Effective Scenario Composition for the Revelation of Blind Spots in Critical Infrastructure Protection Planning

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Abstract: Integral to effective critical infrastructure protection planning is the assessment of infrastructure vulnerabilities, which aims to provide planners with the insights into potential disruptions. For such a task, a set of scenarios is widely regarded in both academic and professional communities to be one of the best tools. Unfortunately, while scenarios are used extensively, they often are not used to their full potential, as scenario composition frequently occurs using a non-systematic "back-of-envelope" approach that relies *solely* on ease-based heuristics. As a consequence, planners are often subject to "blind spots" that minimize, if not exacerbate, the effectiveness of Critical Infrastructure Protection Plans. While recognizing that proper tools and technologies can play an important role in the revelation of blind spots, in this paper we focus specifically on this need for proper methodologies and frameworks to facilitate effective scenario set composition. In particular, we present our methodology for scenario set composition, we examine the role of ontological and geospatial analyses during the construction of scenario sets, and present our critical infrastructure interdependency framework to guide the planning process.

Keywords: Critical Infrastructure Protection Planning, Scenario Set Composition, Critical Infrastructure Vulnerability Assessment, Critical Infrastructure Interdependency Analyses

1 Introduction

Critical infrastructures, by definition, are those infrastructures that, if disrupted, can undermine our Nation's security, economy, public health, and/or way of life. The attacks of 9/11, the blackout in the northeast United States and southeast Canada in 2003, the hurricane damage in Florida in 2004, the hurricane damage in Louisiana and Texas in 2005, and the periodic rolling blackouts in California are recent incidents that exemplify the impacts of critical infrastructure disruptions on our Nation's well-being. While it is unlikely that many of these disruptions can be prevented, an effective practice of critical infrastructure protection planning (CIP planning, hereafter) may and should reduce their frequency, or at least minimize their impacts.

Integral to effective CIP planning is the assessment of infrastructure vulnerabilities, which aims to provide planners with the insights into these potential disruptions. These insights include, but are not limited to, knowledge of the possibility (not probability), magnitude, and likely consequences of the disruptive events. This is by no means an easy task. The U.S. government has identified thirteen (13) critical infrastructure sectors, including electrical power, telecommunications, financial, agricultural, and transportation (*National Strategy for Homeland Security*, 2002). Each of these infrastructure sectors involves multi-dimensional, highly complex collections of technologies, processes, and people. Moreover, all thirteen sectors are highly interdependent with one another. As such, disruptions within one infrastructure almost inevitably cascade and escalate across multiple infrastructures (Rinaldi, 2001). For such a task of dealing with high complexity and uncertainty, a set of scenarios is widely regarded in both academic and professional communities to be one of the best tools (Garrick, 2002).

1.1 The Role of Scenarios in CIP Planning

Unlike predictions that project critical infrastructure vulnerability with probability, a scenario set bounds the range of vulnerabilities by connecting an initiating event(s), or initial conditions, to desired and undesired end states (different levels of damage) with a sequence of events linking the two (Garrick, 2002). Functionally, a scenario set is both a *bridge that connects* the process of analysis with that of planning, and a *cognitive apparatus that stretches* people's thinking to broaden their perspectives of what is possible (Xiang and Clarke, 2003). This dual function entitles scenario sets to be a favored member in the family of instruments for CIP Planning.

Unfortunately, while scenarios are used extensively, they often are not used to their full potential, as scenario composition frequently occurs using a non-systematic "back-of-envelope" approach that relies *solely* on ease-based heuristics (Thieman, 2004). Ease-based heuristics (i.e., formulating results based on the simplest, easiest, and most apparent way) are a natural human tendency (Nisbett and Ross, 1980). The problem of ease-based heuristics is that the cognitive procedures or judgmental strategies employed with such heuristics, while simple, easy, and useful on the one hand (Nisbett and Ross, 1980), are also narrow, shallow, often biased, and sometimes misleading on the other (Bazerman, 2002; Heath *et. al.*, 1998; Nisbett and Ross, 1980; Tversky and Kahneman, 1974). It is thus ironic that while regarded by many scenarists, cognitive psychologists, and behavioral decision scientists as a proper apparatus for the mental exercises that help overcome, eliminate bias, or even repair some of the intrinsic shortcomings of human cognition (Bazerman, 2002; Heath *et al.*, 1998; Hammond *et. al.*, 1999; Heuer, 1999; Hoch, 1984; Russo and Schoemaker, 1989; Schoemaker, 1993; Tversky and Kahneman, 1974), scenarios are frequently composed under the influence of these shortcomings. As a consequence, planners are often subject to "blind spots" that minimize, if not exacerbate, the effectiveness of Critical Infrastructure Protection Plans.

