill the accomplishment of an overall goal. They are just a bit less vital in term of execution priority compared to the others. Even they were
ranked as the second to last and the last in both lists of priority ranking, those indications do not imply that the proposed actions in societal aspect were not held any meaning or could be ignored.

4.4 Representation of System Complexity via Object Oriented Instrument

OOP is a programming paradigm that refers to the usage of “objects” to design applications and computer programs. This body of knowledge was created based on several concepts and techniques, including abstraction, encapsulation, modularity, and inheritance (Section 3.6). In OOP, the objects may contain data, in the form of fields (attributes) and code, in the form of procedures (methods). They are capable of interacting with one another by receiving messages, processing data, and sending information to others. Each of them acts as an independent unit with a distinctive role and responsibility (Ancel, 2011). Overall, the paradigm aims to support the development of efficient data structures and to target the behaviors of real-world elements within the digital environment.

Speaking of which, TopEase® Designer is an OOP software that allows the user to manage critical information of focused systems and to visualize those entities in a holistic view of a complex system (Pulfer & Schmid, 2006). The tool was developed by a Swiss company, named Action4Value. It is a commercial software product, which was intentionally designed to handle business processes and originally used in various fields of the business sector, such as financial institutions, healthcare providers, and real estate firms. The software, which has been used for more than 20 years as a business application tool, comes with the capability to provide methodological procedures to capture a desirable end-state of the organization, company, or enterprise while highlighting the gap between the current “system as is” and desired “system to be” states. The idea behind the development of the software was to establish a balance between
principles and pragmatism. This fundamental concept is laid on the axioms “1-Methodology - 3-Layers - 5-Models - 7-Questions”. The implications of each term can be briefly described as follows:

- **1-Methodology**: The software utilizes only one methodology, which attempts to accomplish its targets or goals based on a pragmatic solution and a balanced manner.

- **3-Layers**: In TopEase®, there are three layers, including definition, support, and implementation. This feature assists the user in obtaining a target audience related business structure.

- **5-Models**: The models allow inputs and data structures to be modeled, documented and elaborated. With a system analysis and design through TopEase®, the output can be validated through value chains and questions, in case all required elements are modeled appropriately. Five models are classified as business, resource, information, delivery, and change.

- **7-Questions**: This function supports the process of interpreting the connections between three layers and five models. It helps the user to determine and verify interrelationships among nodes and objects, that are constructed. These questions are about cost, benefit, risk, quality, feasibility, manageability, and impact.

Nowadays, TopEase® offers even more flexible but powerful features at every step of analysis and design processes to assist the user in achieving continuous improvements and meaningful results. The tool aims to provide sustainable solutions to the system problems by concentrating on the management of system complexity, transparency of data structure, and control of transformation processes. In Phase IV of this ReIDMP platform development, the goal is to present
the benefits of adopting the OOP paradigm as a mean to address and visualize the system complexity. Accordingly, this section will focus on how the OOP based software approach could be useful in handling emergency management operations as enterprise management processes, particularly through the study and investigation from a granted project sponsored by the U.S. DHS.

4.4.1 Critical Infrastructure Resilience of Hampton Roads Region

The safety of CI systems is one of the highest priority tasks for national security. Service interruption on any one or more of them due to either man-made threats or natural disasters, such as terrorist attacks, pandemics, hurricanes, and earthquakes could result in catastrophic failure, not only for the region but also for the entire nation. Thus, after the incidents of the 9/11 Attacks in 2001 and a Hurricane Katrina in 2005, it was obvious that a protection plan itself would not be sufficient and a new perception must be placed on CIs. There is a necessity in establishing more resilient infrastructures to minimize extreme impacts and to withstand damages or disruptions from both expected and unexpected events. However, the main problem in enhancing the resilience capacity of CI systems is that it requires a comprehensive approach and an appropriate tool to incorporate existing protection plans with emergency preparedness actions.

Throughout the past two decades, the security and protection of CI systems have received significant attention from and have become a major concern to the U.S. DHS. Numerous research projects in the area of risk and vulnerability of CIs have been funded to address the key issues and pragmatic solutions. Among those developments, one of the projects, namely “Critical Infrastructure Resilience for the Hampton Roads Region (CIRHRR),” involved in analyzing and assessing the factors that could affect functionality, reliability, security, and resiliency of four particular CI sectors in the region, including energy, water and wastewater, transportation, and
communications. The study introduced a strategic risk assessment process established by the International Risk Governance Council (IRGC), called Risk Governance Framework, to identify systemic risks of imminent threats or adverse events and then employed an object-oriented instrument to demonstrate a multi-dimensional complexity of interconnection and interdependence between two or more large-scale infrastructure systems. The goal of the project was to develop high-level risk management on economic and social impacts from identified threats and to create a risk assessment model that can be implemented as standard procedural security and countermeasure for other regions.

Hampton Roads is a region that consists of a body of water and the surrounding metropolitan areas located in the Southeastern United States. The entire area comprises sixteen jurisdictions, including nine cities and seven counties, with a population over 1.7 million. Hampton Roads has a unique characteristic and highly critical to national security as it is home to the world's largest naval complex station and the second-largest port on the Atlantic Coast. Besides its prominence as the economic hub and one of U.S. military stronghold, the location of a region, though, is low-lying in term of geographic condition, so that it is more likely susceptible to the floods and vulnerable to the effects of seasonal hurricanes and occasional tornadoes. Taking those characteristics and identities of a region into consideration, the Port of Hampton Roads, also officially known as “Port of Virginia”, is a key CI in the Hampton Roads region (Gheorghe, Tokgoz, Cakir, & Vamanu, 2008). Concerning the Port of Virginia, it is a natural deep-water harbor that has a depth of 50-feet with unobstructed channels and berths. Consequently, an autonomous agency is the only major operating port on the U.S. East Coast that receives congressional authorization for 55-feet depth channels (Virginia Port Authority, 2017). It is located just 2.5 hours to the open sea and operates on a year-round schedule due to an ice-free condition.
Most activities and services are facilitated by a total of 22 Suez-class ship-to-shore cranes port-wide and almost 7 miles of on-dock rail track (Virginia Port Authority, 2018).

Furthermore, the four principal facilities, which includes Norfolk International Terminals (NIT), Portsmouth Marine Terminal (PMT), Newport News Marine Terminal (NNMT), Virginia International Gateway (VIG), waterways, and coastal areas are occupied with military assets, nuclear power plants, oil refineries, fuel tanks, pipelines, chemical plants, cargo terminals, and passenger terminals. They, particularly, have inherent security vulnerabilities (Gheorghe et al., 2008). Each facility is relatively spacious and easily accessible by water and land. The terminal is also located in the crowded industrial zone and connected with a transportation network that stretches throughout the nearby metropolitan areas, including Norfolk, Portsmouth, Newport News, Hampton, Virginia Beach, Chesapeake, and Suffolk (DHS, 2005). This transportation system consists of infrastructures and assets, such as roads, railroad, bridges, tunnels, and hundreds of miles of highway. Under these circumstances, the bridges and tunnels are considered vulnerable spots in the area, which pose a significant threat during any event of emergency and crisis situations (Gheorghe et al., 2008).

