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Research Report

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A Risk Assessment of National Critical Functions During COVID-19

Challenges and Opportunities

KEY FINDINGS

- A key strength of the National Risk Management Center's (NRMC's) National Critical Function (NCF) risk assessment framework is its functional approach to understanding critical infrastructure risk, which enables an additional level of analysis that might be missed by a purely sector- or brick and mortar–based approach.
- The NCF risk assessment framework, as operationalized by the Homeland Security Operational Analysis Center (HSOAC), incorporates many best practices for risk assessment, such as including quantitative risk estimates, establishing a specific time frame for the assessment of risk, and incorporating a quality assurance process.
- HSOAC researchers identified some challenges in the implementation of the framework. These include a potential bias toward high risk ratings, difficulty in determining whether ratings were being assigned based on the likelihood of disruption or the consequences of disruption, limitations in assessing risk to individual NCFs in isolation from other NCFs, and difficulty in separating out national from regional impacts.
- The research team also identified several opportunities for improving the framework in future iterations. These include opportunities to review and refine the drivers of risk examined, the indicators used to monitor risk, and the time scale used in assessing risk.

When it became clear that coronavirus disease 2019 (COVID-19) had spread to the United States in the first quarter of 2020, concerns soon arose that the virus would present a severe, ongoing, and evolving threat to public health. However, the virus's potential impacts on other parts of the country's critical infrastructure (CI)—including the manufacturing, banking, law enforcement, oil and gas production, education, and transportation sectors—was less clear. As many regions of the United States began to shut down in March 2020, the Cybersecurity and Infrastructure Security Agency (CISA), a component of the U.S. Department of Homeland Security (DHS), sought a means to actively monitor ongoing risk from COVID-19 to 55 National Critical Functions (NCFs). NCFs represent a new way of thinking about CI risk—one that shifts the focus from physical infrastructure to the functions supported by CI assets and organizations, such as "transmit electricity," "educate and train," or "manage hazardous wastes." CISA has defined NCFs as the "functions of govern-

ment and the private sector that are so vital to the United States that their disruption, corruption, or dysfunction would have a debilitating effect on security, national economic security, [or] national public health or safety" (CISA, 2019, p. 1).

To support its efforts in the national COVID-19 response, CISA sought to understand the potential for significant or long-term disruption to the 55 NCFs due to COVID-19. CISA's National Risk Management Center (NRMC), a planning, analysis, and collaboration center focused on addressing the country's highest-priority CI risks, asked the Homeland Security Operational Analysis Center (HSOAC), a federally funded research and development center operated by the RAND Corporation, to operationalize the NRMC's NCF risk assessment framework and to complete individual risk analyses on an ongoing basis for the 55 NCFs. This effort, which constituted the first application of the NCF risk assessment framework, would support the NRMC's efforts to anticipate, assess, and analyze risks to the NCFs; develop risk management options; and identify options for mitigating risk.

HSOAC began its work in mid-March 2020 and, in the subsequent two months, identified indicators and data sources to measure risk for each function, built out other components of the risk assessment framework, and completed two rounds of detailed assessments for all 55 NCFs. The team subsequently provided updates to these assessments on a rolling, weekly basis up through January 2021, and simultaneously worked to refine and strengthen the framework as lessons emerged from the application and a review of best practices in risk management and risk assessment.

This report presents insights into the use of the NCFs in risk assessment and management and identifies opportunities to enhance and refine the methods and protocols for assessing, managing, and communicating risk, including those embedded in the framework.

Abbreviations

CI	critical infrastructure
CISA	Cybersecurity and Infrastructure Security Agency
COVID-19	coronavirus disease 2019
DHS	U.S. Department of Homeland Security
ECIW	essential critical infrastructure worker
HSOAC	Homeland Security Operational Analysis Center
NCF	National Critical Function
NIAC	National Infrastructure Advisory Council
NRMC	National Risk Management Center
PPE	personal protective equipment
ROE	risk of exposure

A Function-Based Approach to Assessing Critical Infrastructure Risk

In its analyses of risk from COVID-19, HSOAC was asked to employ the NRMC's NCF risk assessment framework. We highlight some key features of the approach here and provide more detail on the approach in "Overview of the NCF Risk Assessment Framework."

In scoping out the risk assessment task, the NRMC adopted DHS's formal definition of *risk* as the "potential for an unwanted outcome as determined by its likelihood and the associated consequences" (Management Directorate, 2017, p. 563). The DHS lexicon offers an extended version of this definition that considers "hazard/threats, assets and their vulnerabilities, and consequences" (Management Directorate, 2017, p. 563). The important aspect of this extended definition is the emphasis on vulnerability, which acknowledges that factors beyond the immediate hazard influence the nature and magnitude of consequences.

The NRMC asked HSOAC to assess risk from COVID-19 to each of the 55 NCFs, which are shown in Table 1. The NCFs represent a new way of thinking about CI risk. Since its inception, DHS has focused on 16 CI sectors

> whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. (CISA, 2020c)

TABLE 1

The National Critical Functions

Category	NCF
Connect	Operate Core Network
	Provide Cable Access Network Services
	Provide Internet Based Content, Information, and Communication Services
	Provide Internet Routing, Access, and Connection Services
	Provide Positioning, Navigation, and Timing Services
	Provide Radio Broadcast Access Network Services
	Provide Satellite Access Network Services
	Provide Wireless Access Network Services
	Provide Wireline Access Services
Distribute	Distribute Electricity
	Maintain Supply Chains
	Transmit Electricity
	Transport Cargo and Passengers by Air
	Transport Cargo and Passengers by Rail
	Transport Cargo and Passengers by Road
	Transport Cargo and Passengers by Vessel
	Transport Materials by Pipeline
	Transport Passengers by Mass Transit
Manage	Conduct Elections
	Develop and Maintain Public Works and Services
	Educate and Train
	Enforce Law
	Maintain Access to Medical Records
	Manage Hazardous Materials
	Manage Wastewater
	Operate Government
	Perform Cyber Incident Management Capabilities
	Prepare for and Manage Emergencies
Manage, continued	Preserve Constitutional Rights
	Protect Sensitive Information
	Provide and Maintain Infrastructure
	Provide Capital Markets and Investment Activities
	Provide Consumer and Commercial Banking Services
	Provide Funding and Liquidity Services
	Provide Identity Management and Associated Trust Support Services
	Provide Insurance Services
	Provide Medical Care
	Provide Payment, Clearing, and Settlement Services
	Provide Public Safety
	Provide Wholesale Funding
	Store Fuel and Maintain Reserves
	Support Community Health
Supply	Exploration and Extraction of Fuels
	Fuel Refining and Processing Fuels
	Generate Electricity
	Manufacture Equipment
	Produce and Provide Agricultural Products and Services
	Produce and Provide Human and Animal Food Products and Services
	Produce Chemicals
	Provide Metals and Materials
	Provide Housing
	Provide Information Technology Products and Services
	Provide Materiel and Operational Support to Defense
	Research and Development
	Supply Water

NOTE: This table is adapted from CISA, undated b.

The NCFs do not replace the 16 CI sectors but shift the focus from the physical infrastructure itself to the functions supported by infrastructure assets and organizations. The goal of this approach is to provide a more integrated and coordinated risk management response across federal agencies and the private sector (CISA, undated a). Table 1 lists the NCFs according to whether the main function of the NCF is to connect, distribute, manage, or supply.

Purpose and Organization of This Report

The purpose of this report is twofold. First, we provide an overview of the NCF risk assessment framework as we implemented it to assess risk from COVID-19. Second, we discuss challenges and opportunities in applying this approach. The discussion of challenges and opportunities includes issues that arose during the implementation of the framework, as well as exploratory analyses of the following key topics relevant to the NCFs:

- the characteristics of high-quality indicators for analysis and tracking of NCFs
- risk mitigation options for COVID-19 and beyond
- interdependencies among NCFs
- different NCFs' relative vulnerability to COVID-19 disruption
- the geographic distribution and concentration of NCFs.

Although there was variation in the methods used to conduct these exploratory analyses (the results of which are described in "Additional Opportunities to Expand and Improve the NCF Risk Assessment Framework"), all incorporated some common elements:

- examination of the framework that we used to support the NRMC in the analysis of COVID-19 risk to the NCFs
- interviews with HSOAC and NRMC analysts, as well as other stakeholders, about their experience in using the NCF framework
- integration of insights from all of HSOAC's work on NCFs and from discussions with government and industry subject-matter experts identified by HSOAC and the NRMC
- analysis across sources to identify key lessons about the NCFs and the methods used in our analyses.

This report draws on interim work products developed during 2020.

We note that the NCF risk assessment framework discussed in this report evolved over the course of this effort and continues to evolve. The COVID-19 pandemic represented the first significant application of the framework to a national emergency. Although the NRMC had identified the major components of the framework before the start of the pandemic, HSOAC and the NRMC made many decisions about how to apply the framework (such as what indicators and data to use to track risk for each of the NCFs) during the implementation process. The historic, unprecedented risk affected decisionmaking processes and decision outcomes; some were subject to time and resource constraints or data limitations. Below, we describe the main components of the framework, and we report on choices we made, in consultation with the NRMC, to operationalize the framework during the global COVID-19 pandemic.