1.2 Blind Spots in CIP Planning

Within CIP Planning, "blind spots" are hidden or poorly understood relationships within a single or among multiple critical infrastructures that may lead to surprises and/or multiply infrastructure disruptions in negative ways – a detailed account of blind spots is offered in Section 3. A challenge to CIP Planning and critical infrastructure vulnerability assessment is thus to reveal blind spots and minimize their negative impact on the planning process. Overcoming this challenge requires both effective methods and sound conceptual frameworks for scenario set construction. Not only should these methods and frameworks be reflective of the high-dimensionality and complexity among the critical infrastructures, but they also should include activities and leverage approaches that facilitate critical thinking.

> *Critical thinking* is a deliberate meta-cognitive (thinking about thinking) and cognitive (thinking) act whereby a person reflects on the quality of the reasoning process simultaneously while reasoning to a conclusion (Moore, 2006).

In the context of CIP Planning, critical thinking is concerned with improving the process by which planners generate plans while simultaneously improving the resulting plans.

Thus, without proper methodologies and frameworks to facilitate scenario set construction, blind spots will persist and continue to affect the planning process negatively. Furthermore, the failure of scenario sets to uncover blind spots will reduce, if not negate the very benefit of scenario sets, i.e., to bound the range of future uncertainties, alternatives, and outcomes (Xiang and Clarke, 2003).

While recognizing that proper tools and technologies can play an important role in the revelation of blind spots, in this paper we focus specifically on this need for proper methodologies and frameworks to facilitate effective scenario set composition. As such, we begin by presenting our methodology for scenario set composition. Next, we examine the role of ontological and geospatial analyses during the construction of scenario sets and present our critical infrastructure interdependency framework to guide the planning process. Third, we provide some concluding remarks and introduce our ongoing related work in tool development

2 A Methodology for Scenario Set Composition

Our methodology for scenario set composition draws from work by McNally (2005), Miller and Waller (2003), Alcamo (2001), Swartz (1991), Moore (2006), and Paul and Elder (2006). This methodology consists of six interrelated steps (see Figure 1). The methodology begins with a planning and design activity and then continues iteratively through collection and analysis, composition and synthesis, assessment and refinement, vivification, and verification and validation activities.

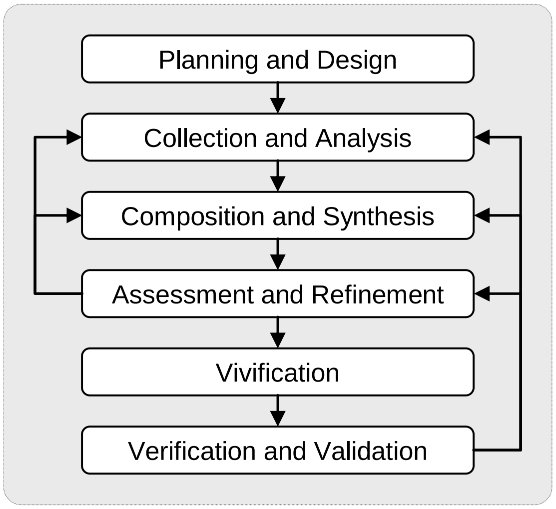

Figure 1: Scenario Set Composition Methodology

2.1 Planning and Design

The planning and design activity is a critical first step to the scenario set composition methodology. CIP Planners must have a clear understanding of the goals for the scenario set being composed.[1] Several key questions must be answered during this step. These include:

- What is the purpose of the scenario set? E.g., vulnerability assessment, training, decision support.
- What are the participating phenomena? E.g., natural, kinetic, digital.
- What is the scope of the scenario set? E.g., geospatial scope, temporal scope, infrastructure scope, single v. multiple phenomena.
- What are the objectives of the scenario set for the given purpose, phenomena, and scope.