As a CI and key national resource, the Port of Virginia is a vital part of the complex systems necessary for the public well-being, national security and global economy. The port and its facilities along with the vessels and barges that sail through the harbor of Hampton Roads are the indispensable components in supporting the free movement of goods and passengers into and out of the United States and the world. Some physical and virtual assets of the port, as well as other associated infrastructures, also even tied to the resistance function and countermeasure ability of the U.S. defense infrastructure systems. A single unexpected attack by terrorist on one or more parts of this CI may cause temporary disruption, massive casualties, or economic damages, but in
the worst-case scenario, the action could even result in the catastrophic failure on the entire system (DHS, 2005). In addition to the man-made threats, the natural disasters are another threat in the Hampton Roads as a region borders with the Atlantic Ocean. So much so that the region is no stranger to risks of storm surges and flash floods. In this area, most flooding could happen from surges, heavy rains, rainstorms, or hurricanes. These events have been known for bringing traffic to a grinding halt and affecting underpasses, tunnels, and bridges, which can be the causes of activity discontinuation and services interruptions between the main facilities and branch locations. As a result, the availability of the Port of Virginia must be constantly assured for national security operations. Addressing the risks and mitigating their potential impacts should remain top priorities, not only to the general public but also to Hampton Roads policy and decision makers.

4.4.2 CIRHRR Through Implementation of TopEase® Designer

Resilient infrastructures are components, facilities, assets, or systems, whether physical or virtual, that must be able to withstand disruption and damage, but if affected, can be readily recovered or cost-effectively restored (Gheorghe et al., 2008). Hence, in order to establish regional disaster mitigation, response, and recovery plan as well as enhance regional security and resiliency of Hampton Roads, a complex set of management and policy issues are required to be addressed. A complete list of critical assets and essential resources, both public and private, need to be integrated as a regional model. All involved facilities, relationships among them, and their dependencies over one another must also be analyzed to determine the capabilities of response and recovery in each of jurisdictions during emergencies (Gheorghe et al., 2008). However, with the complication of diversity on local authorities, federal agencies, and private organizations in multiple jurisdictions, consequently, the City of Hampton was selected as a model city to develop
its Emergency Operation Plan (EOP). The idea of using TopEase® in CIRHRR project is to convert the EOP of the City of Hampton into a form of a digital model for illustrating the interdependencies among CIs.

As has been mentioned, the Hampton Roads region has unique characteristics and is strategically critical to national security, especially economy and military. For this reason, the existence of multiple jurisdictions, military assets, and private utility facilities require an analytical solution through the application of the system of system technology. To analyze the current state of an emergency plan, the process was initiated within TopEase® by outlining four primary CIs in focus as layers. Each of them represents a specific sector of CIs and selected infrastructures, which includes electric power, water and wastewater, transportation and military, and communication. The functionalities of these integrated CI layers and EOP against different threats are cross-cut as predefined issues. These multilayer approach and issue identification are shown in Figures 87 and 88.
The next example of implementation is the modeling of the organizational chart and the visualization of complexity among entities. At this point, it should be noted that when using TopEase® to develop models, every output result needs the input data. In other words, the user must enter all detail and information in which as same as constructing the data structure to generate the models. So that by defining stakeholder, personnel, roles, and responsibilities (Figure 89), the software would produce the graphical output model that shows the relationship between objects and the complexity of emergency management in the format of process support diagram, as displayed in Figure 90.
Regarding the implementation of this organization chart, the software also provides the feature, called RACI matrix, to support the user in evaluating the characteristics and responsibilities of
various positions in the organization chart. In TopEase®, the term “RACI” refers to Responsible, Accountable, Concerned, and Informed. This function facilitates the process by mapping all detail and information in the data structure, which allows the user to analyze the entire organization chart and to identify the influence factors and interdependencies among the objects. The window dialog of RACI function and part of its matrix output are presented in Figures 91, 92, and 93 respectively.

Figure 91. RACI Matrix Function Wizard (Responsible)
Managing emergency operations is a very challenging task. The delay responses to the incidents in minutes or just seconds due to overlapping authority and uncleared instructions could
lead to an undesirable outcome. To avoid such unnecessary confusions and errors, all possible external factors must be identified and included in the plan. In CIRHRR, this step has incorporated additional information, such as the explanatory glossary, detail activities, process lifecycle, influence agents, and reference database, which were directly adapted from the EOP of the City of Hampton into the TopEase®. Some examples are illustrated in Figures 94, 95, 96, 97, and 98. With the data structures of those sets of input, as a result, they would allow the software to produce an inclusive visualization of a model which includes activities, processes, roles, responsibilities, and people in the same diagram. An example of a partial output representation is exhibited in Figure 99.

Figure 94. Data Structure of Additional Information: External Agents
Figure 95. Data Structure of Additional Information: Explanatory Glossary

Figure 96. Data Structure of Additional Information: Reference Database
Figure 97. Data Structure of Additional Information: Influence

Figure 98. Data Structure of Additional Information: Sub-Activities
In addition to the capability of creating the models and graphic representations, TopEase® also comes with the risk catalog function. This feature can handle any kinds of risk to the system that
is being analyzed and modeled. In TopEase®, the risk is defined by two parameters, which are likelihood and impact. The scales and descriptions of each category are given in Table 11.

Table 11. Categories of Likelihood and Impact in TopEase® (Gheorghe, et al., 2008)

<table>
<thead>
<tr>
<th>Description</th>
<th>Likelihood Ranking</th>
<th>Impact Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency of</td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td>Occurring Event</td>
<td></td>
</tr>
<tr>
<td>Improbable</td>
<td>Once Every 10,000 Years</td>
<td>Minor</td>
</tr>
<tr>
<td>Remote</td>
<td>Once Every 1,000 Years</td>
<td>1 in 100</td>
</tr>
<tr>
<td>Occasional</td>
<td>Once Every 100 Years</td>
<td>1 in 100</td>
</tr>
<tr>
<td>Probable</td>
<td>Once Every 10 Years</td>
<td>Likely</td>
</tr>
<tr>
<td>Frequent</td>
<td>Once Every Year</td>
<td>Certain</td>
</tr>
</tbody>
</table>

According to the CIRHRR project, it suggested that Hampton Roads is vulnerable to both man-made disasters and natural catastrophes. Some are considered significant threats to the Hampton Roads (Gheorghe et al., 2008). Thus, the study approached this aspect by assigning the risk of having a disaster on any operation or CI to calculate the total risk of that event. Figures 100 and 101 show a risk template dialog window, where an earthquake was entered as a selected disaster and then assigned to a specific CI, especially nuclear power plants. In TopEase®, the assigned risk can be represented with different options, such as risk matrix or interdependency diagram. The examples of the likelihood of having different types of disaster versus impacts of those disasters on a nuclear power plant are displayed in Figures 102 and 103.
Figure 100. Risk Template: Selection of a Disaster Risk

Figure 101. Risk Template: Assignment of A Selected Disaster to A Specific CI
Figure 102. Risk Scorecard of Nuclear Power Plant

Figure 103. Risk Map of Nuclear Power Plant
CHAPTER 5

CONCLUSIONS

5.1 Overview

As stated by the Rockefeller Foundation and ARUP (2014), resilience, in the view of 100 resilient cities project, is the ability of a system, entity, community, or person to absorb and withstand any shock or stress while maintaining its essential functions, structures, and identity, and to recover quickly and effectively. Therefore, building a city resilience is about making people, communities, and systems to be better prepared in surviving, adapting, and thriving through catastrophic events. In this context, resilience means more than coping with possible contingency or short-term survival. This notion is aimed at sustaining and enhancing the capacity of adaptability to face and resist the uncertainties or shocks. Ultimately, resilience is an attribute which can be learned and a skill that must be experienced (Rockefeller Foundation & ARUP, 2014).