This report is intended to inform the actions of federal agencies, state and local authorities, and the private sector. In particular, this report should be of interest to owners and operators of CI, risk managers, and others involved in COVID-19 risk assessment activities. It should also be of interest to a broader public audience that would like to understand more about how national risks are, and can be, assessed.

The remainder of this report is organized in four main sections:

- "Overview of the NCF Risk Assessment Framework"
- "Challenges and Opportunities Identified in Applying the NCF Risk Assessment Framework"
- "Additional Opportunities to Expand and Improve the NCF Risk Assessment Framework"
- "Conclusions and Action Items for the NRMC"

Overview of the NCF Risk Assessment Framework

In this section, we lay the foundation for the discussion of challenges and opportunities by describing the framework used to assess risk to the NCFs from COVID-19. As noted in the introduction, the NRMC developed the main contours of the framework, and HSOAC was asked to operationalize the framework, a process that, in many cases, involved additional decisions about the framework to enhance its value for risk communication to CISA and its stakeholders. We first describe the components and implementation of the NCF risk assessment framework itself and then discuss key milestones in its implementation.

Initial Components of the NCF Risk Assessment Framework

In tasking HSOAC to assess risk to the NCFs from COVID-19, the NRMC established some basic parameters for us to use. In this section, we describe these components of the NCF risk assessment framework.

The Assessment End Point

DHS defines the risk assessment end point as the risk outcome that is being assessed. The NRMC identified the end point for the purposes of the NCF risk assessment as disruption or degradation of a given NCF such that it reaches a point at which it is no longer capable of adequately addressing essential needs. In applying this end point, we assumed that disruption and degradation reflected *thresholds beyond which nationally significant consequences would arise*. The risk assessment framework therefore assesses the likelihood that these thresholds are exceeded but does not reflect the subsequent consequences of that exceedance. Moreover, determining what constitutes a nationally significant consequence was largely a function of analysts' expert judgments and ongoing iteration with the NRMC.

Drivers of Risk

The NCF risk assessment framework considers the risk of degradation or disruption in response to five potential drivers of risk, as defined by CISA (CISA, 2020b, p. 8):

> **Driver 1—Core Commodity Supply Shortage.** A limited supply of a core commodity is available—or something necessary to produce the core commodity—that is essential for the continued reliable operation of the critical function. Example: A national shortage of Personal Protective Equipment [PPE] affects the ability of the Provide Medical Care NCF to operate reliably.
>
> **Driver 2—Shortage of Workers.** A shortage of workers necessary for the continued operation of a critical function exists, either in whole or a crucial subset. This degradation can occur because of illnesses, social distancing policies, diminished transportation systems, or lack of child care. *Worker absenteeism due to illness, quarantining and lack of child care affects the Manufacture Equipment NCF as some assembly lines cannot operate if not completely staffed.*
>
> **Driver 3—Significantly Increased Demand for the Critical Function.** A demand increase significantly beyond normal operating parameters which could stress the normal operation of the critical function. *Example: A significant increase in demand for healthcare services affects the reliable operation of the Provide Medical Care NCF.*
>
> **Driver 4—Decrease in Demand.** A significant decline in demand for its operation or outputs from COVID-19 impact affects the function. The consequence of a decrease in demand for the function could result from a variety of reasons, including a decline in public confidence in utilizing a critical function or from restrictions placed on use. *Example: A significant decrease in demand affects the normal operation of Transport Passengers by Mass Transit NCF as less demand leads to significant reduction in the transportation service offered.*
>
> **Driver 5—Change in Cyber Posture.** The critical function is experiencing increased use of information and communications technology, new digital platforms, cyber augmentations to business activity, expanded remote access, and/or cascading demand for reciprocal technology-enabled solutions and/or may see

increase in potential adversarial targeting via cyber means. *Example: Tele-medicine replacing in-person doctor visits, requiring technology enablement among patients, doctors, records/financial systems with new demands on network configuration and data privacy.*

We note that HSOAC was charged with assessing only the first four drivers. We did not have firsthand knowledge about the fifth driver, so the NRMC conducted its own analyses of this driver.

The Time Horizon

An explicit intent of the risk assessment activity was to provide early warning and foresight to the NRMC about emerging risks associated with the NCFs, with sufficient lead time to advise government and industry stakeholders and enable potential interventions to mitigate risk. Accordingly, the default time horizon that the NRMC selected for risk assessment was 60 days. This time horizon was assumed to be sufficient to project changes in the NCF risk landscape and to implement responses to mitigate risk. With risk being assessed on an ongoing basis over months, the analysis was implemented as a rolling time horizon, with each iteration looking 60 days ahead.

Probability Levels

Per the DHS definition of *risk*, the NCF risk assessment framework includes judgments about the probability of disruption or degradation to the NCFs. Using guidance that the NRMC provided, we expressed these probabilities in three categories of risk: low, medium, and high. Each category was associated with a quantitative probability range (Table 2). These probability ranges were reevaluated over time based on analysts' experiences in applying them.

Additional Components of the NCF Risk Assessment Framework

Over time, we worked with the NRMC to refine the framework and the associated methods as the pandemic and its consequences progressed and the NRMC's needs changed. In this section, we describe some additional components of the framework that were developed over time. We implemented the risk framework in three phases, as shown in Table 3. Note that phases II and III overlap.

Development of Risk Ratings

HSOAC subject-matter experts rated risks using the high/medium/low probability levels shown in Table 2. We assembled a team of more than 50 analysts with expertise spanning the 55 NCFs. Team members were charged with assessing the risk of disruption to each of the 55 NCFs within the next 60 days by any of the four drivers that the NRMC specified: (1) a core commodity supply shortage, (2) a shortage of workers, (3) significantly increased demand for the NCF, and (4) a significant decline in demand.

Our risk ratings were provided to the NRMC and informed the NRMC's own official risk ratings, which also integrated other information from NRMC analysts, federal agencies, and private-sector stakeholders. The NRMC subsequently shared its ratings with stakeholders, who included leadership and risk managers at DHS and other federal agencies.

Identifying Risk Indicators and Data Sources

To develop risk ratings for the NCFs, HSOAC analysts needed to identify indicators for each NCF—measures that could be used to determine the state or health of an NCF based on the NCF's response to the four risk drivers. For example, indicators used to

TABLE 2
Probability Levels Applied in the NCF Risk Assessment Framework

Level	Definition
Low	A low chance of national-scale disruption or degradation at any point in time over the period of concern occurring as a result of the identified scenario (measured as roughly a 0–10% chance of occurrence)
Medium	A moderate chance of national-scale disruption or degradation at any point in time over the period of concern occurring as a result of the identified scenario (measured as roughly an 11–25% chance of occurrence)
High	A high chance of national-scale disruption or degradation at any point in time over the period of concern occurring as a result of the identified scenario (measured as a chance of occurrence greater than roughly 25%)

TABLE 3
Phases of Implementation

Phase	Period of Effort	Focus
I	March 2020 to May 2020	• Rapid assessments of NCFs that the NRMC identified as high priority • Initial development and application of the NCF risk assessment framework • Completion of two long-form risk assessments covering all 55 NCFs
II	May 2020 onward	• Transition to a weekly risk assessment deliverable designed to track changes in NCF risk ratings over time
III	July 2020 onward	• Reflection on assessment methods, process, and analyses to improve methods to better align them to standard risk assessment best practices and to explore opportunities to expand the scope and further enhance the framework

measure the Educate and Train NCF include pre-K–12 school closures, state and local budgets for education, and access to broadband. HSOAC analysts identified one or more relevant indicators for each driver and NCF, assembling a total of more than 700 indicators across the 55 NCFs. Individual indicators and their sources were identified, as was additional information about each indicator to inform its suitability for the NCF of interest. This included such items as the accessibility of the data, quality of the data, frequency of data updating, geographic coverage, and whether the indicator provided sufficient lead time to serve as an early warning of emerging risk. We then analyzed the indicators to assess whether an NCF was already disrupted or had the potential to be disrupted at a nationally significant level within the subsequent 60 days.

Design of the Risk Assessment Template

HSOAC researchers, in consultation with the NRMC, designed a risk assessment template to facilitate an in-depth, data-driven assessment of risk. This template included a variety of content types, as shown in Table 4, which were standardized across NCFs. The assessment for each NCF ranged from less than four to nearly 20 pages, depending on the NCF's vulnerability to COVID-19 and the volume of information available on the NCF.

The NCF Risk Assessment Dashboard

We employed a dashboard format as a means of presenting the risk ratings for the NCFs. The dashboard presented risk ratings for each NCF and risk driver, using the risk categories in Table 2. A generic example displaying part of a dashboard with some notional ratings is shown in Table 5; the actual dashboards list all 55 NCFs. Note that the dashboard includes driver 5, Change in Cyber Posture, although we did not conduct the assessment for this driver. We also developed individual dashboard-like displays with in-depth information for each NCF describing our rationale for the risk ratings, potential mitigation measures, and supporting data sources. The NRMC used our dashboard and more-detailed NCF analysis to inform its own final risk ratings for each NCF on its own dashboard.