In other words, the planner must identify the principal questions(s) to be answered through the use of the scenario set (Lee and Rine, 2004).[2] Documentation of these is essential for

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[1] These goals are similar to what Moore (2006) describes as *the purpose of critical thinking* and Paul and Elder (2006) describe as *purpose of thought*.

a properly composed scenario set. Furthermore, during this stage the planner should utilize these artifacts to assemble a plan for the remaining scenario set composition activities. The proposed methodology and the generated plans introduce increased scientific rigor to the scenario set composition process, which is critical to reduce the occurrence of blind spots.

2.2 Collection and Analysis

Information that is related to the scope of a scenario set must to be gathered and analyzed. Common informational elements of a scenario set include (Xiang and Clarke, 2003):

- The range of potential events.
- The known immediate and cumulative consequences of each event.
- The causal bonds between consequences and events.
- The time frames between the initiation of an event and its known consequences.
- The geospatial properties of the participating infrastructures.
- The anticipated, immediate, and cumulative consequences of each event.

Scenarios bound the limits of possibility by examining alternatives. The consequences of each alternative differ based on the causal links that bind events and outcomes. Using temporal measurements and place-oriented plots aid in human cognition, especially when dealing with scenarios that impact a geographical space.

Thus, planners must solicit input from multiple, diverse sources that can provide insights and perspectives about issues related to the infrastructures in question to develop a proper *picture of the known*.[3] The sources, however, should not be limited to those directly related to or affected

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[2] These questions are similar to what Moore (2006) describes as *the questions of critical thinking* and Paul and Elder (2006) describe as the *questions of thought*.

[3] This *picture of the known* contains elements that are similar to what Moore (2006) describes as *the evidence, assumptions, implications and consequences regarding the questions of critical thinking* and Paul and Elder (2006) describe as the *information, assumptions, concepts, inferences, and implications of thought.*

by the scenarios. Indirect sources, e.g., non-domain experts, the general public, and open sources are often able to provide valuable input to this context. This practice is critical to the emergence of the unexpected in scenario composition (Xiang and Clarke, 2003).

As information is collected and analyzed, the planner begins to form a *picture of the known* by assembling a compilation of the collected information. Essential to this compilation is the planner's ability to minimize the anchoring and framing effects associated with availability and adjustment heuristics (cite). Proper tools and techniques can aid in this activity.

Finally, CIP Planners identify and document factors that contain substantial variability and/or uncertainty. These factors should, then, be related appropriately to known factors, i.e., factors with little variability and/or uncertainty. To identify factors with variability and/or uncertainty, Swartz (1991) recommends looking for driving forces in societal, technological, economic, political, and environmental aspects within the scenario scope that create variability or uncertainty. This step requires imagination and out-of-the-box thinking by the analysts and the domain experts leveraged. Here again, proper tools and techniques can aid in this activity.

2.3 Composition and Synthesis

Having developed a *picture of the known* by assembling a compilation of the collected information and having identified, documented, and related factors that contain substantial variability and/or uncertainty, the CIP Planner now begins to compose and synthesize scenarios. Scenario composition involves the arrangement of selected infrastructure information into a format that reflects a new future to be considered. It is a synthesis of spatial and functional representations and relationships to create narratives of the possible futures.

While this activity is inherently iterative, the planner must identify for each scenario the initial state, the initiating events, the end state(s), and the rationale that connects the initiating events in the initial state to the end state(s) in accordance with specified assumptions. Given these characteristics, there are three basic approaches to scenario composition and synthesis: a knowledge-driven approach, a case-driven approach, and an evidence-driven (see Figure 2).

