Modeling and assessing capability-based planning for emergency preparedness

by

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

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ABSTRACT

Recent disasters such as Hurricanes Harvey, Irma, and Maria have demonstrated the importance of preparing for large-scale emergencies and how an effective response can save lives. The Capability-Based Planning (CBP) framework, which consists of 32 core capabilities across five mission areas is a popular planning framework to help local, regional, state, and federal emergency management agencies plan for disasters. For state and local agencies, it is critical to effectively allocate funds to improve and sustain these capabilities. When allocating resources for emergency preparedness, it is important to understand the comprehensive systemic impact that improving or not sustaining a capability has on an organization's ability to prepare and respond to emergencies. We develop methods and decision-support tools to identify and quantify the interdependencies among the 32 core capabilities in the CBP framework and how these interdependencies affect an organization's ability to respond to disaster scenarios. We model these interdependencies and their influence on an organization's ability to respond to disaster scenarios with Bayesian belief networks. This model is applied to the Iowa Department of Homeland Security and Emergency Management's CBP framework to generate insights into the current state of Iowa's emergency preparedness and response and demonstrate different types of analyses that can be conducted. This research can help emergency management organizations at every level analyze the comprehensive and systemic impacts of sustaining and improving capabilities and the organization's ability to respond to disaster scenarios.

CHAPTER 1. INTRODUCTION

Recent disasters such as Hurricanes Harvey, Irma, and Maria have demonstrated the importance of preparing for large-scale emergencies and how an effective response can save lives. Preparing for natural disasters and other emergencies can be very challenging because each emergency is different, significant uncertainty exists with emergencies, and emergencies or disasters that have hardly been identified can suddenly spring up and surprise emergency managers. An alternative to preparing for specific emergencies or scenarios is to focus on building capabilities in emergency preparedness and response that can be used for a wide variety of scenarios. Capability-Based Planning (CBP) framework is a popular planning structure for identifying and allocating funding to build necessary capabilities (Caudle, 2005; Davis, 2002; DHS, 2015). CBP in emergency management is designed to increase the nation's preparedness for disasters at the local, regional, state, and federal level. As depicted in Figure 1, the Department of Homeland Security (DHS) through the Federal Emergency Management Agency (FEMA) has identified 32 core capabilities for emergency preparedness that are categorized across five mission areas: Prevention, Protection, Mitigation, Response, and Recovery. Three capabilities span across all five mission areas: Planning, Operational Coordination, and Public Information and Warning. These three capabilities are considered essential for the success of the other capabilities (DHS, 2015).

<table>
<tr><th>Prevention</th><th>Protection</th><th>Mitigation</th><th>Response</th><th>Recovery</th></tr>
<tr><td colspan="5">Planning</td></tr>
<tr><td colspan="5">Operational Coordination</td></tr>
<tr><td colspan="5">Public Information and Warning</td></tr>
<tr><td colspan="2">Intelligence and Information Sharing</td><td>Community Resilience</td><td colspan="2">Infrastructure Systems</td></tr>
<tr><td colspan="2">Interdiction and Disruption</td><td>Long-Term Vulnerability Reduction</td><td>Critical Transportation</td><td>Economic Recovery</td></tr>
<tr><td colspan="2">Screening, Searching, and Detection</td><td>Risk and Disaster Resilience Assessment</td><td>Environmental Response/Health and Safety</td><td>Health and Social Services</td></tr>
<tr><td>Forenesics and Attribution</td><td>Access Control and Identity Verification</td><td>Threats and Hazards Identification</td><td>Fatality Management Services</td><td>Housing</td></tr>
<tr><td></td><td>Cybersecurity</td><td></td><td>Fire Management and Supression</td><td>Natural and Cultural Resources</td></tr>
<tr><td></td><td>Physical Protective Measures</td><td></td><td>Logistics and Supply Chain Management</td><td></td></tr>
<tr><td></td><td>Risk Management for Protective Programs and Activities</td><td></td><td>Mass Care Services</td><td></td></tr>
<tr><td></td><td>Supply Chain integrity and Security</td><td></td><td>Mass Search and Rescue Operations</td><td></td></tr>
<tr><td></td><td></td><td></td><td>On-Scene Security, Protection, and Law Enforcement</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Operational Communications</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Public health, Healthcare, and Emergency Medical Services</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Situational Assessment</td><td></td></tr>
</table>

Figure 1: Core Capabilities for Emergency Preparedness Categorized by Mission Area: Each of the 32 core capabilities are listed under the mission area(s) they belong to

CBP plays an important role in allocating funds for homeland security and emergency preparedness in the United States. DHS announced the dedication of $1.6 billion to eight preparedness grant programs for state and local agencies in 2022 (DHS, 2022). States are required to use CBP to identify resources, training, and activities when requesting and applying for funds from the federal government. Effectively allocating resources and spending money wisely on disaster preparedness requires the ability to identify the most critical capabilities, to understand which capabilities need additional funding for improvement or sustainment, and to analyze how capabilities will help an organization be better prepared for emergencies. A comprehensive understanding of the systemic impact of improving or failing to sustain one or more capabilities can help a state better determine how to allocate resources and identify the type of training, equipment, and personnel needed for successful disaster preparedness. A quantitative model for CBP can provide this comprehensive and systematic understanding of a state's capabilities.

DHS emphasizes using disaster scenarios to identify measurable targets for each core capability and assess the gaps between the current capabilities and their targets. Although state and local governments use these processes to identify areas for improvement, CBP rarely considers the interdependencies that exist among capabilities and fail to connect the improvement of capabilities to performance. Allocating resources to improve one capability may also improve other capabilities and should help an organization reduce the impacts from the threats and hazards. Modeling and analyzing the interdependencies among capabilities and their connection to the standardized impacts will help DHS and state governments understand the broader effects of improving a capability or allowing a capability to degrade. No system, model, or assessment process exists either in practice or in the academic literature that considers the interactions of capabilities or measures how well those capabilities achieve the objectives in emergency preparedness.

The motivation of this research is to analyze capabilities for emergency preparedness and provide a decision-support tool to enable state governments to identify how to improve their emergency preparedness. We create a model to quantify the interdependencies between capabilities and quantify how these interdependent capabilities affect a state's ability to respond to disaster scenarios. The interdependencies will be modeled through a Bayesian belief network (BBN). BBNs are a popular method to model interdependencies within a system. BBNs are directed acyclic graphs where arcs between nodes represent a probabilistic dependency (Zhang et al, 2019). A BBN is used to connect capabilities and provide a visual representation of the interdependencies between capabilities. This research elicits conditional probabilities from subject matter experts to quantify the interdependencies within the BBN. The BBN is connected to disaster scenarios to translate the impacts of improving or degrading a capability to disaster relevant metrics. The BBN for CBP enables organizations to analyze the effects of improving or not sustaining one or more capabilities on other capabilities and their organization's ability to respond to different disaster scenarios.

This research is unique because it represents the first model and decision-support tool to help organizations understand the broader effects and systematic impact of improving or sustaining one or more capabilities. Our research is the first attempt to explore and model interdependencies between capabilities and their impact on disaster scenarios. The subject matter expert elicitation method advances elicitation methodologies, as it builds on a commonly used method to reduce the number of probabilistic assessments. This research uniquely applies a BBN to assess the impact of interdependencies within CBP and relates those capabilities to organization's ability to respond to disaster scenarios.

This thesis presents the necessary methods to derive the interdependencies between capabilities, propagate the BBN with probabilities elicited from subject matter experts, and connect the CBP BBN to disaster scenarios' standardized impacts. Chapter 2 will explore relevant literature for CBP, BBN, and eliciting conditional probabilities from experts. Chapter 3 will provide the necessary methods to build and quantify these models. In. Chapter 4, the derived methods are applied to the Iowa Department of Homeland Security and Emergency Management's (HSEMD) CBP framework to provide insights on the current state of Iowa's capabilities and analyze how the BBN can inform decisions about capabilities. Chapter 5 will provide conclusions and possible areas for future research.

CHAPTER 2. LITERATURE REVIEW

CBP is a framework for government planning. The framework creates a comprehensive view of the current system and projects the system into the future (Neaga et al, 2009). CBP enables planners to identify and measure capabilities necessary to accomplish a task or challenge while considering uncertainty in future scenarios. CBP was initially introduced within the U.S. Department of Defense and other militaries to assist with complex defense acquisition projects (Davis, 2002). A defense capability can be defined as “the enduring ability to generate a desired operational outcome or effect, and its relative threat, physical environment, and the contributions of coalition partners” (UKMOD, 2009). CBP begins by developing specific scenarios. Analysts identify capabilities that are needed to address each scenario (Davis, 2002). The organization focuses on what resources, equipment, and training are needed to build these capabilities rather than on preparing for specific scenarios or threats. In this way, CBP increases an organization’s flexibility and helps an organization build a wide range of capabilities to respond effectively in many different situations. CBP requires military analysts to link mission objectives with high-level requirements (Kerr et al, 2008; Touchin and Dickerson, 2008; Chim et al, 2010; Yue and Henshaw, 2009). CBP in the military may generate detailed scenarios that are too specific and do not consider uncertainty. The types of tools used to analyze these scenarios and generate capability may not be diverse enough to conduct analysis at a mission or campaign level (Davis, 2016). CBP has migrated to engineering through the notion of capability engineering in which designers focus on new systems and platforms that can achieve military capabilities (Neaga et al, 2009, Pagotto and Walker, 2004).