TABLE 4
Content Types Included in NCF Risk Assessments

Content	Question Answered
NCF definition	What is the scope of the NCF?
Consequences of disruption	What would the consequences be to the United States if the NCF were disrupted? What is the NCF's role in supporting economic activity, health, safety, or national security?
Likelihood of disruption	What is the probability that the NCF will be disrupted in the coming 60 days?
Interdependencies	What other NCFs support, or are supported by, the NCF?
Analysis of indicators for each driver	What indicators provide insights into the NCF's status and provide the evidence for judgments about the likelihood of disruption?
Mitigation	What mitigation options could reduce the likelihood or consequences of disruption?

TABLE 5

Generic Example of an HSOAC NCF Risk Dashboard with Notional Ratings

	Driver				
NCF	1: Core Commodity Supply Shortage	2: Shortage of Workers	3: Significantly Increased Demand	4: Decrease in Demand	5: Change in Cyber Posture
1	High	High	High	High	High
2	Medium	High	Low	High	Low
3	Low	Medium	High	Low	High
4	High	High	Medium	Low	Medium
5	Low	Medium	Low	Medium	Medium

Risk Reports

We developed two kinds of risk reports to provide information on our risk ratings to the NRMC. The first type was the NCF long-form risk assessment, which included full risk analyses of all 55 NCFs. Two long-form assessments were completed, one in April and one in May 2020. Long-form analyses focused on the initial identification of indicators for each NCF/driver combination and the rationale for selecting them; a risk assessment based on current and historical indicator performance; potential indicator-based thresholds for changing the assessed level of risk; whether the NCF was provided locally, regionally, nationally, or is a hybrid; consequences of disruption; and potential mitigation measures.

Following production of the second iteration of in-depth analyses of the NCFs, the NRMC asked HSOAC to develop a means of providing agile, more-frequent risk updates. Accordingly, we created a more concise product, referred to as the *COVID-19 NCF weekly risk report*, designed to provide the NRMC with a weekly curation of HSOAC analysts' insights into emerging risks and their impacts on NCF risk ratings. Each production cycle of the weekly risk report consistently included updates on COVID-19 (e.g., case, mortality, and testing trends, as well as regional hot spots), qualitative statements from HSOAC analysts on emerging issues, and the HSOAC NCF dashboard and comparison with the NRMC dashboard. Over time, additional elements were added to the weekly risk report, including visualizations of time series of NCF risk ratings and maps illustrating the intersections of select NCFs with COVID-19 cases and deaths.

We note that, for some NCFs, indicators were available to provide updates with sufficient frequency (e.g., hourly to weekly) to enable near–real-time tracking of NCF performance. For example, NCFs that were directly affected by COVID-19 cases could be monitored with daily case and mortality data from the Centers for Disease Control and Prevention. However, other NCFs were associated with indicators that were not updated with sufficient frequency to allow such monitoring; in such cases, analysts often tracked media reports that might suggest future implications for the NCFs.

Now that we have described the key components of the NCF risk assessment framework, we turn to a discussion of what we learned from its application.

Challenges and Opportunities Identified in Applying the NCF Risk Assessment Framework

COVID-19 presented the first opportunity for operational use of the NCF risk assessment framework. As such, modifications were required to operationalize and refine the framework. In this section, we discuss challenges and opportunities arising from two main streams of work: (1) issues that arose early in the implementation of the framework, some of which were quickly addressed, and (2) issues that arose later in the implementation, as part of an effort to better align the framework to best practices in the field of risk management.

Adjustments to Address Challenges Identified Early in the Implementation of the Framework

As part of our work early in the project, we compared risk ratings from HSOAC analysts with those from NRMC analysts to identify any disparities in risk assessment that would merit further deliberation. Where there were significant and persistent discrepancies, we brought them to the attention of NRMC staff. Discrepancies were often attributed to different analytical judgments or a focus on different data sources. Some pertained to the highly aggregated nature of some of the NCFs (i.e., one NCF can incorporate multiple functions and types of CI) and the different ways in which risk from NCFs is distributed (i.e., some NCFs are provided on a national scale, while others are provided on a local or regional basis, a difference that has implications for managing risk). Other discrepancies were determined to be a function of the assessment process, including the selection of indicators, the use of those indicators in developing risk ratings for specific drivers, and interdependencies among the 55 NCFs.

Some key challenges identified early in the implementation process included the following:

- **NCFs might be too aggregated or not well-enough defined.** In several cases, we found that the NCFs might be too aggregated or not well-enough defined to support clear assessment. For example, Maintain Supply Chains aggregates across numerous current challenges, given the scope of current events by which the entire world economy is affected. In contrast, Provide Internet Based Content, Information, and Communication Services is difficult to separate in a clear way from the other information and communication technology NCFs.
- **Indicators should be selected, tested, and refined over time.** For many NCFs, the indicators were not obvious, and the data were not readily available for analysis. A particular challenge was to determine whether indicators are actually *leading* indicators rather than simply real-time or lagging indicators. For example, many authoritative, national-level data sources on key measures of the economy are released for the most recently concluded quarter of the year.
- **Some NCFs relied on complex inputs that were not traditional commodities but might fit best under driver 1.** Driver 1 is framed as constraints on core commodities. However, some of the NCFs did not rely directly on traditional commodities (e.g., raw materials or agricultural products) but instead rely on more-complex or -refined inputs, which meant that analysts had to consider a wide variety of potential inputs that could affect the supply or availability of a particular function. Further clarification of the scope of commodity constraints to be considered could enhance consensus among analysts.
- **NCF criticality and consequence are missing but potentially vital elements of risk assessment.** A common challenge for HSOAC researchers was the need to determine whether ratings were being assigned based on the *likelihood* of disruption or the *consequences* of disruption. HSOAC analysts were initially advised to focus on the likelihood of disruption of the function rather than downstream consequences, which was considered a broader research challenge beyond the scope of the project. This could partly explain why HSOAC analysts often generated higher ratings than NRMC analysts did and triggered recalibration of the ratings.
- **Assessments were potentially biased toward high risk ratings.** The original NCF risk assessment framework used the risk categories identified in Table 2. After multiple months of applying this framework in the weekly risk reports, the HSOAC and NRMC analysts observed some NCFs receiving persistently high risk ratings. The limited number of risk categories and the range compression that labeled probabilities above 25 percent as high (Table 2) resulted in ratings that were potentially biased to the high rating. As a consequence, the high risk ratings assigned to some NCFs in April and May could not be further elevated in July or October, despite evidence

of more-severe COVID-19 spread during the second and third peaks. Furthermore, the NRMC noted that none of the NCFs associated with persistently high ratings had failed, suggesting that continuing to label NCFs as being at high risk despite their ability to continue to maintain functionality might have overstated the severity of their status.

- **Disruption of locally or regionally provided NCFs can have national significance, but thresholds are needed.** Some NCFs are inherently local to regional in nature (e.g., water and wastewater systems and law enforcement), while others are concentrated in particular U.S. regions (e.g., oil and gas operations in the U.S. Gulf Coast or agricultural production in the U.S. Midwest). As a consequence, reconciling the NCFs' emphasis on national-scale disruptions with the potential for local- to regional-scale disruptions could enhance the utility of NCF analysis to stakeholders.
- **There are inherent limitations in considering risk only to individual NCFs.** The original NCF analyses suggested the limitations of considering risk to individual NCFs in isolation of other NCFs, as well as the need for more in-depth exploration of particular factors that would mitigate risk. This resulted in the extension of the project to address other lines of effort that analyzed, for example, the identification of indicators that appear to be useful for multiple NCFs, mitigation efforts, interdependencies among NCFs, vulnerabilities, and the geographic distribution of NCFs.

We were able to address several of these challenges in subsequent iterations of the framework. For example, over time, we clarified definitions for such key terms as *degradation* and *disruption*. We developed a conceptual model with degradation, disruption, and failure falling along a continuum of NCF deterioration and therefore consequences (Figure 1). Under this model, any loss of function of an NCF from its normal baseline represents a degradation. However, once degradation proceeds to the point of representing a nationally significant loss of function or performance, that degradation is classified as a disruption. A complete loss of a function would constitute failure.