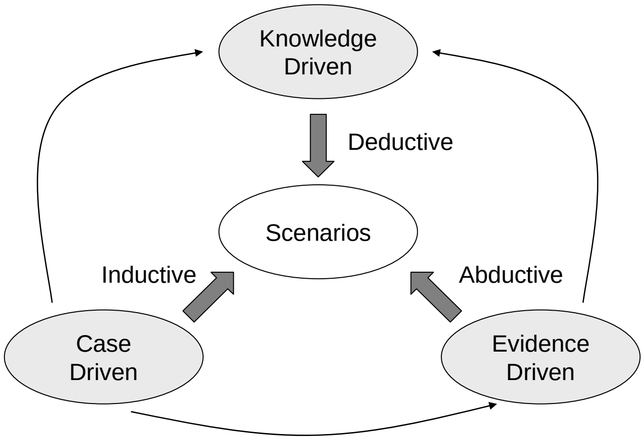

Figure 2: Approaches to Scenario Composition and Synthesis

Knowledge-driven scenario composition and synthesis is a deductive approach that utilizes the infrastructure rules and relationships that were compiled while developing the picture of the known. This approach is a top-down exploratory process whereby planners examine the emergent attributes of the infrastructures to synthesize scenarios (Van der Heijden, 1996). This process begins with planners identifying the initial state and initiating events within infrastructures of interest. The process continues with the exploration of the compiled information and associated causalities to discover possible end state(s).

Case-driven scenario composition and synthesis is an inductive approach that utilizes descriptions of past incidents to articulate the general rules and relationships that guide scenario development (Lee and Rine, 2004). With case-driven scenario composition, planners develop scenarios that *mimic* past incidents utilizing the induced rules and relationships as well as information that was compiled to develop the *picture of the known* (e.g,, the description of past infrastructure disruptions). The resulting scenarios (i.e., initial state, initiating events, end state(s) and causalities) are said to “mimic” past incidents because of the organic nature of critical infrastructures – i.e., the compiled information is an interpreted snapshot in time and likely inconsistent with actual past incidents.

Evidence-driven scenario composition and synthesis is an abductive approach that utilizes the facts (i.e., evidence) about critical infrastructures, i.e., the infrastructure information that was compiled to develop the picture of the known, to identify plausible rules and relationships that are then used to construct scenarios (i.e., initial state, initiating events, end state(s) and causalities) that describe plausible futures. The key to an abductive approach is that the CIP Planner works backwards from the facts using potentially competing rules and relationships to identify the plausible causes that are then used to construct scenarios. This is in contrast to inductive reasoning which attempts to articulate the general rules and relationships based on the facts.

Despite the differences in these approaches, each in isolation remains susceptible to "blind spots" for the CIP Planner. Exploring all three approaches, however, can help to reduce the number of blind spots. Furthermore, CIP Planners must consider a full range of initiating events, i.e., infrastructure disruptions, during composition and synthesis. To that end, we have developed a disruption type taxonomy (see Table 1) recognizing that critical infrastructures are often subject to multiple simultaneous and/or sequenced disrupting events. Together, knowledge-driven, case-driven, and evidence-driven approaches as well as our taxonomy guide the planner in a manner that helps to reduce blind spots during scenario set composition.

DISRUPTION TYPE	DESCRIPTION
Type 1	One disruption event at one location disabling one feature
Type 2	One disruption event at one location disabling multiple features
Type 3	Multiple, simultaneous disruption events of type 1 and type 2
Type 4	Multiple, temporally distributed disruption events of type 1, type 2, and type 3

Table 1: Disruption Taxonomy

2.4 Assessment and Refinement

After composition and synthesis, each of the possible scenarios should be examined for coherence or internal consistency, which is regarded by many as the necessary and sufficient criterion for plausibility (Tversky and Kahnerman, 1974; Vlek, 1984). Several questions should be asked in order to evaluate and further refine the scenarios: Do the envisioned futures follow logically from what is known? Are the causations identified and properly incorporated? Given the initial state and key uncertainties, are the envisioned futures plausible? Answers to these questions will eliminate some envisioned scenarios and lead to the revision of others.

A good scenario set should be cognitively ergonomic, i.e., it should present scenarios in an efficient and precise manner in order not to overwhelm the planner (Xiang and Clarke, 2003). Themes may be used to introduce greater coherence among the scenarios within a scenario set. Single themed scenario sets incrementally change along a single thematic dimension while multi-themed scenario sets contain a unique thematic dimension for each scenario. Critical infrastructures possess multiple interrelated elements that may be analyzed through a number of thematic scenarios sets.

Scenario set size is also an issue to be considered at this point. While scenario sets may vary in the number of participating scenarios, generally two to seven scenarios is considered appropriate since this range is within the human cognitive limits of the “magic” number seven, plus or minus two (Miller, 1956). If a scenario set exceeds this range, then the set should be examined for potential decomposition. If, on the other hand, a scenario set is too small, then it is possible that the scenario set will be ineffective in stretching the planner’s thinking.