DHS began implementing CBP soon after its formation in 2003 (Caudle, 2005). The DHS CBP framework is designed to allow organizations at every level (local, regional, state, and federal) contribute to emergency preparedness in the United States (DHS, 2015). States are required to use CBP as part of the process to obtain grants from FEMA for emergency preparedness. This process is captured in the Threat and Hazard Identification Risk Assessment (THIRA) and Stakeholder Preparedness Review (SPR) (DHS, 2018). The THIRA process identifies potential threats and hazards and establishes targets for each capability. The goal of the THIRA is to help communities understand their risks and identify necessary capabilities to mitigate those risks. Analysts determine the impacts of each threat and hazard according to 34 standardized impacts such as the number of Miles of Road Affected and the number of Businesses Closed Due to the Incident. These standardized impacts are used to create capability targets. Capability targets consist of a task, a timeframe, and an impact. For example, under the core capability Critical Transportation, the capability target language for debris removal is "Within (#) (time) of an incident, clear (#) miles of road affected, to enable access for emergency responders, including private and non-profit" (HSEMD, 2021). After the THIRA, the SPR process assesses gaps in capabilities based on the capability target and the current capability level and determines how additional resources can be used to close those capability gaps (HSEMD, 2021).

An ancillary analysis for CBP is conducted with Emergency Support Functions (ESFs). ESFs are a part FEMA's National Response Framework, which is a guide for how the United States should respond to catastrophes. ESFs coordinate the federal government's interagency response for a federal emergency. There are 15 total ESFs, and each ESF has a set of associated capabilities (FEMA, 2021). When analyzing the CBP framework, states like Iowa use the Planning, Training, and Exercise (PTE) Strategy Plan. The PTE Strategy Plan provides structure for analyzing groups of ESFs and the associated capabilities in the ESFs. For Iowa HSEMD, each year a group of three or four ESFs are chosen, and Iowa HSEMD coordinators analyze the capabilities associated with each of those ESFS (HSEMD, 2023).

As mentioned in Chapter 1, we use a BBN to assess and quantify the interdependencies among the core capabilities in emergency preparedness. A BBN is a common method to model interdependencies within a system. BBNs are directed acyclic graphs where edges or arcs between nodes represent a probabilistic dependency. An arc points from a parent node to a child node, and the probability of the child node's states depends on the state of all the parent nodes (Zhang et al, 2019). The main benefits of BBNs are their ability to model causal relationships, incorporate information from many different sources like subject matter experts, and derive multiple types of probabilistic assessments from one network (Rohmer, 2020). BBNs are increasingly a popular tool to model risks and decisions under uncertainty and complex systems (De Luliis et al., 2021). BBNs have been used to model critical infrastructure risks such as interdependencies among critical infrastructure (Buxton et al., 2010; Jha, 2012), the restoration of electric power and telecommunications services after an earthquake (De Luliis et al, 2021), inland waterway port disruptions (Hossain et al, 2020; Hosseini and Barker, 2016), and the resilience of the electric power system (Hossain et al., 2019). BBNs have been applied to different hazards including floods (Sen et al., 2021; Sun et al. 2023), earthquakes (Cockburn and Tesfamariam, 2012; De Luliis et al., 2021), hurricanes (Haraguchi and Kim, 2016), fires (Wu et al., 2018), and supply chain failures (Lockamy, 2014; Sakib et al, 2021). To our knowledge, BBNs have not been used to model and assess interdependent capabilities for emergency preparedness and response.

When data is not available, subject matter expert elicitation can be used to propagate the conditional probabilities in the BBN (Stallard et al, 2018; Renooij, 2001). There are many different elicitation methods for Bayesian belief network, and there is typically a distinction between direct and indirect methods. Direct methods look to elicit probabilities or similar measurements from the experts. Indirect methods try to elicit a degree of belief and frame the elicitation as a decision for the subject matter expert. Indirect methods typically use a visual aid like a probability wheel or a scale for tying probabilistic words to certain probabilities. These methods can be easier for people because they allow an individual to more easily convey uncertainty. However, these indirect methods are often time consuming especially with a large network (Renooij, 2001).

There have been efforts to shorten the time commitment and difficulty of BBN elicitations. A popular method is Cain's method, which works well for Bayesian belief networks where all the nodes have two states. Cain's method interpolates the entire conditional probability table (CPT) from a small subset of probabilistic assessments (Cain, 2001). The Noisy-OR method utilizes the independent causal relationships of Boolean parent and child nodes in a network (Pearl, 1986). The Leaky-OR method allows for a non-zero probability of the child node's positive state when all the parent nodes are in their negative states (Henrion, 1988). The EBBN method utilizes probabilistic assessments, influence factors, and weights for parent nodes to derive piecewise linear functions which are used to interpolate the rest of the CPT (Wisse, 2008).

Other elicitation methods do not require any probabilistic assessments. Hassall's method uses points and a ranking system to derive the conditional probabilities of Boolean nodes (Hassall, 2019). The InterBeta method utilizes interpolation techniques but elicits the necessary parameters as beta distribution parameters (Mascaro & Woodberry, 2022). Many different approaches for eliciting conditional probabilities from subject matter experts still involve a considerable number of conditional probabilities, time consuming processes, nonconventional quantitative measures, or low fidelity in terms of the CPT construction.

CHAPTER 3. METHODOLOGY

In this chapter, the methods we developed and used throughout this thesis are described. Chapter 3.1 describes how we developed heuristic to determine the interdependencies between capabilities using strategic planning documents. Chapter 3.2 works through Cain's method (Cain, 2001) and how we built off the method to reduce the number of probabilistic assessments. Chapter 3.3 describes how we combined the standardized impacts from disaster scenarios with the developed CBP BBN. These methods and the developed models can be utilized by organizations at every level (Federal, State, or Local) who are using CBP for emergency preparedness; however, we worked closely with Iowa HSEMD to design this model, and the identified interdependencies apply to the state of Iowa.

3.1 Assessing Interdependencies Between Capabilities

This thesis models the interdependence of the 32 core capabilities for emergency preparedness through a BBN. The BBN depicts each of the 32 capabilities as a node, and arrows may connect two capabilities. A connection between two capabilities signifies that the improvement or degradation of a capability will generate an improvement or degradation in the other capability. Since the 32 core capabilities in CBP have largely been considered independent, there is no existing method to identify interdependencies between capabilities. To determine between interdependencies capabilities, we create several heuristics to derive interdependencies using HSEMD reports. The three main Iowa emergency planning documents we use to develop the BBN: 2020 Core Capabilities Assessment, Iowa's 2021 Stakeholder Preparedness Review (SPR), and the Planning Training and Exercise (PTE) Strategy Plan Submission.

The 2020 Core Capabilities Assessment provides an evaluation for each of the 32 core capabilities from Iowa's perspective (HSEMD, 2020). The 2021 SPR is Iowa's completed SPR report, which describes the capabilities' targets and gaps (HSEMD, 2021). The PTE Strategy Plan provides the ESF groups that Iowa plans to analyze for the upcoming year. (HSEMD, 2023).

3.1.1 Utilization of PTE Strategy Plan Submission

The PTE Strategy Plan provides a five-year plan to improve ESFs. Table 1 shows the 15 ESFs and their corresponding ESF number. Each ESF has a set of associated capabilities necessary to support an ESF. Tables 2 shows the 32 capabilities, and table 3 displays the capabilities associated with each ESF.

Table 1: Emergency Support Functions

1	Transportation
2	Communications
3	Public Works and Engineering
4	Firefighting
5	Information and Planning
6	Mass Care, Emergency Assistance, Temporary Housing, and Human Services and Human Services
7	Logistics
8	Public Health and Medical Services
9	Search and Rescue
10	Oil and Hazardous Materials Response
11	Agricultural and Natural Resources
12	Energy
13	Public Safety and Security
14	Cross-Sector Business and Infrastructure
15	External Affairs

Table 2: 32 Core Capabilities

	32 Core Capabilities
1	Planning
2	Public Information and Warning
3	Operational Coordination
4	Intelligence and Information Sharing
5	Interdiction and Disruption
6	Screening, Searching, and Detection
7	Forensics and Attribution
8	Access Control and Identity Verification
9	Cybersecurity
10	Physical Protective Measures
11	Risk Management for Protective Programs and Activities
12	Supply Chain integrity and Security
13	Community Resilience
14	Long-Term Vulnerability Reduction
15	Risk and Disaster Resilience Assessment
16	Threats and Hazards Identification
17	Infrastructure Systems
18	Critical Transportation
19	Environmental Response/Health and Safety
20	Fatality Management Services
21	Fire Management and Suppression
22	Logistics and Supply Chain Management
23	Mass Care Services
24	Mass Search and Rescue Operations
25	On-Scene Security, Protection, and Law Enforcement
26	Operational Communications
27	Public health, Healthcare, and Emergency Medical Services
28	Situational Assessment
29	Economic Recovery
30	Health and Social Services
31	Housing
32	Natural and Cultural Resources

Table 3: Capabilities x ESFs Matrix

Capabilities	ESFs														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2		X			X								X		X
3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4		X			X								X		X
5													X		
6									X	X			X		
7										X			X		
8													X		
9		X			X								X		X
10													X		
11					X		X						X		
12	X				X		X								
13			X		X										
14			X		X									X	
15					X										
16					X										
17			X											X	
18	X						X								
19					X			X		X					
20								X							
21				X											
22	X		X				X					X			
23						X		X							
24		X			X				X						
25													X		
26	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
27								X							
28	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
29					X									X	
30						X		X							
31						X								X	
32											X			X	

ESFs are critical when assessing connections between capabilities in the BBN. The list of capabilities associated with each ESF provides justification for connecting capabilities within the network. However, capabilities that support the same ESF are not always connected because it would lead to too many connected capabilities. The Planning, Operational Coordination, Operational Communication, and Situational Assessment capabilities support every ESF. If two capabilities that support the same ESF are always connected, then these four capabilities would be connected to every capability. Instead, the ESFs are used to filter potential capability connections. ESFs provide a framework for which capabilities could be connected, and other heuristics are employed to confirm potential connections. For example, the Energy ESF is supported by five capabilities: Planning, Operational Coordination, Operational Communication, Situational Assessment, and Logistics and Supply Chain Management. Figure 1 displays how those capabilities are connected in the BBN based on other heuristics that are described later in the paper. This diagram, seen in Figure 2, results in a more meaningful and clearer diagram than connecting all of these capabilities together.