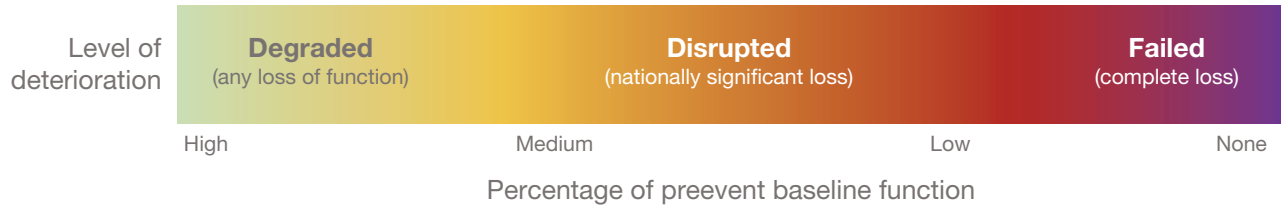
With this conceptualization of degradation and disruption, we developed the following formal definitions:

- *Degradation* is a deterioration of the normal baseline capacity to deliver an NCF. Such degradation can be minor or significant, localized or geographically widespread. Degradation can be reduced through the implementation of mitigation options that alter material inputs, personnel, operations, or outputs in an attempt to maintain the functionality or productivity of the NCF.
- *Disruption* is the degradation of an NCF that is nationally significant in terms of geographic extent, the population served or supported, or the severity of consequences or any combination of these.

We also made changes to adjust the risk ratings, which helped address the challenge of potential bias toward high risk ratings. To address this issue, HSOAC and NRMC analysts explored alternative ways of categorizing risk from the four drivers to the NCFs. These included two key adjustments:

- introduction of an additional risk rating of "critical" to better communicate when an

FIGURE 1
Components of Phase I NCF Risk Assessments



NCF is judged as having a high probability of disruption
- recalibration of the probability ranges for all the risk categories, as well as the use of more-specific probabilistic language.

When combined with the changes to definitions (e.g., emphasis on disruption as limited to nationally significant events), this shift represents a significant recalibration of the risk assessment (Table 6).

In addition to making modifications to the risk assessment methods, in September 2020, we began working with the NRMC to select a subset of NCFs to be the focus of additional assessment activities moving forward. Although the NCFs are all considered, by definition, to be "essential to the functioning of the nation," they are associated with differential levels of vulnerability to COVID-19, and the consequences of disruption are not equivalent for every NCF or every risk. Emphasis was placed on those NCFs anticipated to be particularly vulnerable to disruption during the fall and winter. We developed a quantitative scheme for prioritizing NCFs based on the frequency of different risk ratings associated with an NCF over the entire time span in which we assessed risk and the volatility in those risk ratings from week to week. This resulted in a quantitative ranking of all 55 NCFs.

TABLE 6

Probability Levels Applied in the Updated NCF Risk Assessment Framework

Level	Definition
Low	A national-scale disruption occurring as a result of the identified scenario at any point in time over the period of concern is a *remote possibility* (measured as roughly a 0–20% chance of occurrence).
Medium	A national-scale disruption occurring as a result of the identified scenario at any point in time over the period of concern is *unlikely* (measured as roughly a 21–50% chance of occurrence).
High	A national-scale disruption occurring as a result of the identified scenario at any point in time over the period of concern is *probable* (measured as roughly a 51–80% chance of occurrence).
Critical	A national-scale disruption occurring as a result of the identified scenario at any point in time over the period of concern is *very likely* (measured as roughly a 81–100% chance of occurrence).

SOURCES: Adapted by the authors from federal risk management guidance (DHS, 2009; Computer Security Division, 2012).

In addition, we identified three vulnerability factors that could increase the risk of NCF disruption in the months ahead:

- *Local provision of the NCF* typically means that the NCF is strongly dependent on local government and the sustainability of local government revenue, making such an NCF vulnerable to an observed downturn in revenue for local governments.
- *NCFs that demonstrate strong seasonality*, particularly with greater vulnerability in the winter months, could experience an escalation in risk as demand changes for certain infrastructure services.
- *NCFs that benefit from significant public assistance* (federal or state) to offset the pandemic's adverse economic impacts could be vulnerable to a sudden escalation of risk if support were to cease.

NCFs associated with one or more of these factors were considered to be at greater risk than those without any of these risk factors.

Although we were able to address some of the initial challenges identified, other challenges, such as issues associated with indicator selection, national versus regional impacts, and the need for cross-cutting analyses, required additional analysis and consideration. This resulted in the extension of the project to include additional analyses to explore, for example, the identification of indicators that appear to be useful for multiple NCFs, mitigation efforts, interdependencies among NCFs, vulnerabilities, and the geographic distribution of NCFs. We discuss these efforts in "Additional Opportunities to Expand and Improve the NCF Risk Assessment Framework."

Alignment with Best Practices

In July 2020, we began working with the NRMC on a critical review of the risk assessment methods used in the COVID-19 risk assessment project. This review was designed to

- address observed challenges associated with implementation of the framework and the communication of results to the NRMC

- align the methods to standard risk practices used by DHS and the federal government more broadly.

A key component of this effort was to identify best practices described in risk studies, existing frameworks, and case studies, which we then used to critique the practices we used in our assessment. In Table 7, we note several best practices.

To identify best practices for risk assessment and analysis as a basis for improving the NCF risk assessment framework, we sought insights from risk assessment literature and consulted with experts within the team, across HSOAC and RAND more broadly, and in academia. We used the collective knowledge and expertise of team members, RAND researchers outside the team, as well as an academic thought leader in this area (Granger Morgan) to point us to key literature to guide this review. We consulted peer-reviewed risk studies, case studies, review pieces on theory and practice, and government frameworks for assessing risk. We did not attempt to conduct a comprehensive review of best practices but focused on those that were relevant in the NCF context and that were referenced in multiple sources as being best practices. We cross-referenced best practices reported in the academic literature with those described in federal management guidance and frameworks. The citations included in Table 7 focus on the latter.

Several of the identified best practices were evident within the original NCF risk assessment framework or were addressed in subsequent assessment phases. For example, the original framework was explicit about the probabilities associated with different risk ratings (practice 1). However, those probabilities were modified over time, and the assessments often did not generate quantitative information on the consequences of NCF disruption. Similarly, we established a specific time frame for the assessment of risk (practice 6), and we considered the geographic distribution of risk (practice 5), although, as we discuss later in this report, additional analyses of geographic distribution might be carried out. A quality assurance process was also implemented that included training for analysts on the assessment of risk, evaluation of data quality, peer review of risk assessments, and a critical review and recalibration of risk ratings (practice 9). Finally, the NCF risk assessment framework was specifically designed to help support decisionmaking by DHS and other federal stakeholders about potential interventions to mitigate risk (practice 10).

Some of the practices in Table 7 were not addressed by the NCF risk assessment framework or were not addressed consistently. For example, although we recognized interdependencies among NCFs and the potential for risk to propagate, we did not consistently assess cascading and interacting risks and had limited tools to facilitate such analyses (practice 2). We also did not routinely assess or communicate uncertainty (practice 3) in risk judgments beyond some reported data quality descriptions associated with indicators used for risk assessment. Over the course of the project, HSOAC and NRMC analysts became aware of potential cognitive biases (practice 4) that appeared to influence risk scores for certain NCFs. Analysts implicitly addressed vulnerability and resilience of each NCF in their risk assessments rather than using a set of indicators or methods for making explicit judgments.

In the next section, we report on some further analyses we conducted to identify additional opportunities to improve the risk assessment framework.

Additional Opportunities to Expand and Improve the NCF Risk Assessment Framework

Within the context of the project, we identified several opportunities to further enhance the decision relevance of the NCF risk assessment framework. These opportunities are related to challenges identified in "Challenges and Opportunities Identified in Applying the NCF Risk Assessment Framework" that we were not able to address immediately. In this section, we focus on five areas of opportunity:

- indicator development and quality
- risk mitigation
- interdependence of NCFs
- vulnerability of NCFs
- geographic distribution of NCFs.