2.5 Vivification

Vivid scenario set presentation is instrumental to the efficacy a scenario set. Cognitive psychology indicates that people have a natural tendency to assign inferential weight to information in proportion to the vividness of the information (Nisbett and Ross, 1980). Thus, vivid information has a greater impact on human inferences than pallid information because vivid information is more accessible and more likely to attract and maintain attention while exciting the imagination.

A good scenario set therefore should leverage vivid information during composition and synthesis whenever possible. The following factors can be used to assess information vividness within a scenario set (Nisbett and Ross, 1980; Xiang and Clarke, 2003).

- Is the scenario set emotionally interesting?
- Is the scenario set image provoking?
- Does the scenario set incite one's sense?
- How spatially and temporally proximate is the scenario set to the anticipated users?

These factors indicate that a scenario set ultimately must be tangible and relevant, i.e., an imaginable occurrence in the eyes of the planner. When these factors are effectively met, scenarios become more memorable; and Lingren and Bandhold (2003) indicate that memorable scenarios have a greater utility.

To meet these factors more effectively, creative titles may be employed, compelling narratives may be written, and appropriate visualization techniques, including animation, may be used. In fact, since scenarios are depictions of future worlds, one may even choose appropriately to present scenarios in the style of the science fiction genre (Idier, 2000).

Ultimately, however, scenario set vivification requires planners to pay close attention to their intended audience as some members may be more or less technical than others. Vivid scenarios may be particularly useful for the non-technical members. Moreover, proper tools and techniques can help planners develop more vivid scenario sets. Figure 3 provides an illustration of two scenario visualizations that we have developed and employed as a part of our combined methodology and tool development research in support of CIP planning.

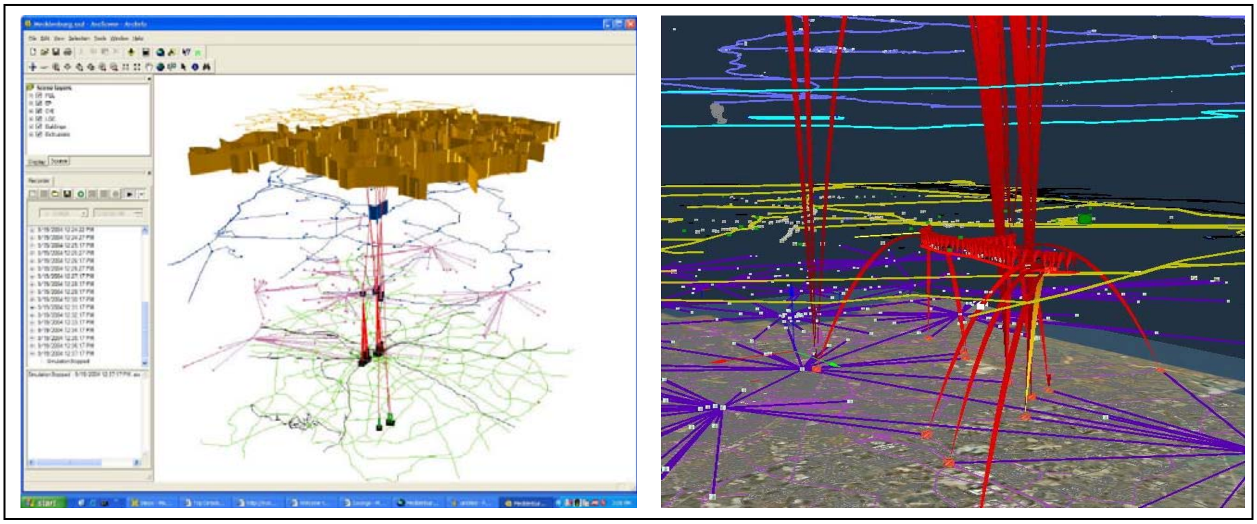

Figure 3: Scenario Set Vivification

2.6 Verification and Validation

Scenario set verification is the process of determining whether the resulting scenarios are an accurate representation of the planner's conceptual *picture of the known* (Kleijnen, 1995; Williams and Sikora, 1991). This determination assesses the internal consistency, reliability and usefulness of the scenario set according to the intended use or goals of the set. (Benbasat and Dhaliwal, 1989). *Scenario set validation*, on the other hand, is the process of determining whether the resulting scenarios are consistent with the "real world" given the intended use or goals of the scenario set (Benbasat and Dhaliwal, 1989).