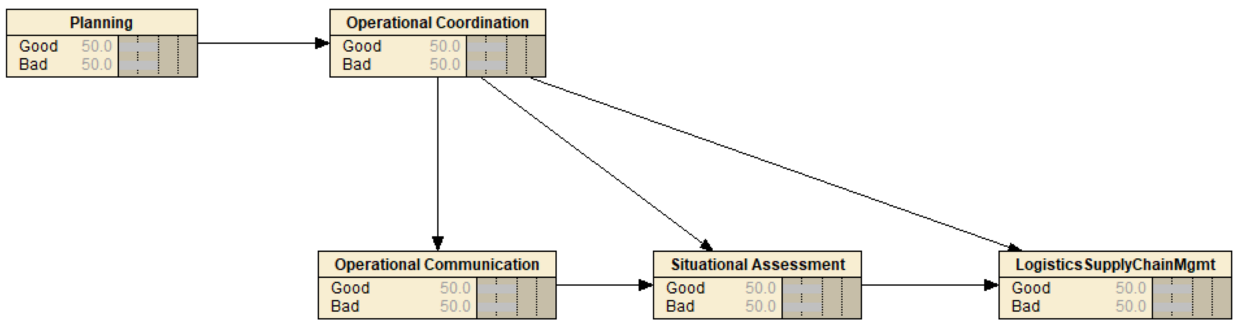

Figure 2: ESF - 12 Network

3.1.2 Capability Definition and Summary Relevancy

Each capability is defined in the 2020 Core Capabilities Assessment according to a standard definition from the National Preparedness Goal (DHS, 2015). These capability definitions describe the functions of the capability. Each capability also has a detailed summary. These summaries describe the capability's domain of functionality, how the capability functions within Iowa, and important stakeholders for the capability. Compiling the information provided in both the capability description and summary allows for a more comprehensive understanding of each capability and its surrounding relevancies. Many of the connections between capabilities are derived from the information provided within the definition and summary sections. For example, the summary for the Interdiction and Disruption capability states, "The Interdiction and Disruption capability takes place once a credible threat has been established." A credible threat derives from actionable information which is included in the definition for the Intelligence and Information Sharing capability:

> Provide timely, accurate, and actionable information resulting from the planning, direction, collection, exploitation, processing, analysis, production, dissemination, evaluation, and feedback of available information concerning threats to the United States, its people, property, or interests; the development, proliferation, or use of WMDs; or any other matter bearing on U.S. national or homeland security by Federal, state, local, and other stakeholders.

Since Interdiction and Disruption requires receiving actionable information, it depends on Intelligence and Information Sharing to receive that information. This dependency results in a connection from Intelligence and Information Sharing to Interdiction and Disruption.

Another example involves the Supply Chain Integrity and Security capability and the Logistics and Supply Chain Management capability. The Logistics and Supply Chain Management capability is defined as:

> Deliver essential commodities, equipment, and services in support of impacted communities and survivors, to include emergency power and fuel support, as well as the coordination of access to community staples. Synchronize logistics capabilities and enable the restoration of impacted supply chains.

The processes involved in the functions of this capability depend on the surrounding supply chain. The surrounding supply chains are strengthened through the Supply Chain Integrity and Security capability. The capability’s summary states:

> The Supply Chain Integrity and Security capability takes place during the protection phase of the emergency management cycle. The capability is predicated on an in-depth

> understanding of supply chains for different sectors in Iowa and nationally, reviewing those sectors to identify key assets and systems, and then implementing mitigation measures to protect those key assets and systems from damage or attack, or to ensure a measure of resilience for that asset or system's role in the overall supply chain.

Since the functions of Supply Chain Integrity and Security impact Logistics and Supply Chain Management capability's performance, the two capabilities are connected in the BBN.

Sometimes, a capability's summary explicitly mentions other related capabilities. For example, the Mass Care Services capability's summary references, "the Mass Care Services capability transitions into longer term care capabilities, including Housing, and Health and Social Services". Thus, the Mass Care Service capability is connected to the Housing and Health and Social Services capabilities.

3.1.3 Capability Target Relevancy

Both the SPR and 2020 Core Capabilities Assessment establish quantitative targets for each of the capabilities. If the capability target for one capability depends on targets assessed for another capability, the two capabilities are connected in the BBN. For example, one of the Community Resilience capability's targets is defined as, "Know and understand what types of systems the impacted community(s) are present and how to build constructive partnerships between those systems." This target is related to the target of the Threats and Hazards Identification capability:

> Identify the worst case, plausible threats and hazards to the State and local jurisdictions, and provide timely and accurate data on these threats and hazards through a continual process of data collection and analysis, in order to form the basis of an emergency management program in accordance with Federal, State and local requirements.

The Threats and Hazard Identification capability enables emergency managers to better understand specific community systems and how they can be affected, and Threats and Hazard Identification is connected to the Community Resilience capability.

Another example is the Critical Transportation capability and the Mass Care Services capability. The Mass Care Services capability's target states:

> Within four hours of an incident, tend to immediate life and temporary protective sheltering needs of affected population. Transition to mobilizing and delivering resources and capabilities to meet the needs of disaster survivors, including at-risk individuals and establish, staff and equip emergency shelters and other temporary housing (including accessible housing) options for the impacted population within 24 hours.

The Critical Transportation capability's target is "Within 72 hours, establish the capacity to provide physical access through appropriate transportation corridors and deliver required resources to save lives and to meet the needs of disaster survivors." The ability for Mass Services to meet its target depends on Critical Transportation meeting its target.

We use this method to derive many of the connections between capabilities in the BBN. Capability targets define the necessary actions for a capability. If the capability targets of one capability relate to the targets of another capability, the capabilities depend on each other.

3.1.4 Functional Area Relevancy

The SPR provides several functional areas for each capability. The functional areas serve as another way to assess the relationship between capabilities. One of the functional areas for the Mass Care Services capability is relocation assistance for housing needs. This functional area assists the functional areas for the Housing capability, which focuses on helping affected individuals transition to permanent housing options.

Mass Care Services

Functional Area(s) – Relocation Assistance

Figure 3: Mass Care Services Functional Areas

Housing

Functional Area(s) – Transition from Interim to Permanent/Long-Term Housing; Addressing Housing Shortages; Housing Accessibility

Figure 4: Housing Functional Area

3.1.5 Planning and Operational Coordination connections

Two capabilities that are especially challenging to determine connections in the BBN are Planning and Operational Coordination. In all the documentations and ESF groupings, Planning and Operational Coordination are treated as overarching capabilities that influence every other capability. To distinguish between the two capabilities, we consider the domain of each capability. The Planning capability's targets have longer time durations than those of the Operational Coordination capability. Capabilities with longer duration targets are also portrayed as capabilities that function well due to planning. Planning is connected in the BBN to capabilities with longer time durations. For example, the Community Resilience capability's target is: "Within 3 year(s), 125,750 households are covered by risk-appropriate insurance, including homeowners, flood, windstorm, and seismic." Since the Community Resilience capability's target has a duration of three years and focuses on planning, Planning is connected to Community Resilience.

The Operational Coordination capability's domain exists during the lead up to or immediate aftermath of a disaster event. For this reason, Operational Coordination is connected to capabilities that have action-oriented targets with shorter durations. For example, the Environmental Response/Health and Safety capability's target is: "Within 24 hour(s) of a hazmat incident, complete decontamination procedures for 178,443 exposed individuals (hazmat-related incidents)."

Since the Environmental Response/Health and Safety capability occurs immediately after an incident with a short duration of 24 hours, Operational Coordination is connected to this capability.

Several capabilities have multiple targets with varying target durations. For example, the Intelligence and Information Sharing capability's target states:

> During steady state, and in conjunction with the fusion center and/or Joint Terrorism Task Force (JTTF), every 12 month(s), review ability to effectively execute the intelligence cycle, including the planning, direction, collection, exploitation, processing, analysis, production, dissemination, evaluation, and feedback of available information, and identify the 6 personnel assigned to support execution of the intelligence cycle. Then, within 24 hour(s)of the identification or notification of a credible threat, identify/analyze local context of the threat for the respective area of responsibility, and facilitate the sharing of threat information with 12 priority intelligence stakeholder agencies/entities in accordance with the intelligence cycle, and all dissemination protocols.

The Planning and Operational Coordination capabilities are both connected to a capability with several targets of different durations, such as Intelligence and Information Sharing.

Tables 4 and 5 depict the capabilities that are connected to Planning and Operational Coordination. Each of the 30 capabilities are connected to at least one of these two capabilities if not both capabilities.

Table 4: Capabilities Dependent on Planning

Operational Coordination
Public Information and Warning
Intelligence and Information Sharing
Access Control and Identity Verification
Cybersecurity
Physical Protective Measures
Risk Management for Protective Programs and Activities
Supply Chain integrity and Security
Community Resilience
Long-Term Vulnerability Reduction
Risk and Disaster Resilience Assessment
Threats and Hazards Identification
Infrastructure Systems
Natural and Cultural Resources

Table 5: Capabilities Dependent on Operational Coordination

Public Information and Warning
Forensics and Attribution
Intelligence and Information Sharing
Interdiction and Disruption
Screening Search & Detection
Access Control and Identity Verification
Critical Transportation
Environmental Response/Health and Safety
Fatality Management Services
Fire Management and Suppression
Logistics and Supply Chain Management
Mass Care Services
Mass Search and Rescue Operations
On-scene Security and Protection and Law
Operational Communications
Public health, Healthcare, and Emergency Medical Services
Situational Assessment
Infrastructure Systems
Economic Recovery
Health and Social Services
Housing
Natural and Cultural Resources

3.2 Elicitation Methodology

After determining the interdependencies between capabilities, we need to quantify the strength of those interdependencies. The interdependency between two capabilities is represented by an arrow in the BBN, which signifies that the states of one capability are probabilistically dependent on the states of the other capability. Since no data exists that represents interdependencies between capabilities, the conditional probabilities are assessed from subject matter experts. The subject matter experts are experienced in homeland security and emergency management but with limited probability knowledge and time. Since the BBN has 32 nodes and some nodes have 5 or more parent nodes, the elicitation method should minimize the number of probability assessments and be straightforward. We modify and adapt Cain's (Cain, 2001) method for assessing probabilities from subject matter experts.