Resilience thinking is a paradigm that challenges the idealistic principle of stability and resistance to change implicitly in sustainable development. However, when it comes to the improvement of city resilience, the city is required to be perceived as a mega-scale system with multi-dimensional complexity, and its embedded systems are demanded to be changed in a way that people used to depend on them. In other words, the city resilience-building process is a challenging task and indeed require a holistic approach (Collier et al., 2013; Hernantes, Maraña, Gimenez, Sarriegi, & Labaka, 2019; Jabareen, 2013). There is a pressing need for new tools or examples of the practical sequential steps in which any cities could adopt as effective guidance for developing city resilience (Jabareen, 2013; Hernantes et al., 2019; Weichselgartner & Kelman, 2014). Most frameworks in the scholar literature still do not focus on providing a systemic roadmap
with a detailed sequence that can be implemented to advance the resilience-building process (Collier et al., 2013; Cavallo & Ireland, 2014; Hernantes et al., 2019). To deal with this dilemma, the current study tries to fill the gap with the development of a new framework, which could be useful in articulating the execution plan and implementation management for the resilient city transformations.

5.2 Implications

First and foremost, the targeted objective of this dissertation is to develop a generic platform based ReIDMP that supports the process of planning and management for the resilient city project. The development intends to propose a practical approach in building or enhancing the capacity of resilience for the city in a systematic and reliable way. The platform was developed based on a combination of several concepts and techniques adopted from academic disciplines and industrial practices, including PM, serious gaming, risk analysis and vulnerability assessment, MCDA, and OOP. It consists of four primary phases. The functions and findings of each phase can be briefly summarized as follows:

- **Phase I - Project Planning and Management:** The first step of resilient city transformation - definition, scope, and tasks - is the most indispensable. To reach significant milestones and achieve resilience, a definition must be clearly defined; a scope must be explicitly established; and the tasks must be comprehensively designated. Overall, the example of a resilient city project plan outlined in PKS software allows the planner, stakeholders, and decision-makers to capture the procedural step of project execution in sequential order, to track the progress of tasks, and to control the ongoing development process.
Phase II – Development of Simulation City and Management of Risk and Vulnerability: This phase is divided into two parts. First is the utilization of a commercial computer simulation game under the concept of serious gaming. Second is the application of risks and vulnerability management. SimCity 2013 was selected and employed to support the process of modeling cities. Then, the simulated outputs were incorporated with a set of assumed scenarios to conduct the analysis and assessment in accordance with the selected technical manuals of risk, vulnerability, and integrated regional risk. Indeed, the experimentations of serious gaming methodology were successfully adapted to the classroom environment and have delivered the learning experiences to the students at a considerable level. Most students are applicable of grasping the basic concept of using SimCity 2013 for non-entertainment purpose and manipulating the mechanism of simulation city building. By using simulation city as the visual presentations in conjunction with the analysis and assessment manuals of risk and vulnerability, students were finally able to come up with the results as examples disclosed in Section 4.2.2.

In a real circumstance, the following step after the completion of Phase II would involve a comprehensive study of the city's problems and the identification of possible alternative or solutions. Thus, the idea of applying the NRC project as a case study in this research is to provide a holistic view of how the whole process of planning and evaluation of the execution plan for the resilient city transformations should be. In particular, this integration also to serve as a connecting point between Phase II and Phase III of this ReIDMP platform development.

Phase III - Evaluation of Alternatives Using MCDA: This phase demonstrates how to transform the set of identified alternatives into the decision problems and how those
decision components can be analyzed. In this regard, a specific part of the information in the NRS document (Resilient Strategies and Actions) was formulated as input data. Later, the decision models were implemented by using two distinct techniques in MCDA framework through two DSS tools, which are LDW (MAUT) and IDS (ER). All in all, these two MCDA techniques possess the capability to handle the decision problems that involve a large group of stakeholders. The examples of results obtained from both software reveal that they can be applied in parallel to compare the difference in alternative prioritization.

- **Phase IV - Representation of Project Complexity**: Due to the complexity and dynamic nature of city resilience, it requires a tool which can provide a holistic view at the time of planning as well as during the time of execution. The final phase of ReIDMP framework relates to the implementation of the visual presentation of management complexity for the resilient city transformation processes. The software-based OOP paradigm was adopted to introduce its ability to handle large-scale data structure and to model a vast number of objects.

The emergence of city resilience is considerably a new topic. It became a prominent term just six years ago when the 100RC project was initiated in 2013 by Rockefeller Foundation. Under this circumstance, building the city that is resilience might mean to make a concept of resilience more meaningful beyond its theoretical context. Nonetheless, making this attribute tangible and practical is still not only complicated but also challenging. The framework presented in this dissertation contributes to the existing issue by proposing a framework that would support the cities in the practical implementation of the concept of resilience. In addition to the intended functions in assisting the planning process and execution management for building a resilient city, this
ReIDMP platform can also be used as a decision analysis toolkit. The platform enables the decision makers and stakeholders to assess the current problem, identify the solutions and strategies, evaluate the alternatives, and most importantly envisage the interrelationship, interconnection, and interdependencies between entities in the city as a system.

5.3 Limitations

The use of a concept of serious gaming in commercial and industrial sectors has been widely accepted and agreed to be a promising strategy in training employee skills as well as promoting customers experiences and satisfaction. Even though this technique was proven to provide a considerable level of success in marketing practices and business management, adopting this technique in the academic field, notably higher education, to teach certain knowledge or to encourage learning experience could be difficult to some extent. By all means, choosing games that can benefit learning experiences and outcomes is quite complicated. The challenges and problems found when adopting games into the educational system are also varied.

In the development of this ReIDMP platform framework, the first part of Phase II was introduced with the application of SimCity 2013. Various versions of this simulation city building game have proven to be valuable within the formal classroom setting at both school and university levels, yet limited in pedagogical contents and features. Bereitschaft (2015) and Gaber (2007) asserted that when using SimCity for an educational purpose, particularly at the university level, the limitations and inaccuracies of the game limit its utility in understanding the complexity of urban planning processes. While professional urban planners and theorists who familiar with the required knowledge or experiences would be able to understand the underlying principle by themselves, most players without the proper training will be contextualized biases woven by the
game mechanism. This reference seems to be valid and consistent to the finding from routine observations on students' modeling progress. During the actual experimentation periods, many students still start the modeling process without laying out the road pattern or conditioning the zones even the completed basic instructions were presented in the classroom. That is to say, in order to optimize the percentage of success in utilizing SimCity 2013 under the concept of serious gaming, clear instructions and comprehensive demonstration must be provided to the students.