TABLE 7

Risk Assessment Best Practices

Practice	Description	Rationale	Example Source
1. Include quantitative risk estimates.	Communicate likelihoods of consequences quantitatively rather than relying solely on qualitative words of probability.	Qualitative descriptors of likelihood are associated with significant ambiguity and might be interpreted differently by different individuals.	National Research Council, 1983; National Research Council, 2010
2. Account for infrastructure interdependencies in the assessment of risk.	Account for risks that can emerge indirectly through disruption of interdependent NCFs.	Risks associated with cascading failures, indirect consequences, or cumulative effects are often overlooked or underestimated in risk assessment.	National Research Council, 2010; NIAC, 2004
3. Incorporate uncertainty.	Explore a wide variety of threat scenarios.	Failure to account for diverse threats in the assessment of risk can leave risk managers vulnerable to surprises and unmitigated risks.	Accounting and Information Management Division, 1999; Computer Security Division, 2012; DHS, 2009; DHS and National Capital Region Coordination Office, 2008; National Research Council, 2010; Office of Risk Management and Analysis, 2011; Office of the Science Advisor, 2014b; Risk Assessment Forum, 1992; Thomason, 2009
	Provide quantitative uncertainty metrics or qualitative uncertainty characterizations for risk estimates.	Risk estimates are invariably associated with uncertainty. Providing risk managers with information on those uncertainties and confidence in the estimates is necessary for decisionmaking about mitigation.	Computer Security Division, 2012; GAO, 2016; National Research Council, 1983; National Research Council, 2010; Office of the Science Advisor, 2014a; Office of the Science Advisor, 2014b
4. Address potential cognitive biases in the interpretation of risk estimates.	Include specific processes to minimize analyst bias in the assessment and interpretation of risk.	Common biases can cause overestimation or underestimation of risk, either of which adversely affects decisionmaking about mitigation.	National Research Council, 1983; National Research Council, 2010
5. Consider the geographic distribution of impacts.	Include specific information about the locations and extent of risk.	Risk to infrastructure functions can vary by geographic area, depending on the distribution of threats and exposed assets.	Accounting and Information Management Division, 1999; National Research Council, 2010; Risk Assessment Forum, 1992; Willis et al., 2018
6. Consider the temporal distribution of risk.	Include specific information about the timing associated with different risks.	Risks can manifest over different time horizons and be valued differently within decisionmaking processes.	Computer Security Division, 2012; Office of the Science Advisor, 2014a; Risk Assessment Forum, 1992
7. Incorporate vulnerability and resilience.	Identify and monitor vulnerabilities, thresholds, and contingencies that influence the likelihood or consequence of adverse outcomes.	Vulnerability and resilience are key factors that mediate the likelihood of adverse outcomes. Therefore, explicit identification of vulnerabilities and factors that convey resilience can clarify the need for and selection of risk mitigations.	Accounting and Information Management Division, 1999; Computer Security Division, 2012; DHS, 2009; DHS and National Capital Region Coordination Office, 2008; GAO, 2016; National Research Council, 2010; NIAC, 2004; Office of Risk Management and Analysis, 2011; Rabkin, 2008; Willis et al., 2018
8. Define assessment inputs and end points.	Provide clear, unambiguous definitions of inputs and end points for the risk assessment.	Rigorous assessment and subsequent communication of risk necessitates clarity in what is being assessed.	Office of the Science Advisor, 2014a; Office of the Science Advisor, 2014b; Risk Assessment Forum, 1992

Table 7—Continued

Practice	Description	Rationale	Example Source
9. Follow quality assurance processes.	Implement processes to verify quality and consistency at important points in the assessment.	Ensuring that assessment inputs and procedures are rigorous and reproducible is necessary for building confidence in results.	National Research Council, 2010; Office of the Science Advisor, 2014a
10. Support good decisions.	Use risk assessments to identify opportunities to intervene to manage risk.	Risk assessment is a process for prioritizing mitigation options. Therefore, assessment activities should be pursued within a broader risk management process.	GAO, 2016; National Research Council, 1983; National Research Council, 2010; NIAC, 2004; Office of Risk Management and Analysis, 2011; Office of the Science Advisor, 2014a; Office of the Science Advisor, 2014b; Thomason, 2009

NOTE: NIAC = National Infrastructure Advisory Council. NIST = National Institute of Standards and Technology. GAO = U.S. Government Accountability Office.

Indicator Quality Could Be Further Refined, and Multiple Approaches Are Needed for the Wide Variety of NCFs

NCF indicators are used to determine the state or health of an NCF as measured by the four risk drivers. Early in the project, HSOAC analysts amassed 750 indicators from various sources, which covered 99 percent of the NCF drivers we were assessing for the 55 functions. As the COVID-19 crisis evolved, we refined the set of indicators to better support the changing risk assessment. Only 57 percent of indicators used in phase I (March to May 2020) were used in phase II (May 2020 to December 2020).

To identify opportunities for further enhancement, we examined the indicators used in the COVID-19 assessment through several lenses, including number per NCF and per risk driver, utilization across phases of the analysis, source type and update frequency, data source, quality and predictive value, and robustness beyond COVID-19. An overarching finding from these analyses is that different approaches are needed to develop indicators for the wide variety of NCFs; there is no one-size-fits-all model of a perfect indicator.

The type, number, and characteristics of indicators needed to assess risk for each NCF varied according to the definition of the NCF, the nature of the crisis being assessed, and time and resource constraints. For example, the number of indicators per NCF ranged from four to 44. Data from both public and private sources were used, although almost all of the indicators' data were open source. U.S. government and industry sources were most common, and HSOAC analysts tended to rate these as being of higher quality than other sources, such as media, although media sources were often used to support updates to weekly risk assessments when other sources were not updated frequently enough.

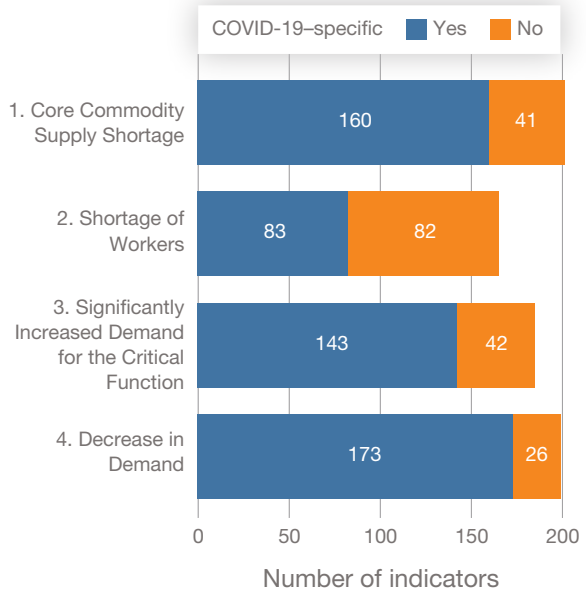
Indicators' utility to the risk assessment sometimes changed depending on the crisis recovery phase in which the indicator was used, the disaster type, and the risk analysis objectives. For example, although analysts rated 96 percent of the indicators as being of high or medium quality in their ability to assess *current* risk, they rated only 82 percent of indicators as being high or medium quality in their ability to predict *future* risk.

Although variation in the indicators used for the NCFs is not necessarily a problem, our analysis did identify challenges in the ways in which indicators are selected and utilized. These include variation in the resources needed and available to adequately characterize risk and cost constraints and uncertainty about access to proprietary indicators. In some cases, proprietary indicators might be able to provide more-specific, -robust guidance and could be worth the investment required to provide higher indicator-data fidelity and emerging-threat predictability.

There was also variation in indicators' robustness for use beyond COVID-19. To examine this issue, HSOAC analysts were asked to identify (using yes/no responses) whether their indicators were developed or created for an explicit purpose related to COVID-19 (Figure 2). As shown, COVID-19–specific indicators accounted for approximately 50 percent of

FIGURE 2

Numbers of Indicators, by Risk Driver and COVID-19 Specificity



the driver 2 (workforce) indicator, compared with a 15- to 30-percent proportion of the other risk drivers. Because COVID-19 directly affects the workforce's health, more indicators were created by authoritative, government agencies to measure COVID-19's effects on driver 2 than for the other risk drivers, demonstrating that the nature of a crisis affects the number of indicators required to assess each risk driver.

In some cases, eliminating non–COVID-19 indicators might decrease the indicator fidelity required for an individual NCF risk assessment. Approximately 13 percent of the NCFs lose 50 percent or more indicators when COVID-19–specific indicators are removed (data not shown). The COVID-19–specific indicators have not been evaluated for steady-state NCF risk analysis, although future NCF and indicator analysis would benefit from validating COVID-19–specific indicators for other disaster types and steady-state analysis. Ideally, an inventory of indicators with demonstrated utility for the steady state and for specific threats and hazards could be developed in advance so that a specific set of indicators could be employed and tested depending on the nature of the disaster (e.g., hurricanes).

Although this analysis illustrates the likelihood that a different crisis type or similarly scaled pandemic would require supplemental indicator analysis to support an accurate NCF risk characterization, the depth required to adequately characterize an NCF's risk environment will vary on an individual basis. When we eliminate COVID-19–specific indicators from the database, the indicator count decreases by 26 percent to 559 indicators and the NCF driver coverage decreases to approximately 89 percent. However, the samples' average quality assessment and predictive threat value for the COVID-19 assessment slightly *increases*. Because the data set has less than 90-percent indicator coverage without COVID-19–specific indicators, more analysis would be required to increase the robustness of the data set beyond COVID-19 and ensure the data set's relevance for other crises. However, the indicators we identified are robust to COVID-19, and, as noted above, there are distinct advantages to employing COVID-19–specific indicators.

Opportunities Exist to Enhance the NRMC's Role in Risk Mitigation

We conducted an overview of risk mitigation strategies and opportunities in the context of the COVID-19 pandemic and beyond. In this process, we analyzed the changing risk landscape over the course of the pandemic, based on our risk rating changes, and identified common adaptation responses and mitigation measures that NCFs implemented. We found that our NCF risk ratings changed during the COVID-19 pandemic for a variety of reasons—namely, shifts in the underlying risk and nature of the pandemic; how NCFs responded to the risk landscape and to the uncertainty around the pandemic and its effects; and the expectations and definitions of *risk* and *failure*, as interpreted by HSOAC analysts.