Cain's elicitation method focuses on one node set at a time. A node set refers to a child node and how it is directly influenced by its parent nodes. If a child node has n parent nodes, Cain's method requires $n + 2$ probability assessments for the child node. Cain's method requires that every node in the BBN has two states, a positive or desirable state and a negative or less desired state. If a parent node is in its positive state, the chance the child node will be in its positive state will be greater than if the parent node is in its negative state. We determine the capabilities in our CBP BBN to have two states based on whether the capability is meeting its capability target. The capability states are: Meets Target and Does Not Meet Target. Defining the states for the capabilities in this way makes it clear to the user which capabilities need improving, allows us to use Cain's method, and minimizes the required number of probability assessments.

The first part of Cain's method is to assess the best-case and worst-case probabilities. The best case is the probability, denoted P_B, that the child node is in its positive state given the states of its parents are all positive. The worst case is the probability, denoted P_W, that the child node is in its positive state given the states of its parents are all negative. After the best-case and worst-case assessments, the next step is to assess a number of probabilities equal to the number of parent nodes. In each of these probability assessments, all the parent nodes will be in the positive state except one parent node which will be in its negative state.

Although Cain's method is effective in reducing the number of probabilistic assessments, the process can become confusing during the assessments where experts must assess the conditional probabilities where one parent is its positive state and the others are in their negative states. This problem is magnified when the number of parents increases. The time commitment and the difficulty of distinguishing between the different strengths of relationships between several parents. Experts may not be able to provide this level of detail over a sustained period of time (Wisse, 2008). We modify Cain's method by asking experts to assign points to each parent node to reflect the relative strength of influence for each parent on the child (Hassall, 2020). Using a points approach for the individual parent assessments reduces the number of necessary probabilistic assessments and simplifies the elicitation process.

If a child has multiple parents, we ask the expert to assign points to each parent capability. The sum of points for all of the parents for a single child must sum to 100. The number of points a parent receives represents the portion of the gap from the worst-case probability to the best-case probability for which that individual parent is responsible. If $0 \leq w_i \leq 1$ represents the fraction of 100 points assigned to parent *i* for $i = 1, 2, \ldots, n$, then the probability P_i that the child is in a positive state given parent *i* is in a negative state and the other *n*-1 parents are in a positive state can be calculated:

$$P_i = P_B - (w_i(P_B - P_w)) \qquad (1)$$

As is the case with Cain's method, Equation (1) assumes that all the parent nodes of a child node are non-modifying parent nodes. A non-modifying parent node means that each parent node can influence the probabilities in the child node, and the individual effect of each parent node is independent of the other parent nodes' effects on the child node (Cain, 2001). This assumption allows us to calculate the conditional probability for the child node given a parent node's state without considering the state of the other parent nodes.

The rest of the CPT can be interpolated based on these *n*+2 probabilities. To interpolate conditional probabilities, interpolation factors are created for *n*-1 parents. These interpolation factors represent the change in a child node's probability when the parent changes from a positive to negative state. The interpolation factor for parent *i*, IF_i, is calculated:

$$IF_i = \frac{P_i - P_W}{P_B - P_W} \qquad (2)$$

After calculating an IF_i for n -1 parents, the entire CPT can be interpolated. To interpolate a new conditional probability, denoted P_{ix}, identify the parent *i* whose state changed from positive to negative from a previously elicited or calculated probability, denoted P_{iy}. Using this previously elicited or calculated probability, where parent *i* was in its positive state, the new conditional probability, where parent *i* is in its negative state, can be calculated with the following equation:

$$P_{ix} = \left[\left(P_{iy} - P_W\right) * IF_i\right] + P_W \qquad (3)$$

The entire CPT can be interpolated from the $n + 2$ assessments elicited from experts according to this method.

An example is provided to illustrate these calculations. The example consists of assessments pertaining to the child capability Physical Protective Measures and its dependencies on the parent capabilities Planning, Risk Management for Protective Programs and Activities, and Access Control and Identity Verification. The node set view of Physical Protective Measures and its parent capabilities can be seen in Figure 5, and the accompanying, empty CPT table can be seen in Table 6.

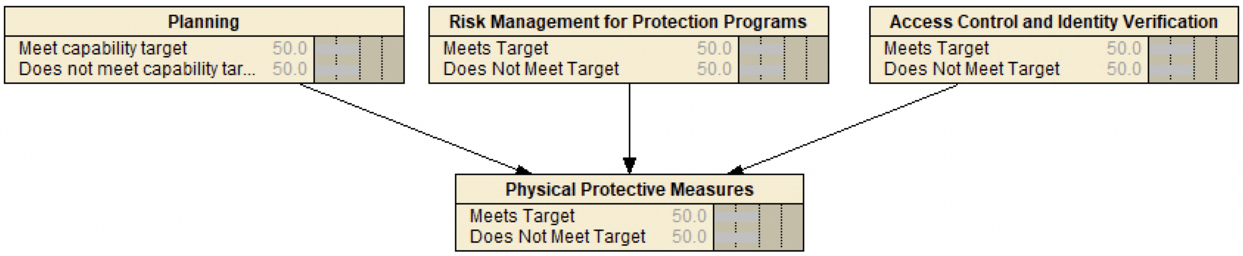

Figure 5: Physical Protective Measures Node Set

Table 6: Conditional Probability Table for Physical Protective Measures

Parent Capabilities			Physical Protective Measures	
Planning	Risk Management for Protection Programs and Activities	Access Control and Identity Verification	Meets Target	Does Not Meet Target
Meets Target	Meets Target	Meets Target		
Meets Target	Meets Target	Does Not Meet Target		
Meets Target	Does Not Meet Target	Meets Target		
Meets Target	Does Not Meet Target	Does Not Meet Target		
Does Not Meet Target	Meets Target	Meets Target		
Does Not Meet Target	Meets Target	Does Not Meet Target		
Does Not Meet Target	Does Not Meet Target	Meets Target		
Does Not Meet Target	Does Not Meet Target	Does Not Meet Target		

The best-case and worst-case assessment conditional probabilities are provided in Table 7.

Table 7: Best-Case and Worst-Case Assessment Conditional Probabilities

Best-Case (P_B)	0.75
Worst-Case (P_W)	0.15

The expert assigns 30 points to Planning, 40 points to Risk Management for Protection Programs and Activities, and 30 points to Access Control and Identity Verification. Table 8 converts these points into the probabilities and interpolation factors using equations 2 and 3.

Table 8: Individual Points Assessment and Calculations

Capability	points	w_i	P_i	IF_i
Planning (i = 1)	30	0.3	0.57	0.70
Risk Management for Protection Programs and Activities (i = 2)	40	0.4	0.51	0.60
Access Control and Identity Verification (i = 3)	30	0.3	0.57	0.70

With the best-case and worst-case assessments and individual points assessments completed part of the CPT can be filled in as depicted in Table 9.

Table 9: Partially Complete Conditional Probability Table for Physical Protective Measures

Parent Capabilities			Physical Protective Measures	
Planning	Risk Management for Protection Programs and Activities	Access Control and Identity Verification	Meets Target	Does Not Meet Target
Meets Target	Meets Target	Meets Target	0.75	0.25
Meets Target	Meets Target	Does Not Meet Target	0.57	0.43
Meets Target	Does Not Meet Target	Meets Target	0.51	0.49
Meets Target	Does Not Meet Target	Does Not Meet Target		
Does Not Meet Target	Meets Target	Meets Target	0.57	0.43
Does Not Meet Target	Meets Target	Does Not Meet Target		
Does Not Meet Target	Does Not Meet Target	Meets Target		
Does Not Meet Target	Does Not Meet Target	Does Not Meet Target	0.15	0.85

Given these assessments and calculations, the entirety of the CPT can be interpolated. An example of how a conditional probability is interpolated from a previously calculated or elicited probability can be seen by interpolating the probability P_{3x} = P(Physical Protective Measures = Meets Target | Planning = Meets Target, Risk Management = Does Not Meet Target, Access

Control = Does Not Meet Target). Equation 3 and $P_2 = P_{3y}, P_W, IF_3$ are used to calculate $P_{3x} = 0.402$. The rest of the interpolated CPT of Physical Protective Measures for this example can be seen in Table 10.

Table 10: Complete Conditional Probability Table for Physical Protective Measures

Parent Capabilities			Physical Protective Measures	
Planning	Risk Management for Protection Programs and Activities	Access Control and Identity Verification	Meets Target	Does Not Meet Target
Meets Target	Meets Target	Meets Target	0.75	0.25
Meets Target	Meets Target	Does Not Meet Target	0.57	0.43
Meets Target	Does Not Meet Target	Meets Target	0.51	0.49
Meets Target	Does Not Meet Target	Does Not Meet Target	0.402	0.598
Does Not Meet Target	Meets Target	Meets Target	0.57	0.43
Does Not Meet Target	Meets Target	Does Not Meet Target	0.444	0.556
Does Not Meet Target	Does Not Meet Target	Meets Target	0.402	0.598
Does Not Meet Target	Does Not Meet Target	Does Not Meet Target	0.15	0.85

3.3 Standardized Impact Methodology

The final portion of this method connects the CBP BBN to the scenarios and standardized impacts seen in the THIRA. Iowa's THIRA contains 16 threats and hazards and 34 standardized impacts. Connecting the capabilities to the standardized impacts can inform emergency preparedness officials how the performance of capabilities will impact their organization's ability to respond to a threat or hazard. Similar to the interdependencies among capabilities, no data exists describing how capabilities influence the standardized impacts. The THIRA and SPR reports are used to determine the relevancy between capabilities and the standardized impacts, aggregate the performances of capabilities to the standardized impacts, and compare the standardized impacts performances to the threats and hazards.