Besides the limitation of the pedagogical tool embedded in the game itself, the mindset condition of participants could be a concern as well. Frequently, when a serious gaming is included in the coursework as a learning tool, players (students) will try to master the game context and mechanism for experiencing the learning contents. However, non-gamers, people who have less or no digital gaming experience, will spend more time and effort to figure out how to play the game rather than exert to understand the intended learning material. Heeter, Lee, Magerko, & Medler (2011) suggested that this situation even makes it harder for them to benefit from serious games. Feeling lost or incompetent while attempting to play the game could cause negative impacts that create performance deficiencies, which in turn resulting in negative consequences for learning.

Another limitation of this research is the use of data and information of NRS document as input in Phase III. As was previously stated, the main focus of this ReIDMP platform development is to form an initiative framework of a systemic approach that supports the process of resilient city transformations. Consequently, the purpose of adopting the NRC project as a case study is to provide an example of how the decision analysis in Phase III of ReIDMP could be functional and helpful in real situations. It should be acknowledged that the current study did not take into account the aspect of subject matter experts, which could potentially contribute to a more comprehensive platform framework. Validating this type of study and finding will require a great effort from a
group of stakeholders, decision makers, and people who involved with the actual project implementation.

5.4 Future Direction

Management of risk and vulnerability is the fundamental element of building resilience. The ReIDMP platform covers this underlying implication by including those activities in the second part of Phase II. In this development, three analysis and assessment methods were performed and provided as examples. They were introduced to delineate some specific aspects of risk and vulnerability, which are prioritization of risks due to the major accidents related industries, integrated risk management in large industrial areas, and highway vulnerability for critical asset protection. However, when it comes to the development of city resilience, all possible aspects of risk and vulnerability must be taken into consideration. Additional methodologies of analysis and assessment in different areas of risk and vulnerability can be incorporated to extend the parameter of the platform. Such a study will render extra advantages in analyzing the entire community resilience as well as identifying strategies and actions to cope with risk and hazards.

Hopefully, it is believed that this initiative framework would lead to a tremendous effort by researchers and others in developing a more comprehensive resilience-building process framework or a better resilient city transformation platform in the near future.
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**APPENDICES**

**APPENDIX A: DEFINITIONS OF COMMUNITY RESILIENCE**

**MOST RECOGNIZED DEFINITION OF RESILIENCE ACCORDING TO SPECIFIC FIELDS OF STUDY**

Adapted from Community and Regional Resilience Institute (2013)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecology</td>
<td>The persistence of relationships within a system; a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist.</td>
<td>Holding (1973)</td>
</tr>
<tr>
<td>Ecology</td>
<td>Buffer capacity or the ability of a system to absorb perturbation, or the magnitude of disturbance that can be absorbed before a system changes its structure.</td>
<td>Holling, Schindler, Walker, and Roughgarden (1995)</td>
</tr>
<tr>
<td>Ecology</td>
<td>Positive adaptation in response to adversity; it is not the absence of vulnerability, not an inherent characteristic, and not static.</td>
<td>Waller (2001)</td>
</tr>
<tr>
<td>Ecology</td>
<td>The ability of a system that has undergone stress to recover and return to its original state; more precisely (i) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction and (ii) the degree to which the system is capable of self-organization.</td>
<td>Klein, Nicholls, and Thomalla (2003)</td>
</tr>
<tr>
<td>Ecology</td>
<td>The amount of change or disruption that is required to transform the maintenance of a system from one set of mutually reinforcing processes and structures to a different set of processes and structures.</td>
<td>Anderies, Janssen, and Ostrom (2004)</td>
</tr>
<tr>
<td>Ecology</td>
<td>Maintenance of natural capital (as the basis for social systems' functioning) in the long run.</td>
<td>Ott and Döring. (2004)</td>
</tr>
<tr>
<td>Ecology</td>
<td>The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks.</td>
<td>Walker, Holling, Carpenter and Kinzig (2004)</td>
</tr>
<tr>
<td>Domain</td>
<td>Definition</td>
<td>Reference</td>
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<tr>
<td>Ecology</td>
<td>The ability by an individual, group, or organization to continue its existence (or remain more or less stable) in the face of some sort of surprise. Resilience is found in systems that are highly adaptable (not locked into specific strategies) and have diverse resources.</td>
<td>Longstaff (2005)</td>
</tr>
<tr>
<td>Ecology &amp;</td>
<td>The ability of communities to withstand external shocks to their social infrastructure.</td>
<td>Adger (2000)</td>
</tr>
<tr>
<td>Society</td>
<td>The ability to persist (i.e., to absorb shocks and stresses and still maintain the functioning of society and the integrity of ecological systems) and the ability to adapt to change, unforeseen circumstances, and risks.</td>
<td>Adger (2003)</td>
</tr>
<tr>
<td>Society</td>
<td>A system's capacity to absorb and recover from the occurrence of a hazardous event; reflective of a society's ability to cope and to continue to cope in the future.</td>
<td>Timmerman (1981)</td>
</tr>
<tr>
<td>Society</td>
<td>The capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back</td>
<td>Wildavsky (1991)</td>
</tr>
<tr>
<td>Society</td>
<td>The ability to recover from or adjust easily to misfortune or sustained life stress.</td>
<td>Brown and Kulig (1996)</td>
</tr>
<tr>
<td>Society</td>
<td>The process through which mediating structures (schools, peer groups, family) and activity settings moderate the impact of oppressive systems.</td>
<td>Sonn and Fisher (1998)</td>
</tr>
<tr>
<td>Society</td>
<td>The capacity to adapt existing resources and skills to new systems and operating conditions.</td>
<td>Comfort (1999)</td>
</tr>
<tr>
<td>Society</td>
<td>The ability to withstand an extreme event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community.</td>
<td>Mileti (1999)</td>
</tr>
<tr>
<td>Society</td>
<td>The ability to respond to crises in ways that strengthen community bonds, resources, and the community's capacity to cope.</td>
<td>Chenoweth and Stehlik (2001)</td>
</tr>
<tr>
<td>Society</td>
<td>The capability to bounce back and to use physical and economic resources effectively to aid recovery following exposure to hazards.</td>
<td>Paton and Johnston (2001)</td>
</tr>
<tr>
<td>Society</td>
<td>A sustainable network of physical systems and human communities, capable of managing extreme events; during disaster, both must be able to survive and function under extreme stress.</td>
<td>Godschalk (2003)</td>
</tr>
<tr>
<td>Domain</td>
<td>Definition</td>
<td>Reference</td>
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<tr>
<td>Society</td>
<td>The ability of individuals and communities to deal with a state of continuous long-term stress; the ability to find unknown inner strengths and resources in order to cope effectively; the measure of adaptation and flexibility.</td>
<td>Ganor and Ben-Lavy (2003)</td>
</tr>
<tr>
<td>Society</td>
<td>Two types of social resilience: (1) a social system's capacity to facilitate human efforts to deduce the trends of change, reduce vulnerabilities, and facilitate adaptation; and (2) the capacity of a [social-ecological system] to sustain preferred modes of economic activity.</td>
<td>Kofinas (2003)</td>
</tr>
<tr>
<td>Society</td>
<td>Resilience consists of (1) the amount of change a system can undergo and still retain essentially the same structure, function, identity, and feedbacks on function and structure, (2) the degree to which a system is capable of self-organization (and re-organize after disturbance), and (3) the degree to which a system expresses capacity for learning and adaptation.</td>
<td>Quinlan (2003)</td>
</tr>
<tr>
<td>Society</td>
<td>A community's capacities, skills, and knowledge that allow it to participate fully in recovery from disasters.</td>
<td>Coles (2004)</td>
</tr>
<tr>
<td>Society</td>
<td>The capability of a system to maintain its function and structure in the face of internal and external change and to degrade gracefully when it must.</td>
<td>Allenby and Fink (2005)</td>
</tr>
<tr>
<td>Society</td>
<td>The return or recovery time of a social-ecological system, determined by (1) that system's capacity for renewal in a dynamic environment and (2) people's ability to learn and change (which, in turn, is partially determined by the institutional context for knowledge sharing, learning, and management, and partially by the social capital among people)</td>
<td>Gunderson (2005)</td>
</tr>
<tr>
<td>Society</td>
<td>The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure.</td>
<td>UN/ISDR (2004)</td>
</tr>
<tr>
<td>Society</td>
<td>The ability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change.</td>
<td>Community &amp; Regional Resilience Institute (2013)</td>
</tr>
</tbody>
</table>
APPENDIX B: GAMIFICATION