Verification and validation methodologies are widely used in the applied sciences and computer technology communities. These methodologies were originally designed to verify and validate models whose characteristics allowed for experimental scientific testing.

Experimental validation methodologies traditionally follow an iterative, four-step process (Fraedrich and Goldberg, 2000). We discuss this process in the context of scenario composition. Experimental validation methodologies begin with *a priori* tests. These tests, without the use of empirical data, examine a scenario set to determine if it faithfully represents the conceptual *picture of the known*. The second step involves designing and executing real-world experiments. The objectives of this step are twofold: to assess the accuracy of scenario outcomes against real-world (i.e., measured) outcomes; and to conduct a sufficient number and range of experiments so that scenario set shortcomings are uncovered. The third step involves a comprehensive assessment of measured and predictive outcomes to determine the “goodness of fit” of the scenario set. The fourth (optional) step is to develop enhancements to the scenario set that address significant shortcomings by returning to previous scenario composition steps as shown in Figure 1. As mentioned, this process is iterative and, thus, continues to repeat as needed.

However, to employ experimental validation methodologies four prerequisites must hold (Fraedrich and Goldberg, 2000; Hodges and Dewar, 1992).

1. The real-world situation must be observable and measurable
2. The real-world situation must exhibit constancy of structure in time
3. The real-world situation must exhibit constancy across variations in conditions not specified in the model
4. The real-world situation must permit the collection of ample data.

Unfortunately, the very nature of critical infrastructures, both in their structure and operation, raises significant doubt as to whether these prerequisites can be met for experimental validation of scenario set. The complexity, magnitude, and scope of multi-infrastructure events make real-worlds situations difficult to observe and measure with the necessary completeness. The difficulty of gaining access to these data and situations outside the United States is a well-known intelligence problem. Inside the United States, much of the Nation’s critical infrastructures are owned and operated by the private sector. As such, the data and situations that are observable and measurable are proprietary and sensitive. Furthermore, with the exception of places like the National SCADA Test-bed at the Idaho National Engineering and Environmental Laboratory, conducting experiments to collect measured outcomes is infeasible. Moreover, the issues of constancy expressed in these prerequisites are not satisfied due to the human and organizational processes that interweave the operation of critical infrastructures.

Thus, when experimental validation methodologies for scenario set validation are inappropriate, evaluative methods are required (Weeks, 2006). Evaluative validation methods differ from experimental validation method in that they are not trying to predict the future, but rather to bound the set of “plausible” outcomes as well as to expose the relationships and bases that lead to those outcomes. Key aspects of evaluative validation methods include (Williams and Sikora, 1991):

- Documentation – This aspect focuses on exposing the scenario set by providing details on structure, assumptions, and validation outcomes.
- Logical Verification – This aspect examines the appropriateness of the scenario set in the context of its use.
- Code Verification – This aspect ensures proper tool implementation in support of scenario sets.
- Face Validation – This aspect: (a) is performed by people who are knowledgeable (e.g., Subject Matter Experts); (b) involves a determination of scenario set accuracy by reviewers; (c) is subject to the biases and knowledge of the reviewers.

Although different than experimental validation outcomes, evaluative validation outcomes remain substantive as their focus is on plausibility, not predictability. They are particularly substantive for the scenario composition as scenarios embrace the notion of transparency and lay bare the rationale (e.g., the causalities) that leads to scenario outcomes. Such transparency strengthens the evaluative validation outcomes (Weeks, 2006).

2.7 Methodology Summary

In summary, a methodological approach to scenario set composition is essential to the development of scenario sets that effectively undercover blind spots in CIP Planning. Nevertheless, a proper methodology is not sufficient as such a method only addresses the "how" question of scenario set construction. CIP Planners also require guidance to address the "what" question of scenario set construction. In the following section, we examine this latter question in greater detail.