The same terminology is found in both the standardized impacts and the capability targets. Capabilities are connected in the BBN to the standardized impacts with whom they share the same standardized language. For example, the Planning capability's target is described as:

> "Within every 2 year(s), update all emergency operations plans that define the roles and responsibilities of 29 partner organizations involved in incident management across 947 jurisdictions affected, and the sequence and scope of tasks needed to prevent, protect, mitigate, respond to, and recover from events." (HSEMD, 2022)

In this target, "partner organizations involved in incident management" and "jurisdictions affected" are described using the standardized language and derived from the standardized impacts. The Planning capability is connected to two standardized impacts: Partner Organizations Involved in Incident Management and Jurisdictions Affected.

Multiple capabilities may be connected to the same standardized impact. It is necessary to determine how the combination and the performance of capabilities influence the standardized impacts. As described in the Planning capability example, the capability targets represent the level of impact to which a capability should be able to respond. In other words, Planning should be able to partner with 29 partner organizations across 947 jurisdictions. We treat the standardized impacts as a deterministic node within in the BBN. If all of the capabilities that are parent nodes of a standardized impact child node are meeting their targets, the organization can achieve the maximum target. If none of the capabilities that are parents of a standardized impact child are meeting their targets, the organization can only achieve half of the maximum target.

If a standardized impact has multiple parent capabilities, the amount of the target that the organization can achieve increases proportionally to the number of parent capabilities that meet their target. An example of this process can be seen in Table 11. The example is the number of jurisdictions, and the maximum target is 947 jurisdictions. The standardized impact has four capability parents.

Table 11: Example of a Standardized Impact as a Function of Capabilities

Number of Capabilities Meeting Their Target	Number of Jurisdictions (Standardized Impact)
4	947
3	827
2	709
1	591
0	473

The standardized impact node that reflects the capability targets is connected to another standardized impact node that reflects the impact envisioned by each threat or hazard in the THIRA. Each threat or hazard contains multiple standardized impacts that can result from the threat or hazard. If the level of a standardized impact to which the organization can respond based on the capabilities is greater than or equal to the standardized impact for a given threat or hazard, the node is assigned the state, “Can Fully Respond to the Scenario.” If the level of a standardized impact to which the organization can respond is less than the expected number for a given threat or hazard, the node is assigned the state, “Cannot Fully Respond to the Scenario.” Since a threat or hazard may not generate a standardized impact, if the standardized impact is not applicable for the threat or hazard, this node is assigned the state, “NA.” These nodes are referenced as standardized impact scenario nodes. A single node that contains all of the threats and hazards in the THIRA is added to the network and connected to each of the standardized impact scenario nodes. When a specific threat or hazard is selected, the standardized impact scenario node reflects the probability that the standardized impact can be responded to based on the organization's capabilities. Figure 6 displays an example of this network layout for the standardized impact number of jurisdictions.

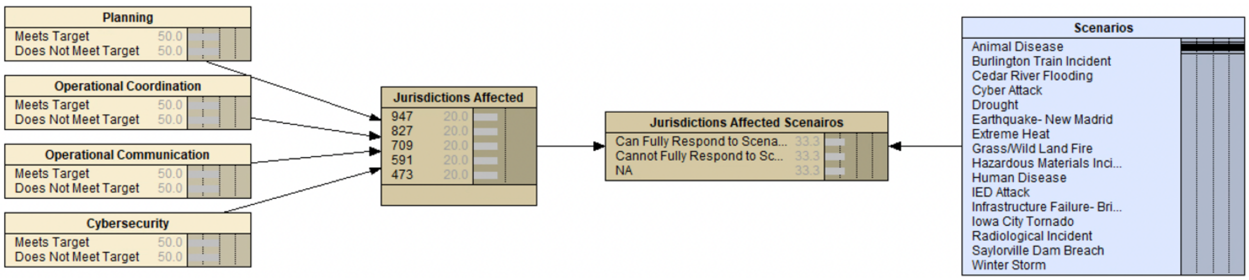

Figure 6: Standardized Impact BBN Layout Example

CHAPTER 4. RESULTS

4.1 Survey Results

We follow the heuristics created in section 3.1 to build the CBP BBN. The resulting network has 32 nodes. The Planning capability node is the only node without any parents, and the Public Information and Warning capability has most parent nodes with seven. Since Planning does not have any parent nodes, we assign a 0.5 probability that Planning meets its target. Online surveys were created to quantify the connections among nodes. Surveys are a common direct method to conduct quantitative assessments with experts (Thompson, 2007), and they allow busy experts to complete the surveys when free. Since some experts are more knowledgeable about different areas of emergency response, the elicitations of capabilities were split across the five mission areas (see Figure 1). Experts who specialize in one mission area could just complete the assessments for their relevant mission area(s).

Before completing the surveys, experts watched a 12-minute training video, which provided background information on the project and described how to make the probability and point assessments. Each capability was presented on an individual page of the survey. The survey showed the node set view of a child node with all of its parent nodes and the capability targets and ESFs for the parent and child capabilities. The subject matter expert was asked to provide the best-case and worst-case assessments and then the individual point assessments. These assessments follow the elicitation method described in section 3.2. An example of a survey page for one of the capabilities can be seen in Appendix A. Officials in Iowa HSEMD received links to the survey, and the five surveys generated 11 total responses. These individuals self-described their roles as Trainer, IT Specialist, or Planner. The distribution of responses between the mission areas can be seen in Table 12.

Table 12: Distribution of Survey Responses

Mission Area	Number of Responses
Prevention	1
Protection	1
Mitigation	2
Response	5
Recovery	2

The assessments were aggregated for the surveys with multiple responses. The median response is used for the best-case and worst-case assessments and the distribution of 100 points to calculate the conditional probabilities describing the influence of the parents on a child node. Taking the median response can result in a more calibrated response and reduces the effect of outliers compared to the mean (Hora, 2013). The software Netica, sold by Norsys, is used to visualize, compile, and analyze the CBP BBN with the CPTs informed by subject matter experts at Iowa HSEMD.

4.2 CBP BBN

The CBP BBN shows the quantified interdependencies between the capabilities. Each capability's node displays belief bars and the probabilities that the capability meets its target and does not meet its target. The entire quantified network can be seen in Figure 7. Almost all capabilities have a 0.40-0.65 probability of meeting their targets. The Prevention, Protection, and Mitigation mission areas contain capabilities with smaller chances of meeting their targets. These capabilities have a 0.45-0.50 probability of meeting their target. This is due to these capabilities having smaller best-case and worst-case probabilities than the capabilities in the Response and Recovery mission areas. The capabilities within the Response and Recovery mission areas have slightly larger probabilities of meeting their targets with most having a 0.50-0.65 probability of meeting their targets. Table 13 shows the distribution of the P(Meets Target) probabilities across the network.

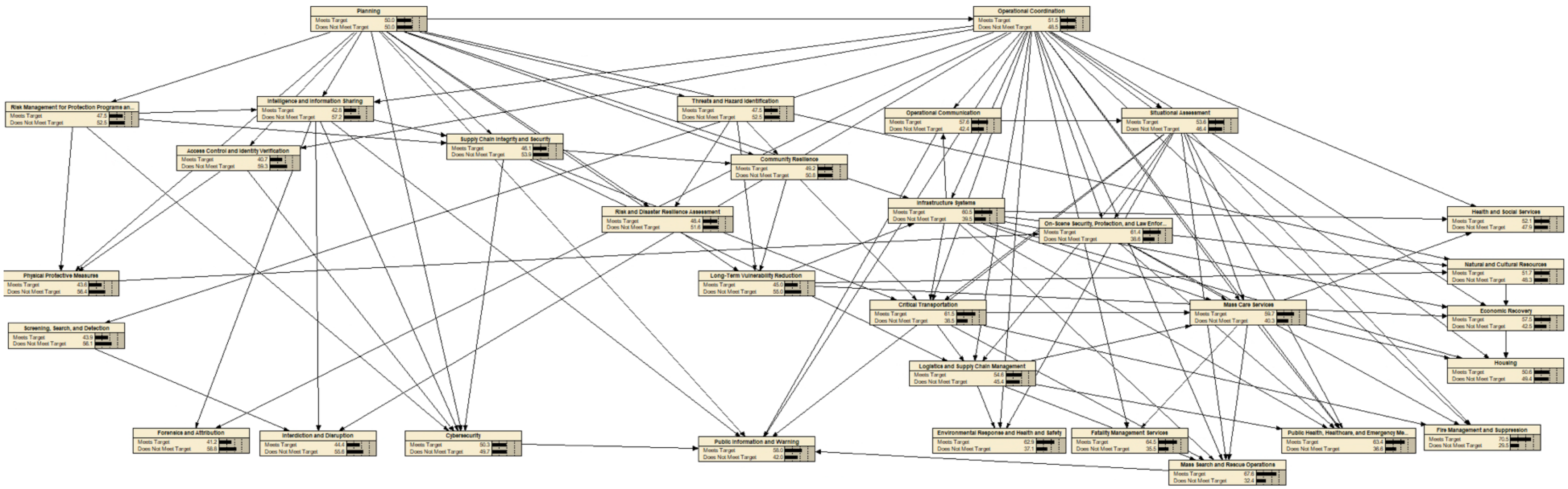

Figure 7: Quantified CBP BBN: There are 32 nodes for each capability and arrows represent interdependencies between capabilities

Table 13: Distribution of Probabilities that Capabilities Meet their Targets

Range of P(Capabilities Meet Their Target)	Number of Instances
0.90 - 1.00	0
0.80 - 0.89	0
0.70 - 0.79	1
0.60 - 0.69	7
0.50 - 0.59	12
0.40 - 0.49	12
0.30 - 0.39	0
0.20 - 0.29	0
0.10 - 0.19	0
0.00 - 0.09	0

The CBP BBN can be used to assess the importance of each capability and help HSEMD determine the most important capabilities to work to improve and to sustain. The CBP BBN can also demonstrate the effect of not sustaining a capability and letting it degrade. For example, if HSEMD improves Planning such that the organization is 100% certain that the capability will meet its target, the CBP BBN calculates the probabilities that all the other capabilities will meet their targets. Table 14 displays the range of probabilities for the other 31 nodes given that Planning meets its target and given that Planning does not meet its target. If Planning meets its target, all the other capabilities have at least a 0.60 probability of meeting their targets, and 8 of the 31 capabilities have at least a 0.80 probability of meeting their targets. If HSEMD chooses not to sustain the Planning capability so that it is certain that Planning does not meet its target, all the 31 other capabilities have less than a 0.60 probability of meeting their targets. Eleven capabilities have less than 0.20 probability of meeting their targets. The largest change in probabilities occurs in the Prevention, Protection, and Mitigation mission areas because these capabilities are more likely to be directly influenced by Planning.