Seeing that some students frequently complain about traditional lecturing classroom as a boring and ineffective way of schooling while many instructors continuously seek the innovative way of teaching to motivate their students, they still admitted that existing educational lessons and instructional strategies lack incentive and engagement powers (Lee & Hammer, 2011). The use of serious games as a learning tool is one of the most promising approaches. Games can deliver not only the knowledge but also strengthen skills, such as communication, collaboration, and problem solving (Dicheva, Dichev, Agre, & Angelova, 2015). To create and utilize such that highly engaging classroom atmosphere with serious games, however, it is complicated, expensive, and time-consuming. This class implementation requires an integration of appropriate pedagogical contents and certain technical infrastructures (Kapp, 2012). Under these situations, another approach that many lecturers are now pursuing is known as gamification.

In recent years, gamification has firmly positioned itself in the commercial sector and has been rapidly adopting by various companies, firms, and enterprises to encourage employee performance, to improve corporate management, and thus far to promote marketing strategies and customer engagement especially. For instance, customers can earn stars, points, tiers, discount coupons, and any other forms of reward for visiting retail shops or shopping through online store via the mobile phone application (Lee & Hammer, 2011). This result is driven by its capability to shape and influence consumers' behavior in a desirable direction. Loyalty programs, such as credit card rewards and frequent-flyer mileage rewards are often provided as clear case studies of successful gamified mass-market products. Nonetheless, while the term is gaining ground in the business world, the potential uses of its application in an academic discipline are quiet a relatively
emerging trend (Dicheva et al., 2015). Actually, traditional schoolings already have several similarities of game elements. Students must complete and submit the assignment in order to get points, and then these points would transform later to letter grades. Students may also receive rewards for desirable behaviors or punishments for improper actions. With these grading and rewarding systems, if students perform well, they will earn an equivalent grade point average (GPA) and be promoted to the higher level at the end of every academic year. It seems that, given all these points, school is already being at the ultimate gamified experience. However, something about this environment of game-like elements fails to fascinate not all but many students. The typical classroom atmosphere often leads to schooling misconduct and undesirable outcomes, including absence, cheating, withdrawal, incomplete grade, and dropping out. Those students, at any rate, would not describe classroom-based activities in school as playful experiences. Thus, the existing game-like elements do not satisfactorily generate the power of engagement and encouragement.

Today, gamification is expanding toward and becoming more prevalent in an educational system because of its persuasive ability to inspire students and to reinforce the learning process and experience. Speaking about this technique in a scholastic term, gamification, defined by Deterding, Dixon, Khaled, and Nacke (2011), refers to the use of game design elements, including mechanics, dynamics, and frameworks in non-gaming environments. According to this definition, it is important to be aware that the fundamental concept of gamification is different from serious gaming. While serious gaming is annotated as the use of full context or end product of games for non-entertainment purposes, the gamified application is emphasized on an employment of merely game elements (Lee & Hammer, 2011). Educational gamification focuses on using or adapting game-like culture roles, player experiences, and rule systems to influence students' behavior. To
maximize the potential of gamification, albeit, it is significant to understand that how this technique can be best deployed in practice. In this case, there are three primary domains of development in which gamification can serve as an intervention, including:

- **Cognitive:** Games, as has been explained in section 1.5, provide a complex set of rules for players to explore and discover through active experimentations. They guide players through unconsciously skillful processes and keep them evolved with potentially challenging missions or difficult assignment (Koster, 2004). Games also provide multiple routes to fulfill main and sub-objectives and allow players to choose their goals to succeed complex tasks. These are precisely the benefits that games offer to support motivation and engagement (Locke & Latham, 1990). Therefore, gamification most likely, when applied to teaching, will transform students' perspective on schooling. It can help students to perform with understanding a clear purpose and true value of the tasks or works. In a case of best-designed games, the reward for accomplishing a mission or solving a problem is a harder and more complicated one (Gee, 2008). Gamification hopes to duplicate the same aspect in schools as well.

- **Emotional:** Games usually stimulate powerful emotions, ranging from curiosity to frustration to enjoyment (Lazarro, 2004). They can invoke many positive emotional experiences, such as dignity, integrity, respect, and sympathy (McGonigal, 2011). Likewise, they can also help players persist through negative sentimental encounters, like aggressiveness, egoism, and impatience and even convert into optimistic ones. Comparing these advantages to existing game-like environments in school where the stakes of failure are high, and the cycles of feedback are long, on the other hand, students frequently feel hesitant or reluctant to risk their stakes with few opportunities. No wonder that many
students experience anxiety instead of anticipation because if they try, but fail, it will cost them high stakes (Pope, 2003). Gamification is a promising strategy that offers resilient opportunities for students to face failures by reframing those failures as an essential part of schooling. It can also shorten feedback cycles, render low stakes options to determine learners' performances, and create an ambiance in which effort can be rewarded. With these intentions, students will perceive failures as learning opportunities instead of feeling fearful, hopeless, and overwhelming.

- **Social:** Games allow players to experience new identities and roles and direct them to make decisions based on their in-game positions and perspectives (Squire, 2006; Gee, 2008). Players can select characters that are less explicitly fictional in order to explore their new sides or predominant skills in the safer way of learning. For instance, a shy adolescent may become a governor who leads a dozen of mayors (other players) in regional urban planning and city development. Having a strong foundation of school-based identity helps students with schooling in the long term (Nasir & Saxe, 2003). Even if any of them feel like “they cannot do school” (Pope, 2003), gamified environments can give these helpless students an opportunity to try on the unfamiliar identities, roles, and tasks. Gamification also helps students to openly identify and confidently present themselves as scholars through gaming sessions, to put it another way, games can provide social credibility for outstanding performance and public recognition for academic achievement. In addition to recognition, it is usually provided by educators only, yet gamification can induce students to reward each other with in-game currency. Overall, a well-structured gamification environment would influence students to explore meaningful roles, which are fruitful for learning. By ensuring a playfulness of new identities development and an appropriateness of rewarding
system, educators can convince students to think differently about schooling purposes and not to underestimate their potential in school.