3 A Functional and Spatial Framework for Scenario Set Composition

The methodology presented in the previous section provides a systematic and comprehensive approach to scenario set construction. It prescribes "how" to construct scenarios so as to increase the validity and efficacy of the resulting scenarios. In this section, we examine the issue of "what" scenarios to construct in order to reduce some of the intrinsic shortcomings associated with of the ease-based heuristics and increase the potential to uncover blind spots. For this purpose, we have developed a framework that examines critical infrastructure interdependencies (both intra-infrastructure dependencies and cross-infrastructure dependencies) simultaneously along functional and spatial dimensions.

A *functional dependency* is a bond between two critical infrastructure features where one feature depends on the other feature in order to operate properly. Functional dependencies can be unidirectional or bidirectional. For example, roads depend on traffic lights to control automotive flow properly at intersections. Traffic lights, however, do not depend on roads to operate properly. Consequently, the functional dependency between roads and traffic lights is unidirectional from roads to traffic lights. As another example, telecommunications require electric power to operate properly. At the same time electric power companies uses telemetry to monitor their operational equipment. As such, the functional dependency between the telecommunications and electric power infrastructures is bidirectional.

To confound matters, during a catastrophic event, some unidirectional dependencies may become bidirectional. For example, as previously described traffic lights typically depend on electric power to operate properly while electric power does not typically depend on traffic lights to operate properly. Yet, when electric power distribution is disrupted, e.g., due to a fallen power line, electric power restoration could be delayed due to inoperable traffic lights. These examples illustrate that some functional dependencies are direct while others indirect. Indirect dependencies are those that are related through a mediating object(s), e.g., a repair crew.

A *spatial proximity* is the observed spatial proximity between two infrastructure features. As physical objects, infrastructure features are spatially tangible and, as such, are often spatially proximal to one another. This spatial proximity may be influenced by several factors. First, a spatial proximity may reflect the necessary technological requirements of a critical infrastructure to deliver a service or commodity. As such, a spatial proximity may emerge due to the functional dependencies between and among infrastructure features. For example, some infrastructure features may exhibit a high spatial proximity due to a direct functional dependency. Networked infrastructure features, however, may exhibit low spatial proximity in order to ensure adequate service area coverage, e.g., substations typically exhibit low spatial proximity as they are dispersed to provide adequate electric power to service region. In such situations, the functional dependency that influences the spatial proximity is often an indirect dependency. Second, there are situations where spatial proximity is determined by other factors such as: land use, land availability, zoning, NIMBY (not-in-my-back-yard) constraints, or defined physical barriers such as mountains, oceans, rivers, lakes, and other terrain features.

Our framework combines functional dependencies with spatial proximity to organize the domain of CI interdependencies. Table 2 depicts this framework in matrix form. The resulting quadrants provide additional insight into the types of critical infrastructures interdependencies that must be considered during scenario set composition in support of CIP Planning.

		FUNCTIONAL INTERDEPENDENCIES	
		Direct	**Indirect**
SPATIAL PROXIMITY	High	**<u>Examples</u>** Substations and regulators Tandem offices and toll centers Regulators and pipelines ***Quadrant A***	**<u>Examples</u>** Gas pipelines and high power lines MTSOs and toll centers Roads and substations ***Quadrant B***
	Low	**<u>Examples</u>** Central office and Central office Towers and MTSOs Power plant and substations ***Quadrant D***	**<u>Examples</u>** Power plants and central offices Power plants and regulators Roads and high power lines ***Quadrant C***

Table 2: A Functional and Spatial Framework for Critical Infrastructure Interdependencies

3.1 Quadrant A: Direct Functional Dependency with High Spatial Proximity

Critical infrastructure interdependencies in quadrant A exhibit a direct functional dependency with high spatial proximity. This follows closely with Tobler's *First Law of Geography* which states that proximal objects are more likely to be functionally related than distant objects (Tobler, 1970). For example, a long distance telephone toll center and a local telephone central office are often housed in a same building (i.e., a tandem office) because of their direct functional dependencies. Similarly, mobile telephone switching offices (MTSOs) are often proximal to a telephone central office as this is necessary for call completions. This quadrant of our framework has been, and will continue to be, a central focus of CIP Planning due to the high vulnerability of these relationships.