Table 14: Distribution of Probabilities that Capabilities Meet their Targets (Planning and Mass Care Services)

	Number of instances			
Range of P(Capabilities Meet Their Target)	Planning Meets Target	Mass Care Services Meets Target	Planning Does Not Meet Target	Mass Care Services Does Not Meet Target
0.90 - 1.00	1	0	0	0
0.80 - 0.89	7	0	0	0
0.70 - 0.79	14	3	0	0
0.60 - 0.69	9	12	0	2
0.50 - 0.59	0	9	4	8
0.40 - 0.49	0	7	6	13
0.30 - 0.39	0	0	7	8
0.20 - 0.29	0	0	3	0
0.10 - 0.19	0	0	8	0
0.00 - 0.09	0	0	3	0

Table 14 also shows the effect of HSEMD improving the capability Mass Care Services or letting Mass Care Services degrade. Mass Care Services has a more limited on the other capabilities than Planning. If Mass Care Services is certain to meets its target, the probabilities the other 31 capabilities meet their targets range between 0.40 and 0.79. If Mass Care Services does not meet its target, the probabilities the other 31 capabilities meet their targets range between 0.30 and 0.69. It is more important for Iowa HSEMD to sustain and improve its Planning capability than to sustain and improve Mass Care Services.

When analyzing the network, it may also be important to analyze the impact of multiple capabilities either meeting or not meeting their targets. For HSEMD, capabilities are typically analyzed in groups, and the groups are commonly derived from the ESFs. With the CBP BBN, the impact of improving an entire ESF and the impact of not sustaining an ESF can be explored. For example, ESF-12 focuses on Energy and includes the following capabilities: Planning, Operational Coordination, Operational Communication, Situational Assessment, and Logistics and Supply Chain Management capabilities. Table 15 shows the distribution of the probabilities P(Meets Target) for the other 27 capabilities if all the capabilities in ESF-12 meet their target or if none of the capabilities in ESF-12 meet their target.

Table 15: Distribution of Probabilities that Capabilities Meet their Targets (ESF - 12)

	Number of instances	
Range of P(Capabilities Meet Their Target)	All ESF-12 Capabilities Meet Target	All ESF-12 Capabilities Do not Meet Target
0.90 - 1.00	0	0
0.80 - 0.89	11	0
0.70 - 0.79	11	0
0.60 - 0.69	5	0
0.50 - 0.59	0	1
0.40 - 0.49	0	5
0.30 - 0.39	0	8
0.20 - 0.29	0	1
0.10 - 0.19	0	10
0.00 - 0.09	0	2

The performance of the CBP BBN increases substantially if all of the capabilities in ESF-12 meet their targets. This is expected, as every capability in the network is connected to at least one of Planning and Operational Coordination, and the elicited experts believe these two capabilities have a significant influence on the other capabilities. Planning and Operational Coordination are considered essential capabilities within the CBP framework. The capabilities in the Response mission area are also highly dependent on the Situational Assessment capability. This analysis highlights the same information that we analyzed when testing individual capabilities, but analyzing a group of capabilities allows for us to explore more complex and widespread relationships in the network. It is especially interesting to analyze capabilities grouped by ESFs, as ESFs group capabilities that relate to a specific domain, like energy. We see how capabilities are dependent on specific domains by analyzing the ESFs.

The CBP BBN provides a tool for state emergency management planners to test several different scenarios. The network is highly flexible in the way that any combination of capabilities meeting and not meeting their targets can be tested. The data gathered from this network can be utilized during funding decisions as a supporting piece of information. Although this data is insightful, it may be more applicable if the capabilities and their performances are translated to the standardized impacts and THIRA scenarios.

4.3 CBP and Standardized Impacts BBN

The standardized impacts are connected to the CBP BBN via the method described in section 3.1. Compiling the network results in the quantified CBP BBN which is connected to the quantified standardized impact response nodes, each of which is connected to its corresponding standardized impact scenario nodes. Figure 8 shows an outline of the network structure, and the entire 101 node BBN can be seen in Appendix B. The standardized impact response nodes are used to aggregate and translate the capabilities' performances to the metrics used in the standardized impacts and THIRA scenarios. These nodes represent how much of a standardized impact HSEMD can respond to.

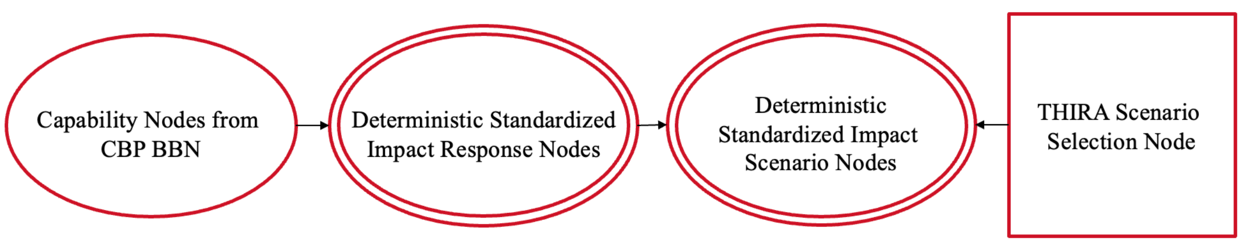

Figure 8: Structure of Connected CBP and Standardized Impact BBN

Several insights can be gained from the current state of the model. As seen in Table 16, a comparison between the expected value of the standardized impact response nodes and the maximum for each standardized impact can help identify which standardized impact may be the most difficult to fully respond to for the state of Iowa. Similar to capabilities, the standardized impact response nodes can be analyzed if a group of capabilities, such as those in ESF-12, all meet their targets.

Table 16: Standardized Impact Response Node Values (ESF-12)

Standardized Impact	Expected value	Expected value if capabilities if ESF-12 meet target	Maximum value
(#) jurisdictions affected	721	923	947
(#) partner organizations involved in incident management	87	109	116
(#) people affected	2,520,000	2,880,000	3,155,070
(#) people with access and functional needs (affected)	2,140,000	2,460,000	2,713,336
(#) people with limited English proficiency affected	150,000	172,000	189,305
(#) customers (without water service)	297,000	331,000	370,341
(#) customers (without wastewater service)	262,000	292,000	326,771
(#) customers (without communication service)	378,000	420,000	470,419
(#) customers (without power service)	350,000	389,000	435,695
(#) people requiring evacuation	147,000	161,000	181,958
(#) people with access and functional needs (requiring evacuation)	38,200	41,900	47,314
(#) miles of road affected	137,000	150,000	169,801
(#) hazmat release sites	10,900	12,400	13,414
(#) exposed individuals (hazmat- related incidents)	145,000	165,000	178,443
(#) fatalities	519,000	572,000	631,014
(#) structure fires	328	359	385
(#) people requiring shelter	347,000	416,000	441,710
(#) people with access and functional needs (requiring accessible shelter)	1,010	1,120	1,267
(#) people requiring food and water	49,600	59,400	63,100
(#) people with access and functional needs (requiring food and water)	12,500	13,800	15,648
(#) animals requiring shelter, food, and water	136,000	150,000	170,596
(#) people requiring temporary, non-congregate housing	55,900	61,700	69,973
(#) people with access and functional needs (requiring accessible, temporary, non-congregate housing)	1,990	2,200	2,497
(#) people requiring rescue	52,900	58,600	63,101
(#) people requiring medical care	1,800,000	1,950,000	2,208,549
(#) businesses closed due to the incident	18,300	19,700	23,178
(#) affected healthcare facilities and social service organizations	99	112	131

Table 16 Continued

Standardized Impact	Expected Value	Expected value if capabilities if ESF-12 meet target	Maximum Value
(#) people requiring long-term housing	27,400	29,400	36,392
(#) people with access and functional needs (requiring accessible long-term housing)	954	1,020	1,267
(#) damaged natural and cultural resources and historic properties registered in the jurisdiction	263	298	346
(#) people requiring screening	18,800	22,600	26,171
(#) people with access and functional needs (requiring screening)	1,620	1,950	2,251
(#) personnel	25	29	34
(#) priority intelligence stakeholder agencies/entities	9	10	12

Table 16 shows that the expected values of the standardized impact response nodes achieve approximately 75% of their maximum values. Although the standardized impact response nodes of each standardized impact are close to the maximum, there are still areas to improve performance. This can be explored when analyzing the improvements to the standardized impact response nodes when it is certain ESF – 12 will meet its target. The results in Table 16 show an improvement to all the standardized impact response nodes. With the improvements to ESF-12, the expected values of the standardized impact response nodes are 80-97% of their maximum values. The standardized impacts Jurisdictions Affected and Partner Organizations Involved in Incident Management increase the most, by 28% and 25% respectively. These two impacts are directly dependent on many of the capabilities in ESF-12. Standardized impacts like People Requiring Healthcare and Businesses Closed Due To The Incident had much smaller improvements, approximately 8% improvement. These smaller improvements indicate these standardized impacts have a weaker dependency on the capabilities in ESF-12. This type of analysis can be insightful to HSEMD as the complex relationships between capabilities can now be translated to disaster specific impacts, which can lead to a more direct analysis when improving capabilities. We can expand on this analysis by investigating the probabilities that a standardized impact can be fully responded to, given a scenario.