The integration of game-like components and conventional education can be complementary but are not always necessary (Lee & Hammer, 2011). Indeed, gamification can provide educators powerful instrument to guide and reward students, drive students to participate in classroom activities, and especially allow them to perform themselves at a full performance in the pursuit of learning. It can reveal students the trends that education in the modern era can be an enjoyable experience. The challenges, however, are critical and need to be accounted. A design procedure of gamified environment and implementation might adsorb instructors' endeavors, consume extensive resources, or even mislead students in a way that they should only try and learn when provided with rewards (Lee & Hammer, 2011). That is to say, there are significant risks that gamification and schools could either damage another or make each other worse. The results of combining gamification and school together, at any event, could turn out to be a downfall.
APPENDIX C: FACULTY INNOVATOR GRANT 2016

Faculty Innovator Grant 2016
Center for Learning and Teaching

Memorandum of Understanding

I, Dr. Adrian Gheorghe, agree to abide by the following stipulations in the event that I am awarded a Faculty Innovator Grant for 2016:

• I agree to abide by the proposal as submitted in response to the RFP. If modifications are made, written descriptions of the changes will be submitted to the Instructional Designer assigned to my project at the time they are made.

• I agree to maintain regular communication with the Instructional Designer assigned to my project.

• I agree to provide a projected budget with the RFP and a detailed financial report at the conclusion of the project.

• I agree to submit a final project report describing the project, any development activities, and analysis of the evaluation data, including a description of any modifications made or anticipated once the data has been analyzed.

• I authorize the Center for Learning and Teaching to publish the project report online. I agree to present my project as part of the Center for Learning and Teaching’s panels, workshops, and/or special events.

• I agree to comply with all Old Dominion University copyright regulations.

• I acknowledge that I have not received a Faculty Innovator Grant within the last 12 months.

Signed: ____________________________  (Grant Requestor)

Date: ________________________________

Acknowledged: ______________________  (Requestor’s Dean)

Date: ________________________________
Primary Faculty Name: Dr. Adrian V. Gheorghe
Department: Engineering Management and Systems Engineering
Email Address: agheorgh@odu.edu
Office Phone Number: 757-683-4558

Project Title: GB2L : Enhancing Engineering Education with Game Based Learning Labs (Learning by Doing BCET Initiative within the Current and Future Strategic Plan)

Brief Description
We will use SimCity—an entertainment simulation game—in our “ENMA 7/871 – Complex Systems Risk and Vulnerability Management” course to enhance the students’ learning experience. The subject matter of this course concerns large-scale infrastructure systems like energy generation and distribution or public transportation systems. For financial, pragmatic and safety reasons, it is difficult to offer students an opportunity to engage the topic in a practical way. Serious gaming offers us the possibility to interact with the material in a realistic and engaging way.

JOINT PROPOSAL: Check here and complete the “FIG Additional Faculty for Joint Proposals” form at the end of this document.

General Information about the proposed project:

<table>
<thead>
<tr>
<th>Course Delivery Type (mark one)</th>
<th>[ ] Face-to-Face</th>
<th>[ ] Broadcast</th>
<th>[ X ] Web-based (online)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course Offering (mark all that apply)</td>
<td>[ ] Fall</td>
<td>[ X ] Spring</td>
<td>[ ] Summer</td>
</tr>
<tr>
<td>Course Average Enrollment per semester (mark one)</td>
<td>[ X ] 1-25</td>
<td>[ ] 26-50</td>
<td>[ ] 51-75</td>
</tr>
<tr>
<td>Number of students potentially affected by your project annually</td>
<td>[ X ] &lt;100</td>
<td>[ ] 100-199</td>
<td>[ ] 200-299</td>
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<td></td>
<td>[ ] 300-399</td>
<td>[ ] 400-499</td>
<td>[ ] &gt;500</td>
</tr>
</tbody>
</table>
Section 1: Learning Issue

Critical Infrastructures (CIs) are large-scale networked systems that provide essential services like energy, water or transportation. CIs are becoming increasingly interdependent as they evolve, making them ever more complex. They can be widely distributed across large geographical regions. Our “ENMA 7/871” course focuses on understanding the risks and vulnerabilities that affect these systems and learning methods to mitigate such risks.

So far, we have taught this course using primarily three learning activities: lectures, assigned readings and case studies. These methods tend to emphasize discursive and declarative knowledge at the expense of functioning and practical knowledge. We have observed that such an approach does not maximize the students' engagement with the complexity of the topic.

Options such as site visits would have been good additions to our set of leaning activities. Unfortunately, in our hybrid delivery method, with students dispersed around the country, this would be nearly impossible to organize efficiently.

We propose to use of gaming technology to enhance the engagement and the practical experience of our students in Critical Infrastructure Analysis. If successful, we will expand this experiment to various other courses of the Engineering Management and Systems Engineering program (Cyber Systems Design, Supply Chain Management, Risk Management, etc.) that have similar characteristics. Ultimately, we envision the creation of a gaming laboratory for engineering management education.

Section 2: Learning Outcomes

The goal of our Game Based Learning Labs is to enhance a set of skills in our students:

- Situational awareness
- Decision making under uncertainty
- Crisis management
- Risk mitigation

We already teach frameworks pertaining to these skills, albeit only discursively. The game will complement the other learning activities with an interactive dimension that we hope will enhance practical skills and knowledge retention.

Section 3: Approach

“Serious Gaming” is becoming more and more popular. It is used by both the government and private sectors in design and training scenarios. The Delft University of Technology, a leading institution in Serious Gaming defines it as follows:

“Serious gaming involves the use of concepts and technologies derived from (computer) entertainment games for non-entertainment purposes such as for research, policy and
decision-making, training and learning. Serious gaming often combines analogue techniques (pen and paper) and social interaction with state of the art game and simulation technology (immersive 3D virtual game worlds)” (TU Delft, 2015).

Figure 1 shows how we intend to transform the course. From the current situation in which we divide the time equally between lectures on the one hand, and case study and reading assignments on the other, we will adopt a three tiered approach. Lecturing is still important because this is when we anchor theoretical notions and methodologies. We will also maintain reading assignments and case studies, because they allow the students to learn from past real life cases, with real word detail and complexity such as the Bhopal or Fukushima disasters. The innovation is to add a third dimension to the course. With gaming, although we do not have real world detail and granularity, the students can interact in real time with the systems and have some experience of managing risk and vulnerability in of critical infrastructures.