In the context of the NCF and driver-based risk assessment framework, we also found that, within the scope of our analyses, NCFs' adaptation and risk mitigation responses were generally focused on enhancing workforce protection (e.g., PPE use, remote work), securing supplies of commodities (e.g., stockpiling key inputs, working with suppliers), and adapting to changing demands (e.g., reallocating workers, realigning production). We also recognized that not all adaptation or mitigation measures resulted in

adequate provision of NCFs over the course of the pandemic. Some NCFs, such as Educate and Train, might have mitigated the risk of COVID-19 spread among NCF actors, but the results of these measures (such as remote learning) also significantly hampered the NCF's ability to function as normal and sufficiently educate and train the American population.

We interviewed members of CISA's NIAC who volunteered to serve as individual subject-matter experts (SMEs) in support of the NRMC's and HSOAC's ongoing efforts to characterize risk to the NCFs as a result of COVID-19. Although these discussions covered COVID-19's broad effects on the NCFs, we also identified mitigation needs among NCFs at the time of these interviews (April 2020). During these interviews, SMEs highlighted significant interdependencies between CI sectors, such as energy, water, transportation, agriculture, and finance, suggesting that one role CISA might be able to play is that of information broker, particularly by providing information about the status of other sectors on which a given sector is dependent. SMEs also noted the need for guidance from the federal government on key issues, such as recommendations for protective equipment for essential employees or acquiring supplies and commodities in the face of increased competition.

We leveraged the NRMC's internally developed list of COVID-19 CI risk mitigation strategies by risk driver, intended to serve as a foundational document outlining the role of various stakeholders in the public and private sectors in risk mitigation during the pandemic (CISA, 2020a). We also sought to gain a clearer picture of CISA's activities that supported risk mitigation over the course of the pandemic and identify opportunities for CISA moving forward. We examined the breadth of publicly available materials produced by the NRMC and CISA and drew from discussions with a variety of NRMC personnel, which focused on their roles in supporting or directly implementing actions to mitigate risk to NCFs. These interviews included both sector-specific and incident-specific experts in the NRMC, various personnel across leadership ranks, and CISA regional directors. From these groups, we interviewed 15 people between October and November 2020.

Drawing on these methods and resources, we examined the role that CISA itself has played in supporting risk mitigation over the course of the pandemic and the role it could play moving forward. We identified seven roles—data collection, analysis and dissemination, planning and guidance, convening, coordination, and training and direct support—that align in some way across the various activities and risk mitigation strategy documents in which CISA and the NRMC have been engaged.

Our review of CISA planning and guidance documents and interviews with NRMC personnel revealed that the NRMC also encountered challenges, including the following, in engaging in risk mitigation actions:

- a broad mission to measure, assess, and support the management of risk for national CI
- a focus on national-scale risks, limiting the NRMC's role at regional to local scales
- a supporting role; not an owner-operator of CI
- CISA's ability to raise emerging issues but with the onus often left to other entities to mitigate risk to their systems
- the need to clearly define lanes of responsibility in interagency and multisectoral work
- the lack of available data at the fidelity needed to assess and prioritize interventions.

We also identified a variety of opportunities that CISA and specifically the NRMC could implement to enhance the agency's role in risk mitigation moving forward, based largely on insights and challenges identified in our interviews with NRMC and CISA personnel. CISA could leverage existing analytical and topical expertise to deepen its capacity to advise and support the implementation of risk mitigation strategies. One example of this would be for the NRMC to review, validate, and prepare a list of essential CI workers (ECIWs) for relevance in other disasters or extend and formalize the current ECIW list to support vaccine distribution. Given the NRMC's broad role in national risk assessment and the types of interventions it has supported to date during the COVID-19 pandemic, risk mitigation strategies that fall within the NRMC's current purview and capacities could include any or all of the following elements:

- Leverage existing data sets or data that CISA could easily extend.

- Utilize CISA expertise in risk analysis.
- Be cross-sectoral; fill a gap in existing responsibility, expertise, or awareness.
- Take advantage of existing networks within CISA's coordinating and convening capacity to disseminate or implement strategies.

CISA could also extend its analytical processes, data collection, and monitoring efforts and methods to further support risk mitigation. This could include working with CISA regional directors and their CI partners to systematically collect data and identify and monitor risk mitigation activities and their relative impact on NCFs. This would provide situational awareness for risk mitigation for CISA and NRMC staff, as well as help risk analysts better understand the role that mitigation strategies are playing during risk assessment. These efforts could also be extended to bolster data collection efforts more broadly. For example, collecting and centralizing data on absenteeism among key CI workforces could be more formally executed in coordination with regional directors. CISA could also further leverage internal expertise on risk monitoring and assessment to build or strengthen an internal analytical structure or framework to assess multisector risk reduction. With a clear analytical structure, NRMC analysts could more readily identify relevant mitigation strategies or track the progress of those implemented by NCF stakeholders. Such an analytical structure could, for example, help the NRMC determine how to allocate materials, such as PPE or industrial chemicals, needed by different CI sectors in which they provide the greatest risk reduction value.

This review included some academic literature but focused primarily on publicly available DHS and CISA policy and planning documents related to risk mitigation, especially those that included either detailed risk mitigation strategies or a framework for characterizing risk mitigation.[1]

Assessments of Interdependence Illustrate How Risk to One NCF Can Affect Other NCFs

Interdependence, as defined by the DHS lexicon (Management Directorate, 2017, p. 346), refers to a "mutually reliant relationship between entities (objects, persons, or groups)." Interdependence between NCFs can result from a variety of processes, including linkages between NCFs such that the outputs of one NCF are inputs to another NCF, and noneconomic network structures, such as software or cyberdependencies, which mean that a disruption to one NCF affects other NCFs.[2]

The interdependence of NCFs might be a significant factor that translates isolated risks into more-systemic ones. We adopted the definitions used in Welburn and Strong, 2021:

- *Cascading risk* is the potential propagation of failures throughout a system, a so-called domino effect. Power lines, for example, are a common example of the potential for cascading failures being a significant source of risk.
- *Common-cause risk* is the risk of several subsystems failing because of the same driver. Floodplains are a source of common-cause failure: Multiple houses can flood simultaneously because of their shared locations.

NCF interdependence does not imply only negative consequences, however. For example, if there is a disruption to a pipeline (transport materials by pipeline), alternative transportation, such as rail, might be used to overcome the consequences of the disruption. Accordingly, disruption to one NCF can increase demand for another NCF. Knowing these functional relationships allows for clearer consideration of the consequences of disruptions.

Interdependencies can give rise to central NCFs with elevated importance in assessing risk. HSOAC analysts illustrated this point by visualizing the economic linkages between NCFs as a network and estimating each NCF's value-added multiplier, which helps improve the assessment of an NCF's relative criticality for specific categories of events.

To estimate the NCF's value-added multiplier, we translated each NCF into an economic sector or set of sectors and then assessed the ripple effect as spending in one industry led to spending in another industry and then another, in a series of cycles. This series of cycles can be summarized by the multiplier effect—that is, given an initial dollar of spending in a particular industry, the multiplier describes that dollar's overall contribution to local economic activity. This multiplier can be interpreted as the aggregate

impact of production from each NCF. For example, consider Transport Materials by Pipeline: The multiplier indicates that every $1 produced by this NCF generates $1.80 to the system of NCFs.

By quantifying and visualizing the economic linkages between NCFs as a network, we can start to see how NCFs are interdependent and how those interdependencies help us recognize central NCFs that exert influence on other NCFs through interdependence. This analysis reveals how NCFs are interconnected and how those connections elevate the importance of specific NCFs. These interconnections provide a mechanism for more-dynamic assessments of risk to NCFs.

By analyzing the NCF-to-NCF ties, we were able to rank-order most NCFs according to their value-added multipliers. For example, in examining economic interdependence, we found that, when ranking NCFs by their economic multipliers, Operate Core Network, Provide Capital Markets and Investment Activities, Provide Radio Broadcast Access Network Services, and Educate and Train rose to the top of the list for COVID-19 because these provide the backbone of numerous businesses and services across NCFs. However, because most of these NCFs were not put at risk as a result of COVID-19, their relative importance to the overall response would not be reflected by their multiplier rankings.

Although each multiplier indicates the relative criticality of a specific NCF, one NCF's impact on others depends on both the NCF's multiplier and its total output. An NCF with a lower multiplier but very high total output might have more impact than an NCF with higher multiplier but less output. For example, Operate Core Network has a higher multiplier than Exploration and Extraction of Fuels, but, because the latter has more total output, it has a larger total economic impact.

Understanding the economic interdependence of NCFs can be challenging, in part because the NCFs are of varying levels of specificity in economic terms. Although some refer to very specific economic sectors (closely following the sectors identified by North American Industry Classification System codes), others are broader. For example, each of the NCFs Develop and Maintain Public Works and Services, Generate Electricity, Produce Chemicals, Provide Metals and Materials, and Provide Information Technology Products and Services applies to a set of economic sectors and consequently can carry a range of economic multipliers. Furthermore, substitution effects across NCFs are likely to occur but were not captured by our analysis. Consider, for example, a loss of the ability to transport fuel by rail: Transportation by road and pipeline might provide adequate substitutes. Wireless networks might provide similar substitutes for losses in wireline access.