As mentioned in Chapter 3, the Iowa THIRA contains 16 different threats and hazards ranging from natural disasters to pandemics to intentional attacks. The BBN can be used to analyze the state of Iowa's ability to respond to these different threats and hazards. Table 17 depicts the probabilities that the state of Iowa can respond to the standardized impacts for two different threats and hazards: Grass/Wild Land Fire and Cyberattack. If the threat does not generate a standardized impact, the standardized impact scenario node is assigned the state NA. As seen in Table 17, the CBP BNN shows that that the state of Iowa can fully respond to every relevant impact for the Grass/Wild Land Fire except for Structure Fires. HSEMD has a 0.7 probability of being able to fully respond to Structure Fires for this threat. Overall, the Grass/Wild Land Fire does not present a challenge for the HSEMD. The Cyberattack threat presents a much more difficult challenge for the state of Iowa. The state of Iowa has less than a 0.6 probability of being able to fully respond to 10 standardized impacts and has less than a 0.5 probability of being able to fully respond to 3 standardized impacts, Jurisdictions Affected, Partner Organizations Involved in Incident Management, and Peopled Affected, for Cyberattack.

Table 17: Distribution of Probabilities to Fully Respond to Scenario for Grass/Wild Land Fire and Cyberattack

Range of P(Fully Respond to Scenario)	Grass/Wild Land Fire	Cyberattack
0.90 - 1.00	25	7
0.80 - 0.89	0	0
0.70 - 0.79	1	0
0.60 - 0.69	0	4
0.50 - 0.59	0	3
0.40 - 0.49	0	0

Table 17 Continued

Range of P(Fully Respond to Scenario)	Grass/Wild Land Fire	Cyberattack
0.30 - 0.39	0	1
0.20 - 0.29	0	2
0.10 - 0.19	0	0
0.00 - 0.09	0	0
NA	8	17

Since Cyberattack is a challenging threat for HSEMD, focusing on the relevant capabilities such as Cybersecurity and Access Control and Identity Verification can improve Iowa's ability to respond to this threat. Table 18 shows the probabilities of responding to the standardized impacts for the Cybersecurity threat if the capabilities Cybersecurity and Access Control and Identity Verification are certain to meet their targets. Iowa has at least a 0.6 probability of fully responding to every standardized impact except for Partner Organizations Involved in Incident Management. Iowa has a 0.60-0.69 probability of fully responding to 3 standardized impacts and a 0.70-0.79 probability of fully responding to 6 standardized impacts. Although the Cyberattack threat remains a difficult challenge for HSEMD, the BBN shows that Iowa can manage this threat much better if the Cyberattack and Access Control and Identity Verification capabilities meet their targets. HSEMD can use this type of analysis to determine the optimal set of capabilities to respond to more standardized impacts and maximize their probability to fully respond to each threat or hazard. This analysis can help inform funding decisions and result in a better allocation of resources for emergency preparedness capabilities.

Table 18: Distribution of Probabilities to Fully Respond to Cyberattack (Cybersecurity and Access Control and Identity Verification

Range of P(Fully Respond to Scenario)	Cyberattack Scenario Before Improvements	Cyberattack Scenario After Improvements
0.90 - 1.00	7	7
0.80 - 0.89	0	0
0.70 - 0.79	0	6
0.60 - 0.69	4	3

Table 18 Continued

Range of P(Fully Respond to Scenario)	Cyberattack Scenario Before Improvements	Cyberattack Scenario After Improvements
0.50 - 0.59	3	1
0.40 - 0.49	0	0
0.30 - 0.39	1	0
0.20 - 0.29	2	0
0.10 - 0.19	0	0
0.00 - 0.09	0	0
NA	17	17

CHAPTER 5. CONCLUSION

This research proposes a method to derive and quantify the interdependencies between the capabilities within the DHS CBP framework using a BBN and a method to translate the performances of the capabilities to the standardized impacts from different threats and hazards. We determined the connections between capabilities by using several developed heuristics: capability definition and summary relevance, capability target relevance, and functional area relevance. We adapted an elicitation method to obtain the conditional probabilities from subject matter experts while reducing the number of probabilistic assessments. The performances of capabilities determine the level of a standardized impact to which a state can respond, and these levels are compared to the impacts generated by the threats and hazards in the THIRA. The BBN calculates the probabilities that a state can fully respond to each standardized impact for each threat and hazard.

We quantified the BBN for the state of Iowa with assessments from HSEMD. Capabilities within the Prevention, Protection, and Mitigation mission areas have smaller probabilities of meeting their targets than capabilities in the Response and Recovery mission areas. This analysis identifies areas of improvement for Iowa HSEMD's CBP. According to the BBN, the expected values of the standardized impacts are approximately 75% of the maximum impacts. Iowa's ability to fully respond to these impacts depends on the threat or hazard, and Cybersecurity is particularly challenging Iowa HSEMD.

The current state of the BBN motivates the need to analyze different funding alternative to improve the state's ability to prepare and respond to different threats and hazards. For example, allocating funding to improve the Planning capability many of the capabilities in the Prevention, Protection, and Mitigation mission areas are improved, but the capabilities in the

Response and Recovery mission areas were not largely affected. Planning has a much larger impact on other capabilities than Mass Care Services, indicating the network is more dependent on Planning than Mass Care Services. The example with ESF-12 shows how improving multiple capabilities resulted in major impacts on the network. The BBN allows HSEMD to analyze more complex relationships and the large systemic impact multiple capabilities can have on emergency preparedness. These examples demonstrate how funding for a capability or a group of capabilities can improve all of the capabilities and how failing to sustain one or more capabilities can harm other capabilities and hurt emergency preparedness.

The BBN demonstrates how capabilities improve Iowa's ability to respond to 34 standardized impacts. If all five capabilities in ESF-12 meet their targets, the expected values of some standardized impacts, such Jurisdictions Affected, increase significantly (20%), but other impacts, such as Businesses Closed Due to the Incident, increase much less (6%). This analysis highlights the importance of analyzing complex and domain specific relationship's impact on an organization's ability to respond to disasters. The improvement of capabilities can be applied to specific threats or hazards. If the capabilities Cybersecurity and Access Control and Identity Verification meet their target, Iowa's ability to fully respond to standardized impacts for the Cybersecurity threat is enhanced. Only one standardized impact, Partner Organizations Involved in Incident Management, had a probability to fully respond less than 0.60.

These examples highlight the practical use cases for these networks. With limited funding, Iowa HSEMD should identify the most effective allocation of resources when improving capabilities. The CBP BBN allows HSEMD to analyze the comprehensive systemic impact of improving one or more capabilities on other capabilities and through the lens of the THIRA threats and hazards. The BBN also demonstrates the importance of sustaining capabilities. Acquiring funding to sustain a capability can be difficult. The BBN can demonstrate the comprehensive systemic impact of not sustaining one or more capabilities and provide support for funding the sustainment of capabilities.

Although this research provides a major step forward for emergency planning and CBP, there are limitations. To reduce the computational requirements from experts in the elicitation process, each capability node only has two states. This limits the analysis of how a capability may improve or degrade. The subject matter expert elicitations also limited this research. Since data describing these interdependencies did not exist, we elicited probabilities from experts that were not comfortable or experienced with probabilities. Two mission areas only had one survey response, and two other mission areas had two survey responses. This makes the results dependent on one or two individual beliefs.

Future research can explore increasing the number of node states for the capability nodes to examine the effects of marginal improvements in the capabilities. Translating specific funding alternatives to capabilities in the BBN could link the model and analysis more explicitly to decisions that emergency planners consider. For example, how should an organization spend $1 million to improve these core capabilities and its ability to respond to disasters? Due to the size and complexity of the BBN, it is challenging to provide a clear prioritization for the most important capabilities. Future research could adapt or create new summary statistics for each capability based on the BBN that can help an organization such as Iowa HSEMD prioritize among its capabilities.

Although these limitations exist, this current research provides a large step forward for emergency preparedness. For the first time, the interdependencies between capabilities have been identified and quantified. With this model, DHS organizations at every level can explore the comprehensive systemic impact one or more capabilities have on other capabilities and the standardized impacts found in disaster scenarios. This research provides an initial step forward for CBP funding allocation and can lead to future research to increase the effectiveness of this planning framework.

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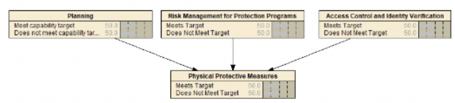
APPENDIX A. ELICITATION SURVEY LAYOUT

The surveys used to elicit the conditional probabilities from subject matter experts in Iowa's HSEMD were distributed through Qualtrics. The top of the survey provides the node set view of the child capability and its parent capabilities, the capability targets for every capability, and the ESFs that each capability supports. This information ensures the experts have the same base level of information for the relevant capabilities. An example of how this information for the Physical Protective Measures capability appeared in Qualtrics can be seen in Figure 9.



This assessment focuses on the Physical Protective Measures capability and its dependency on three capabilities:
(1) Planning, (2) Risk Management for Protection Programs and Activities, and (3) Access Control and Identity Verification.

Capability targets

Physical Protective Measures: Within 1 year(s) of completing a risk and vulnerability assessment, appropriate authorities review and update physical security plans covering 16 publicly managed and/or regulated critical infrastructure facilities to incorporate new information from the assessment.