3.2 Quadrant B: Indirect Functional Dependency with High Spatial Proximity

Critical infrastructure interdependencies in quadrant B exhibit an indirect functional dependency with high spatial proximity. For example, major natural gas pipelines and power transmission lines often share the same right-of-way easements due to cost sharing, zoning regulations, and/or NIMBY constraints. Along with this close proximity comes a high degree of vulnerability because a single event could simultaneously disrupt multiple critical infrastructures. The consequences of such events are then multiplied due to the relationships of quadrant A. However, owing largely to industry boundaries (e.g., natural gas distribution industry v. electric power industry) and to indirect functional dependencies, critical infrastructure interdependencies in this quadrant usually receive insufficient attention during planning activities (McNally, 2005; Thieman, 2004) resulting in blind spots for the CIP Planner.

3.3 Quadrant C: Indirect Functional Dependency with Low Spatial Proximity

Critical infrastructure interdependencies in quadrant C exhibit an indirect functional dependency with low spatial proximity. Such relationships emerge when there are mediating objects between the critical infrastructure features and when there are no correlating spatial factors, such as easements, that bond the features together. For example, power generation facilities produce electricity that flows through several mediating objects before powering a telephone office. At the same time, there is low spatial proximity between the location of the power generation facility and the telephone office. Nevertheless, the indirect functional dependency and the low spatial proximity do not suggest that this interdependency should be ignored during CIP

Planning. In fact, there are many incidents in which major catastrophic events were triggered by a failure in the seemly trivial critical infrastructure interdependency of this kind. For example, according to the U.S-Canada Power System Outage Task Force (2004), a tree limb coming into contact with an overloaded, and thus sagging, transmission line in Ohio was a critical, though seemly minor event the August 2003 electric power blackout in the northeast United States and southeast Canada. At the same time, this event also impacted telecommunication service that was not spatially correlated with the transmission line due to the indirect functional dependency. Unfortunately, critical infrastructure interdependencies in this quadrant are usually overlooked in the practice of CIP Planning resulting in further blind spots for the planner.

3.4 Quadrant D: Direct Functional Dependency with Low Spatial Proximity

Critical infrastructure interdependencies in quadrant D exhibit a direct functional dependency with low spatial proximity. These interdependencies are often found within networked features of a single critical infrastructure, i.e., these interdependencies are often intra-infrastructure interdependencies. As each critical infrastructure provider is vested in the continuous operation of its infrastructure, these interdependencies are normally well-studied by the provider. Consequently, such measures as contingency plans and crisis response protocols are already established based on analyses derived from these interdependencies. However, the segmented nature of critical infrastructures and their supporting industries often present a barrier to analyses that extend beyond the interdependencies of this quadrant. As a result, a provider’s contingency plans and response protocols frequently do not account for vulnerabilities that are present due to interdependencies between critical infrastructures.

3.5 Framework Summary

Collectively, these four quadrants provide CIP Planners with a framework that can systematically guide scenario set composition by exposing to the CIP Planner the full range of spatial and functional relationships that influence critical infrastructure disruptions.

4 Conclusions

In this paper, we present our methodology as well as our functional and spatial framework for scenario set composition. Our methodology begins with a planning and design activity and then continues iteratively through collection and analysis, composition and synthesis, assessment and refinement, vivification, and verification and validation activities. Collectively, these activities provide a systematic approach to address the “how” question of scenario set composition. Our framework, on the other hand, combines functional dependencies with spatial proximity to organize the domain of CI interdependencies in a manner provide additional insight into the types of critical infrastructures interdependencies that must be considered during scenario set composition in support of CIP Planning. As such, this framework begins to address the “what” question of scenario set composition.

We have applied our methodology and leveraged our framework to develop several scenario sets that were then reviewed and validated by an advisory board composed of utility company representatives (McNally, 2005). In addition, to facilitate these activities, we have actively pursued the design and development of tools and technologies to support the revelation of blind spots during scenario set composition (Tolone et. al., 2004; McNally et. al., 2006). While we have modeled our framework within our tools and have applied our tools to support all steps of our composition methodology, the tools can be particularly useful to model and organize the picture of the known during collection and analysis, to explore knowledge, case, and evidence-driven approaches during composition and synthesis, to assess and refine candidate scenarios, and vivify the scenario set in preparation of verification and validation. Collectively, the scenario sets that emerge from our methodology reveal to the CIP Planner blind spots that if undiscovered can negatively impact CIP vulnerability assessment and planning.

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