Our analysis took an initial step toward capturing interdependence among NCFs, although we were able to focus on only one important type of interdependence: economic interdependence. Understanding how NCFs are exposed to cascading and common-cause risks can help navigate the challenges of emerging, and possibly unmodeled, risks. To better capture this concept, future NCF risk analyses might give greater consideration to the implications of interdependence.

Understanding Vulnerability Can Help Identify Priorities for Risk Mitigation

Incorporating vulnerability into risk analyses is one of the best practices identified in Table 7, and, as noted above, HSOAC analysts identified three vulnerability factors that could increase the risk of NCF disruption due to COVID-19 (i.e., local provision of the NCF, NCFs that demonstrate strong seasonality, and NCFs that benefit from significant public assistance). However, we recognized that additional analysis of the vulnerability of NCFs could reveal potential opportunities to further enhance the risk assessment approach.

Although all NCFs can be vulnerable to any of the drivers of risk to some extent, vulnerability is also likely to vary considerably across NCFs, with significant implications for assessing and managing risk. We examined this issue primarily through the lens of workplace and worker vulnerabilities, which are particularly relevant to COVID-19. The team developed an occupation-based measure of the risk of COVID-19 transmission using detailed U.S. Department of Labor information about the job duties and social interaction undertaken by people in these occupations. We first examined the distribu-

tion, by occupation, of the risk of exposure (ROE), determined by the number, duration, and strength of contacts required to perform the job. We then linked demographic information based on the population of people in these occupations. Finally, we aggregated the occupational analysis to the industry level and drew conclusions about the NCFs that were closely aligned with industry outputs (Table 8).

We found a direct relationship between occupational risk and NCF vulnerability. High–economic impact sectors are, generally speaking, at high risk of transmission. For example, a large number of jobs in certain sectors (e.g., health care, transportation, education) require workers to be in the workplace while also having elevated risk of transmission. Because of high levels of social interaction, many white-collar and service jobs are at high risk without mitigation, which means that higher-wage workers and those with more education tend to have higher risks than many blue-collar workers (e.g., production and craft workers who operate machinery or work in relative isolation), who often have more-limited social interactions on the job.

However, we note that, in our analysis, the ROE is based on occupational data from prior to the pandemic and does not take into consideration behavioral changes, such as physical distancing, remote work, and use of PPE, which can mitigate occupational risk. We also note that other attributes of workers, such as living in group quarters, not having paid sick leave, and using public transportation to travel to and from work, are not accounted for in this analysis. In addition, we explored only one aspect of individual disease risk; however, more-sophisticated models would rely on data about total social interactions and the efforts to mitigate transmission, such as mask wearing, while taking into consideration disease prevalence in the community.

There are no easy solutions for returning to normal: PPE, hygiene, and, ultimately, a vaccine are the current and future solutions to keeping crucial occupational areas open and functioning during the crisis. Our findings focus on occupations that are especially vulnerable to exposure to or transmission of COVID-19, providing guidance for mitigation priorities. In addition, the methodology we used to examine vulnerability could be applied to occupational impacts from other hazards, such as disaster events, other epidemiological events, and environmental hazards.

TABLE 8
Highest and Lowest Risks of Exposure, by Occupation

Occupation	ROE
Ten with the highest ROEs	
Emergency management director	16.4
Preventive medicine physician	15.8
Clinical nurse specialist	15.6
Education, guidance, school, or vocational counselor	15.5
Licensed practical or licensed vocational nurse	15.5
Lodging manager	15.5
Child, family, or school social worker	15.5
Health care social worker	15.5
Social or community service manager	15.5
Education administrator, elementary or secondary school	15.4
Ten with the lowest ROEs	
Patternmaker, wood	11.0
Mine shuttle car operator	10.9
Sewing machine operator	10.9
Model	10.8
Solderer or brazer	10.6
Farmworker or laborer, crop	10.6
Proofreader or copy marker	10.5
Hunter or trapper	10.5
Faller	5.6
Poet, lyricist, or creative writer	0.0

Geographic Variation Can Help Identify Areas of Vulnerability

NCFs can vary both in terms of their geographic *distribution* (how their components are arranged across space) and their geographic *concentration* (the spatial scale at which their services are provided). The geography of NCFs consists of numerous differentiated components, including facility locations, workforce

distributions, capital flows, and policy frameworks. Mapping these components coherently at varying levels of temporal and spatial granularity can be analytically and cartographically complex, posing challenges to risk assessment. However, geographic analysis of even limited subsets of infrastructural components also provides opportunities to understand how an NCF's spatial properties are fundamental determinants of its vulnerability to hazards.

Geographic analysis illuminates important gaps between the scale at which an NCF is concentrated and the scale at which data are available. For example, although COVID-19 testing is carried out locally, readily available performance indicators are provided regionally at the state level, limiting identification of geographic hot spots of testing accessibility. Likewise, school-reopening policy recommendations are provided by states, but implementation data (that is, data on actual school reopenings) are unavailable at the local district level. When data used for risk assessment do not align with the scale at which an NCF operates, analysts risk mischaracterizing the geographic concentration of an NCF or missing important predictors of vulnerability.

Geographic analysis of multiple infrastructural components is required to capture the diversity of functions of a single NCF. This is particularly apparent for Produce and Provide Agricultural Products and Services and Produce and Provide Human and Animal Food Products and Services, whose components collectively make up the entire food production and delivery system. Given the wide array of inputs and processes involved in bringing food from farm to fork, any mapping of individual NCF components will illustrate only limited portions of the food supply chain.

We found that some of these limitations can be linked to specific data gaps. For example, depending on the specific use case, geolocated data might not be available for granular analysis within a sector. U.S. Bureau of Labor Statistics and U.S. Census Bureau data do not identify workforces linked to specific crop types or farm sizes, commodity types processed at individual facilities, or the type of work conducted at each facility. More fundamentally, however, such multifaceted NCFs can encompass components and activities normally associated with other NCFs with different or hybrid geographic concentrations. In the case of the food system, hot spots of agricultural production (e.g., farmland) are linked to intermediate processing facilities through regional transport networks and finally to end consumers at retail stores through local distribution networks, rendering these two NCFs as special cases of a third, hybrid concentrated NCF, Maintain Supply Chains. It might therefore be analytically convenient to identify areas of functional interdependence between related NCFs before selecting data to represent NCF components. In other cases, assessing NCF performance might require making broad assumptions about the functioning of components, such as testing capacity at individual COVID-19 testing sites, which might not be available for every locality. Given widespread geographic variation in testing (Collins, 2020), such assumptions might be insufficient to inform real-time risk assessment during a pandemic.

An NCF's vulnerability to disaster depends not only on the location of infrastructure but also on the type and location of interactions between infrastructure and human populations. Knowing where people use or support the services that an NCF provides is crucial for understanding how such interactions can amplify risk at multiple scales of geographic concentration. For example, a disease outbreak in a food-processing plant has both local and regional impacts in that both the health of the workers at the plant and the food security of the region served by the plant can be threatened. In addition, because food processing is relatively concentrated, there is also the potential for national-level impacts. These could take several forms; for example, even if actual supply-chain impacts are minimal, public perception could lead to an increase in demand that causes short-term shortages in product availability. Because disaster vulnerability is often highly context-dependent, these interactions should be considered carefully when selecting vulnerability indicators.

Where real-time data are unavailable or infeasible to obtain, proxy data, such as population data, might be able to serve as a substitute indicator of vulnerability; however, such proxies often fail to account for infrastructural redundancies that provide resilience, such as backup power or hardening against hazards in the case of water treatment plants. Other assessments might require combining elements from

multiple NCFs to understand the relevant human–infrastructure interaction effects. For example, we found that COVID-19's impact on education is especially high in areas with both low internet connectivity rates and large school-age populations. A full assessment of the risk of COVID-19 to Educate and Train would thus involve such considerations as the background level of connectivity, the core telecommunication network's resilience to increased strain, the period during which online lessons are expected to increase, the type of activity expected during these periods (e.g., streaming video versus email), and how these factors vary geographically.

These findings point to an opportunity for future assessments of risk to NCFs to incorporate analysis of the geographic properties of their infrastructural components. A geographical risk analysis framework would enable mapping of risk to multiple, overlapping NCFs in a single area, posed by disasters occurring at varying scales.

Conclusions and Action Items for the NRMC

CISA identified the 55 NCFs less than a year before the COVID-19 pandemic led to dramatic changes across all aspects of American life. The events of 2020 represented a significant challenge to many of the NCFs, which were placed, at times, under tremendous, often unrelenting, strain. Similarly, the events of 2020 tested the concept of identifying NCFs and the application of a risk assessment framework to assess their relative health and risk of disruption. Although, in the beginning days of the pandemic, our analysis focused on the health of individual functions, over the course of the pandemic, we began an intensive effort to review the application of the NCFs and the NCF risk assessment framework to one of the country's largest and deadliest events while seeking to identify lessons that might be applied to future disasters, regardless of their nature.