Figure 1: Course Transformation

Figure 2 provides a schematic description of the course plan. We will begin with theoretical discussions of the domain, followed by an introduction to risk management frameworks through lectures and case studies. At this point, the students have a sufficient background to solve risk and vulnerability problems in the infrastructure domain. The practice component will be provided by the game based learning lab. First, the students will learn to become proficient in the game. After that, we will ask them to replicate portions of the city of Norfolk in the game environment. After that, we will ask them to simulate a series of incidents, to apply the Rapid Risk Assessment Framework and to write a report that links theory to game practice. We will conclude the semester by debriefing the outcomes of the game to reinforce the theoretical and methodological concepts introduced earlier in the semester. In essence, we want to integrate knowledge with practice, as schematized in Figure 3.
Phase 1 (Week 1-3)
Theoretical Introduction to the Critical Infrastructures Domain:
- Lectures
- Readings

Phase 2 (Week 4-7)
Introduction to Risk, Vulnerability and Resilience
Theoretical Frameworks:
- Lectures
- Case Studies

Phase 3 (Week 8–14)
Integration of the knowledge through the game based learning lab:
- Introduction of SimCity
- Building a city with its infrastructure
- Apply the rapid risk assessment framework to the virtual city

Figure 2: New Course Organization

Figure 3: Combining Discursive and Practical Knowledge
Section 4: Evaluation Plan

In previous semesters, the learning objectives of the course were written as follows:
After successfully completing this course, the student will be able to:

- Understand the nature and significance of CIs
- Describe the risk and vulnerability characteristics of CIs
- Implement common risk and vulnerability assessment methods
- Prioritize the results from risk and vulnerability assessment based on the ALARA principle

Our learning objectives have not changed, but we expect the addition of gaming technology to enhance the quality of learning. To evaluate that the game based learning lab has been effective, we will use three main instruments:
Using the spring 2016 semester as a base case and maintaining the same final exam, we will implement:

- A qualitative survey of student learning self-assessment
- A quantitative analysis of exam scores
- A comparative analysis of all other aspects of student opinion surveys.

Section 5: Impact of project

Once this project completed and the assessment is deemed satisfactory, we will formalize the concept of game based learning lab and publish our findings in Engineering Education journals. We will also use these lessons learned to expand it to our Engineering Management curriculum when most course share the same characteristics of complexity and practicality. We will also develop a framework for assessing the usefulness of entertainment games in engineering education.

Section 6: Budget Plan

<table>
<thead>
<tr>
<th>Description of the Proposed Budget Plan:</th>
</tr>
</thead>
</table>

A latest version of simulated computer game “SimCity” is selected to use as additional learning tool in ENMA 7/871 at this time. Each copy of SimCity Complete Edition is cost $30, the number of licenses will be purchasing based on the actual number of enrollment shown in ODU Leo-Online respectively. Ideally, since the course average enrollment per semester in the past was around 20 students, it can be assumed that the maximum quantity of purchasing will be 25 copies per semester, then the rest portion of granted budget for SimCity Complete Edition will be transferring to continue the experiment in the next semester, which are Fall 2016 or Spring 2017. In addition, ENMA 7/871 was usually offering in the spring semester due to the availability of instructor, Professor Dr. Adrian V. Gheorghe (Department Chair). However, if the...
results from students have shown a sign of significant improvement in learning experiences, there will be a possibility that a course can be opened for registration in Fall 2016 to continue a project and to test the experiments.

<table>
<thead>
<tr>
<th>Itemized Proposed Budget: 1</th>
<th>Source of Funds</th>
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<tr>
<td><strong>Budget Item</strong></td>
<td><strong>Quantity</strong></td>
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<tr>
<td>SimCity Complete Edition</td>
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</tr>
<tr>
<td>Agent Based Modeling for Joint Research</td>
<td>1</td>
</tr>
<tr>
<td>TopEase 6.8*</td>
<td>50</td>
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<tr>
<td>Workshop of Norfolk Initiative “100 Resilient cities”</td>
<td>2</td>
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</tbody>
</table>

* In kind contribution from Business 4 Value Company, Zurich, Switzerland

**Section 7: Technology**

SimCity is an open-ended and simulated computer game for city building and urban planning, which originally designed and formally introduced by American video game designer named ‘Will Wright’, a co-founder of the game development company ‘Maxis’. The game was first published in 1989 as SimCity, renamed later as SimCity Classic, and then was continually spawned its first original version to several different editions later including SimCity 2000 (1994), SimCity 3000 (1999), SimCity 4 (2003), and SimCity Society (2007). Eventually, following the massive success of all five previous editions in the past two decades, SimCity 2013, a whole new design of the game, was released in March, 2013.

In the 2013 version, players have the ability to construct a settlement that can consistently grow into a city by zoning land for commercial, industrial, and residential development, as well as essential service facilities. Cities in a region will be interconnected and interdependent via predefined regional networks, such as highways, railways, and waterways. The major infrastructures, like economic, energy, transportation, and pollution systems will start flowing between cities (Electronic Arts, 2013). Moreover, cities also trade resources or share public services with their neighbors, like garbage collection or healthcare service. Cities can pool their collective wealth and resources to build a greater and larger system network, and to provide benefits for the entire region, such as a massive solar power plant or an international airport as same as a concept ‘the larger in the size of region, the higher in the number of cities and great works that can be built’ (Electronic Arts, 2013).

In term of game planning, operation, and management strategies, players will need to specialize each of their cities on certain industries, such as manufacturing, tourism, education, and others. Each of them will require distinctive appearances, simulate behavior, and economic strategies (GameInformer, 2013). Players will have either option to heavily specialize on single industry in each city or to assign multiple specializations in any given city for diversity (Electronic Arts, 2013). The game will also
feature a simulated global price and economy. For instance, prices of key resources, including coal, ore, and crude oil will fluctuate depending on the game global supply and demand (The Guardian, 2013). In particular, if players all over the world are predominantly selling particular resource on global market in the game during the same period of time, this will drive the price for that resource down. Conversely, a resource that experiences very little exposure in the world market will be considering as a scarce resource, which driving the price up.

There is no competitive element in SimCity; it is impossible to play SimCity either against another person or the computer. Second, there is no external imposition of goal structure. It is impossible to win at SimCity, unless by fulfilling self-chosen and self-defined goals. Regarding to SimCity's designer, Will Wright claimed that due to the fact that SimCity's lack of goals, it makes SimCity not a game, but just a toy (Bos, 2001).

Hence, SimCity may serves as a setting for self-defined games: build the grandest possible megacity; maximize how much your people love you; and build a city that relies solely on mass transit. This open-endedness makes it particularly adequate for the use we intend.

An Engineering Management Graduate Assistant has been provided a license over the past two semesters and has become sufficiently proficient to support our scenario building efforts.

Section 8: Post-Award Consultation and Support

We will approach CLT and distance learning to discuss the specific way in which we can embed this project in our hybrid learning environment. For example, we still need to consider the most effective way to use WebEx to monitor the progress and communicate with students in a game lab setting. We will also be interested in collaborating in sharing our findings in the form of presentations and publications in higher education forums.