Planning: Within every 2 year(s), update all emergency operations plans that define the roles and responsibilities of 29 partner organizations involved in incident management across 947 jurisdictions affected, and the sequence and scope of tasks needed to prevent, protect, mitigate, respond to, and recover from events.

Risk Management for Protection Programs and Activities: Every 1 year(s), appropriate authorities conduct a review of relevant physical and cyber threats and hazards, vulnerabilities, and strategies for risk management covering 16 publicly managed and/or regulated critical infrastructure facilities.

Access Control and Identity Verification: Within 24 hour(s) of an event, be prepared to accept credentials from 12 partner organizations involved in incident management.

ESFs

Physical Protective Measures: ESF-13 Public Safety & Security

Planning: ESF-1 Transportation, ESF-2 Communications, ESF-3 Public Works & Engineering, ESF-4 Firefighting, ESF-5 Emergency Management, ESF-6 Mass Care, ESF-7 Logistics & Resource Management, ESF-8 Public Health & Medical, ESF-9 Search and Rescue, ESF-10 Hazmat, ESF-11 Agriculture & Natural Resources, ESF-12 Energy, ESF-13 Public Safety & Security, ESF-14 Recovery, ESF-15 External Affairs

Risk Management for Protection Programs and Activities: ESF-5 Emergency Management, ESF-7 Logistics & Resource Management, ESF-13 Public Safety & Security

Access Control and Identity Verification: ESF-13 Public Safety & Security

Figure 9: Qualtrics Survey Provided Information

After reading the provided information, the expert was asked to assess the best-case and worst-case assessments. This assessment is conducted with sliders, which allows the experts to select the assessed probability by increments of 5%. Figure 10 depicts an example of this assessment for the Physical Protective Measures as displayed in Qualtrics.

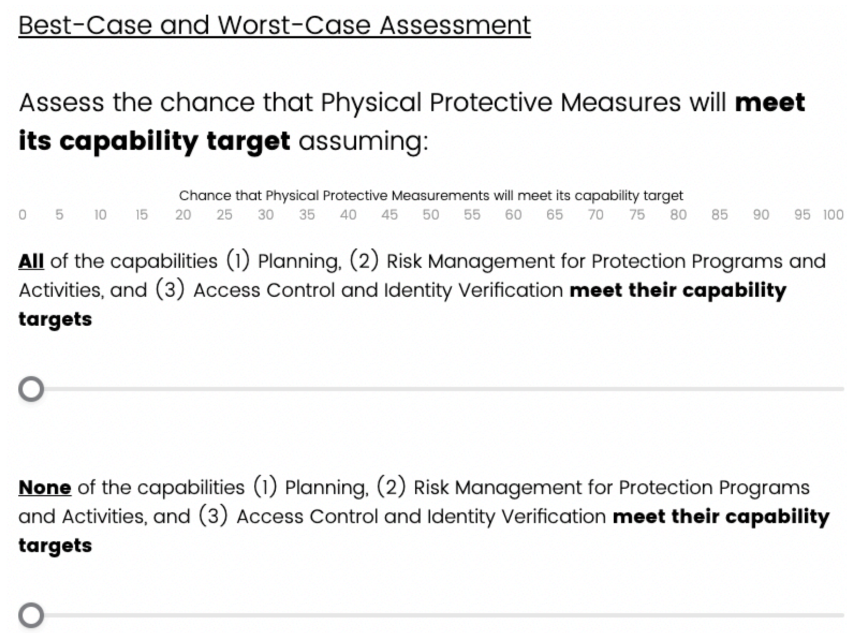
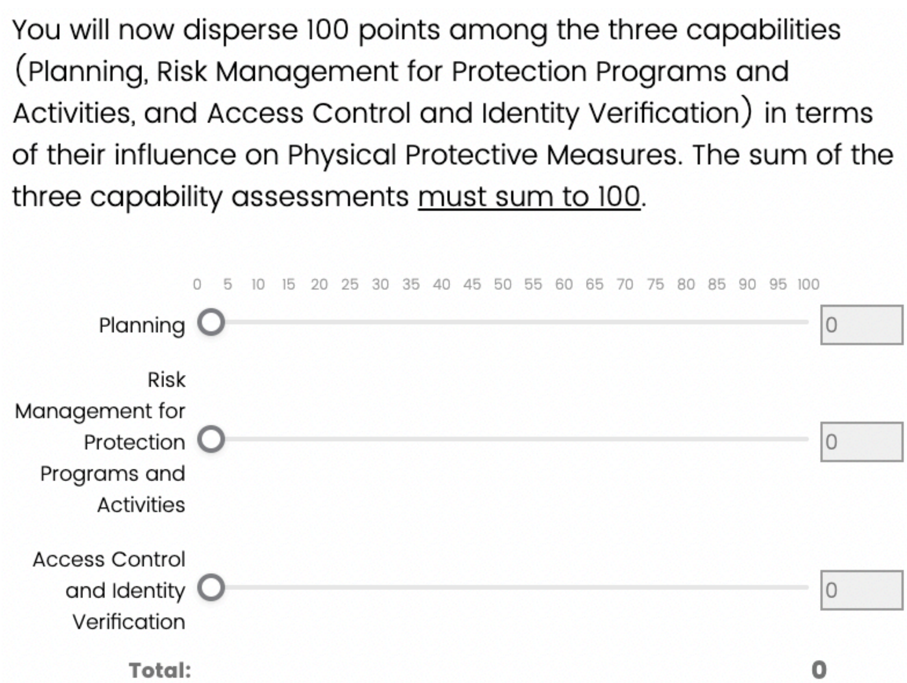


Figure 10: Best-Case and Worst-Case Assessments in Qualtrics

Finally, the expert was asked to assign the individual points assessment for the parent capabilities. This assessment is conducted with weighted sum sliders, which ensures the expert distributes all 100 points. An example of this assessment for the Physical Protective Measures capability is shown in Figure 11. The Qualtrics survey did not allow the expert to advance to the next page until the points for the individual capabilities summed to 100.


You will now disperse 100 points among the three capabilities (Planning, Risk Management for Protection Programs and Activities, and Access Control and Identity Verification) in terms of their influence on Physical Protective Measures. The sum of the three capability assessments must sum to 100.

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Planning 0

Risk Management for Protection Programs and Activities 0

Access Control and Identity Verification 0

Total: 0

Figure 11: Individual Points Assessment in Qualtrics

APPENDIX B. STANDARDIZED IMPACT BBN

Since the Standardized Impact BBN has 101 nodes, it is difficult view clearly outside of the Netica Software. We have provided the zoomed-out view of the BBN in this Appendix and can be seen in Figure 12. On the left side is the CBP BBN. The first column of nodes to the right of CBP BBN are the standardized impact performance nodes. To the right of the first column are the standardized impact scenario nodes. The right most node is the scenario decision node, which allows users to select a disaster scenario to analyze.

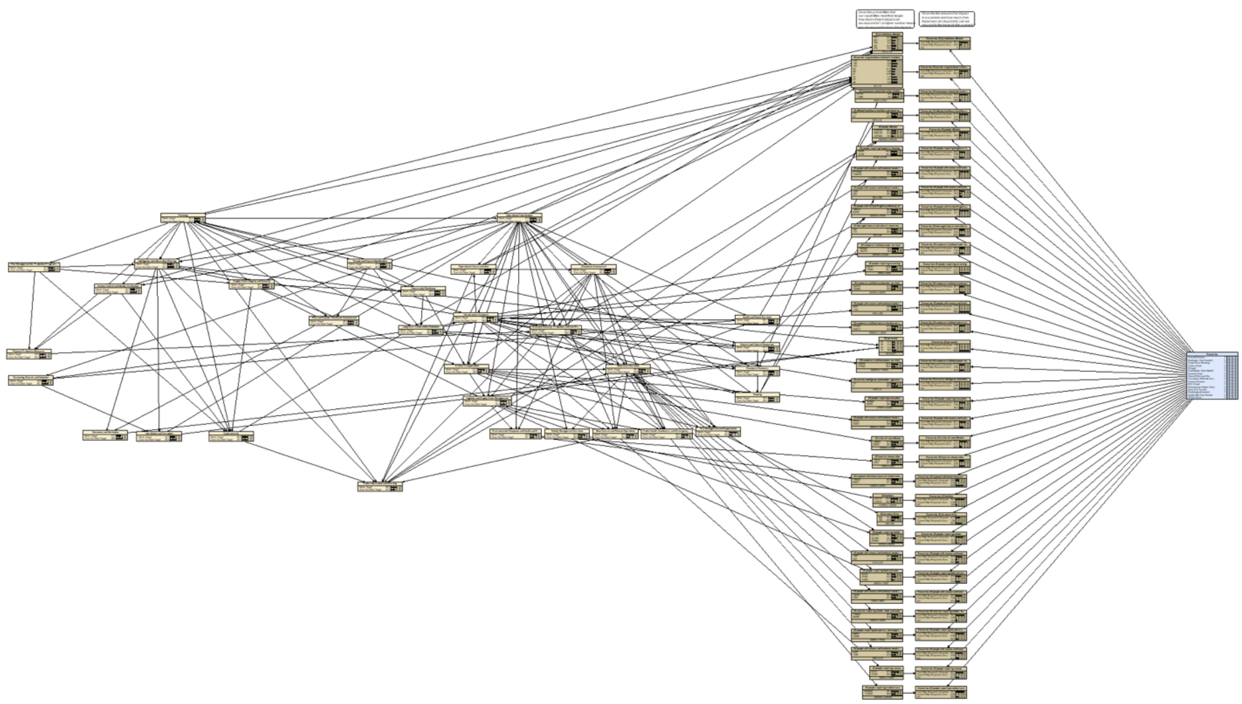


Figure 12: Zoomed-Out Standardized Impact BBN: Left side of the figure is the CBP BBN, the two columns to the right of the CBP BBN are the standardized impact response and scenario nodes, and the furthest left node is the scenario selection node.