Section 9: Joint Proposal

Total Number of Faculty: 2
Total Number of Graduated Assistant 1
Number of Departments involved: 1
Number of Colleges involved: 1
Faculty Innovator Grant 2016
Center for Learning and Teaching
Proposal Request Form

## ADDITIONAL FACULTY FOR JOINT PROPOSALS

<table>
<thead>
<tr>
<th>PROJECT TITLE</th>
<th>GB2L: Enhancing Engineering Education with Game Based Learning Labs</th>
</tr>
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<tbody>
<tr>
<td>PRIMARY FACULTY</td>
<td>Dr. Adrian V. Gheorghe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Faculty Name:</th>
<th>Dr. Adrian V. Gheorghe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department:</td>
<td>Engineering Management and Systems Engineering</td>
</tr>
<tr>
<td>Email Address:</td>
<td><a href="mailto:agheorgh@odu.edu">agheorgh@odu.edu</a></td>
</tr>
<tr>
<td>Office Phone Number:</td>
<td>757-683-6801</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Faculty Name:</th>
<th>Dr. Mamadou D. Seck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department:</td>
<td>Engineering Management and Systems Engineering</td>
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<tr>
<td>Email Address:</td>
<td><a href="mailto:mseck@odu.edu">mseck@odu.edu</a></td>
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<td>Office Phone Number:</td>
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<table>
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<tr>
<th>Ph.D. Student Name:</th>
<th>Jarutpong Vasuthanasub</th>
</tr>
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<tbody>
<tr>
<td>Department:</td>
<td>Engineering Management and Systems Engineering</td>
</tr>
<tr>
<td>Email Address:</td>
<td><a href="mailto:jvasutha@odu.edu">jvasutha@odu.edu</a></td>
</tr>
<tr>
<td>Office Phone Number:</td>
<td>757-683-4558</td>
</tr>
</tbody>
</table>
1. **Purpose:** State the plan’s purpose.
2. **Area Security:** Define the assets considered critical and establish priorities for their protection.
3. **Access Restrictions:** Define and establish restrictions on access and movement into critical areas. Categorize restrictions to personnel, materials, and vehicles.
   3.1. **Personnel restriction**
      3.1.1. Authority for access
      3.1.2. Criteria for access
      3.1.3. Employees
      3.1.4. Visitors
      3.1.5. Contractors
      3.1.6. Vendors
      3.1.7. Emergency responders
      3.1.8. National guard
   3.2. **Material restrictions**
      3.2.1. Requirements for admission of material and supplies
      3.2.2. Search and inspection of material for possible sabotage hazards
      3.2.3. Special controls on delivery of supplies or personal shipments in restricted areas
   3.3. **Vehicle restrictions**
      3.3.1. Policy on search of departmental and privately-owned vehicles, parking regulations, controls for entrance into restricted and administrative areas:
         ▪ Departmental vehicles
         ▪ POV's
         ▪ Emergency vehicles
         ▪ Vehicle registration
4. **Countermeasures:** Indicate the manner in which the following countermeasures will be implemented on the installation.
   4.1. **Protective barriers**
      4.1.1. Definition
      4.1.2. Clear zones
      4.1.3. Criteria
      4.1.4. Maintenance
   4.2. **Signs**
      4.2.1. Types
      4.2.2. Posting
   4.3. **Gates**
      4.3.1. Hours of operation
4.3.2. Security requirements
4.3.3. Lock security

4.4. Barrier plan

4.5. Protective Lighting System
4.5.1. Use and control
4.5.2. Inspection
4.5.3. Action taken in case of commercial power failure
4.5.4. Action taken in case of commercial failure of alternate power source

4.6. Emergency lighting system
4.6.1. Stationary
4.6.2. Portable

4.7. Intrusion Detection System
4.7.1. Security classification
4.7.2. Inspection
4.7.3. Use and monitoring
4.7.4. Action taken in case of alarm conditions
4.7.5. Maintenance
4.7.6. Alarm logs or registers
4.7.7. Tamper-proof provisions
4.7.8. Monitor-panel locations

4.8. Communications
4.8.1. Locations
4.8.2. Use
4.8.3. Tests
4.8.4. Authentication

4.9. Security personnel. General instructions that would apply to all security personnel
4.9.1. Detailed instructions such as special orders and procedural information should be attached as annexes
4.9.2. Security personnel include
  - Composition and organization
  - Length of assignment
  - Essential posts and routes
  - Weapons and equipment
  - Training
  - Method of challenging with signs and countersigns
  - Integrating with the local incident command system

5. Contingency planning: Required actions in response to various emergency situations.
5.1. Detailed plans for situations (counter terrorism, bomb threats, hostage negotiations, disaster, fire, and so forth) should be attached as annexes
5.1.1. Individual actions
5.1.2. Management actions
5.1.3. Security actions
## Key Issues in Ecological Assessment Program


<table>
<thead>
<tr>
<th>AREA I</th>
<th>AREA II</th>
<th>AREA III</th>
<th>AREA IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>What ecological resources are at risk?</td>
<td>What is the current condition of the environment?</td>
<td>To what level of pollutants that the ecosystem have exposed?</td>
<td>How do pollutant exposures affect ecosystems?</td>
</tr>
<tr>
<td>What are the characteristics of these ecosystems?</td>
<td>How is this environment changing?</td>
<td>What levels of pollution existed in the environment?</td>
<td>What structural properties of chemicals predispose ecosystems to be biologically active?</td>
</tr>
<tr>
<td>How do they react to the pollution?</td>
<td>What are the baseline characteristics that defined a normal condition of ecosystem against the measured change?</td>
<td>What biological, chemical or physical processes form or transform complex pollutants?</td>
<td>What are the best methods for predicting the effect on those ecosystems?</td>
</tr>
<tr>
<td>What are the best possible indicators and endpoints to evaluate the condition of these ecosystems?</td>
<td>How are the affected ecosystem changing?</td>
<td>How are those forms and transformations taken up in the environment?</td>
<td>How can affected be predicted in long-term, indirect, or cumulative exposures of ecosystems to pollutants?</td>
</tr>
<tr>
<td>What are the best possible methods for assessing pollutants in these ecosystems?</td>
<td>Which pollutants are the cause of deterioration to ecosystem?</td>
<td>What are the most distinctive and sensitive biomarkers of pollutant exposure?</td>
<td>How can laboratory data be extrapolated to ecosystem effects?</td>
</tr>
<tr>
<td></td>
<td>How accurately can ecosystem exposure and effect models predict reality?</td>
<td></td>
<td>How can effects seen in one species, population, or community be extrapolated to others?</td>
</tr>
</tbody>
</table>
VITA

EDUCATION

Ph.D., Engineering Management | 2019
Department of Engineering Management and Systems Engineering
Old Dominion University, Norfolk, VA

M.E.M., Engineering Management | 2011
Department of Engineering Management and Systems Engineering
Old Dominion University, Norfolk, VA

B.S., Civil Engineering | 2007
School of Civil Engineering and Technology
Sirindhorn International Institute of Technology, Pathum Thani, Thailand

RESEARCH INTERESTS

Resilient City, Critical Infrastructures, Resilient Informed Decision-Making Process, Risk and Vulnerability Management, Serious Gaming, Urban Planning Simulation Computer Game, SimCity

EXPERIENCE

Graduate Research & Teaching Assistant | 2013 – 2019
Department of Engineering Management and Systems Engineering
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Assistant Structural Engineer (Intern) | 2007
On-Site Assistant Engineer at Sansiri Prachautit – Suksawat
Sansiri Public Company Limited, Bangkok, Thailand

TEACHING

Teaching Assistant:
ENMA 670 – Cyber System Engineering
ENMA 705 – Fundamentals of Financial Engineering
ENMA 712 – Multi-Criteria Decision Analysis and Decision Support
ENMA 771 – Risk and Vulnerability Management of Complex Interdependent Systems
ENMA 795 – Topic in System Analysis

Guest Lecture:
ENMA 751 – Complex Complexity, Engineering and Management
ENMA 771 – Risk and Vulnerability Management of Complex Interdependent Systems

PUBLISHED PAPERS