The HSOAC team's experience in applying the NCF risk assessment framework suggests that the framework provides a flexible system for assessing risk to the country's most critical functions. At the same time, our review identified some challenges, as well as potential enhancements, that could be addressed in future applications of the framework. In this section, we draw some high-level conclusions about the challenges and opportunities discussed in this report and provide some action items that the NRMC might pursue to enhance future applications of the NCF risk assessment framework.

Using the NCF Risk Assessment Framework for National Risk Management

A key strength of the NCF risk assessment framework is its functional approach to understanding CI risk, which enabled an additional level of analysis that might have been missed by a purely sector- or brick and mortar–based approach. For example, many of the disruptions to the NCFs that occurred during COVID-19, such as closure of schools, were not associated with damage to physical infrastructure; nevertheless, the function of those systems was disrupted. On the other hand, a challenge in the NCF approach is that, in some cases, individual NCFs are not discrete functions linked to physical infrastructure but rather represent complex systems or even systems of systems. There are also functional gaps in the NCFs, in which a given function is not readily captured by any one NCF. For example, during the pandemic, HSOAC analysts identified the U.S. Postal Service as having particular importance for the Conduct Elections NCF. However, it was not intuitively clear whether risk to USPS should be reflected in one or multiple NCFs, given that the Postal Service has equities in several NCFs, including the Operate Government and some of the transportation-related NCFs. Indeed, provision of postal services could arguably rise to level of an NCF itself, given its importance during the pandemic.

Generating the capacity to consistently assess risk of COVID-19 to the NCFs in near-real time was contingent on identifying indicators of an NCF's response to COVID-19 (directly or indirectly). Those indicators had to be quickly identified at the onset of the project, necessitating judgments about which indicators were likely to be relevant for anticipating risks to NCFs. However, for those NCFs for which specific indicators were not readily available, COVID-19 case numbers provided a convenient,

frequently updated proxy for risk. Yet, the exact relationship between case numbers and NCF performance was often assumed rather than empirically demonstrated. Moreover, COVID-19 case numbers obviously would not be a useful indicator for assessing the risk of non–COVID-19 threats to an NCF.

Potential Action Items

In light of our findings, the NRMC might consider taking the following actions:

- **Review the NCFs in light of the experience with COVID-19 to identify gaps and opportunities to refine the composition of NCFs and their definitions.** CISA's ongoing NCF-decomposition efforts are likely to be extremely valuable in identifying areas of overlap, potential gaps, or ambiguity about where a subfunction of an NCF is accounted for or when a definition needs to be modified.
- **Develop a core set of vetted NCF indicators that can be used to monitor NCFs' performance under baseline conditions, as well as in response to diverse shocks and stresses.** Identifying trusted indicators that are frequently updated and that are specific to an NCF's performance, rather than the hazards to which it is exposed, can enable risk managers to efficiently anticipate emerging risks.

Developing and Applying the NCF Risk Assessment Framework to the COVID-19 Pandemic

Risk assessment is now a mature decision-support practice for the public and private sectors, including within DHS and its various components, such as CISA. Therefore, in developing the NCF risk assessment framework, certain design features were consistent with risk assessment best practices, as described earlier in this report.

In applying the NCF risk assessment framework, opportunities for improvement became apparent. Some were able to be implemented quickly during the course of the project. Meanwhile, other potential improvements, including the integration of approaches to assessing interdependencies among NCFs and NCF vulnerability to COVID-19 and to mapping the geography of NCFs, were more challenging.

Given that the COVID-19 threat is associated with an infectious disease, the bulk of the risk from the pandemic has been associated with driver 2, a shortage of workers. This highlights the importance of having a risk assessment framework and allied indicators that are robust to diverse types of threats so that risk managers can quickly develop situational awareness as new threats emerge.

Potential Action Items

In light of our findings, the NRMC might consider taking the following actions:

- **Review and validate COVID-19 NCF indicators.** Although we identified many indicators, their quality varied with the reliability of the underlying data, the frequency with which the indicators were updated, and the strength of their association with NCF performance. Therefore, undertaking retrospective analyses of indicators could be used to establish their baseline variability during blue-sky conditions, assess how far outside that baseline they deviated during the pandemic, and assess their signal strength vis-à-vis NCF performance. Collectively, such analyses would help to identify those indicators that are most robust to COVID-19 risk and establish thresholds that are indicative of significant disruption.
- **Review drivers used in the NCF risk assessment framework.** The NCF risk assessment framework includes four risk drivers (or five, given that the NRMC also considered Change in Cyber Posture). Situations arose in which assessing NCFs against some drivers was challenging (e.g., whether the loss of revenue to local governments represents a Core Commodity Supply Shortage or a Decrease in Demand). Although such challenges are to be expected in applying any risk assessment framework, it would be worthwhile in future disasters to consider whether other drivers or driver definitions might be more effective for risk assessment.

- **Consider multiple time scales of risk.** The NCF risk assessment framework consistently assessed risk on a rolling 60-day time horizon. However, some risks could be anticipated over much longer time horizons, and consideration of longer-term risk might provide a useful supplement to the 60-day time horizon for some disasters. Regarding COVID-19, the shift to online learning in many parts of the United States in the spring of 2020 reflected an attempt to maintain the provision of education. However, online learning is not an equivalent form of education, particularly for young children and vulnerable students, and it did not provide other forms of services often associated with schools (e.g., meals). The longer education remains online, the likelier students are to fall behind. Consideration of a longer time horizon could capture this type of risk.
- **Enhance system-based methods for COVID-19 NCF risk assessment.** Although the risk assessment methods for COVID-19 were developed to examine NCFs largely in isolation of one another, examples of NCF interdependencies were readily apparent. This more-rigorous perspective on NCFs can enable richer and insightful assessment of risk; it also adds significant complexity to such assessment.
- **Undertake an NCF damage and recovery needs assessment.** Our efforts have revolved around the assessment of risk to the NCFs, but limited analysis was dedicated to identifying and communicating specific consequences or the mechanisms by which COVID-19 contributed to those consequences. An in-depth after-action report that details direct and indirect consequences, their implications for disruption or failures of NCFs at different geographic scales, and their comparison with other real-world disasters could be a valuable learning tool for the NRMC. This review could assess both actual incurred damage and predicted damage that did not occur to determine whether these costs were avoided as a result of specific mitigation measures.

Using the NCF Risk Assessment Framework During Steady-State Conditions and Non–COVID-19 Emergencies

The mapping of NCF indicators to different threats could help identify information gaps during steady-state conditions and enhance preparedness for future threats to the country's infrastructure. The most–commonly used indicators among HSOAC analysts were from the U.S. government and open-source data from financial institutions. Many of those indicators could likely be used for other threat scenarios. Risk assessors could use a hierarchy of indicator types that stratifies and defines indicator value, availability, and applicability to different threats to quickly identify the indicators of value for a given threat situation. In addition, apparent gaps in indicators—that is, areas in which indicators for a given NCF are particularly weak—would signal the need to enhance investments in data collection in order to enable data-driven risk assessments in the future.

The NRMC might also consider how alternative and novel data sources could help fill existing indicator gaps and enhance access to near–real-time information. The methods used for assessing COVID-19 risk to the NCFs could benefit from clear guidance for incorporating and using alternative or intermittent indicator sources. For example, HSOAC analysts frequently made use of news sources for tracking NCFs, yet the quality and comprehensiveness of such reporting are often highly variable. Similarly, risk assessment efforts could benefit from the development of standard operating procedures for emerging data-source types that update with greater frequency. These could include prediction markets, social media, and crowdsourcing.

Potential Action Items

In light of our findings, the NRMC might consider taking the following actions:

- **Develop a rigorous and flexible NCF indicator data hub and allied standard operating procedures that can be deployed to monitor NCFs and changes in NCFs in the event of a threat.** By building on our NCF indicator work and combining it with the NRMC's

existing systems and data, the NRMC can shorten the time- and resource-intensive process of developing and researching indicator databases for future disasters and crises. Building and maintaining a reliable indicator database would efficiently streamline the analytical requirements of future risk assessment; identifying or creating non–COVID-19 indicators to increase NCF driver coverage for baseline analysis would increase the robustness of such a repository.

- **Stress-test the NCF risk assessment framework against other potential threats to the nation.** COVID-19 presented an opportunity for testing the NCFs and the risk assessment framework against one type of threat. Given the observed value of the approach, efforts could be undertaken now to plan for how the framework would be deployed against other types of threats to help identify which drivers, indicators, vulnerabilities, interdependencies, and geographic dynamics are relevant.
- **Develop the data and computing infrastructure for the monitoring of NCFs and system interoperability among DHS and its contractors.** Various opportunities exist for streamlining the analysis of NCF indicators, the assignment of risk ratings, and the generation of online, dynamic dashboards for risk communication. Ideally, this should build on DHS's existing investments in computational and geospatial analysis tools. In addition, enhancing mechanisms for easy data sharing and visualization between DHS and its contractors would facilitate faster collaboration among analysts in different organizations.

Mitigating Risk to the NCFs During Future Emergencies

There are also opportunities to consider how the NCF risk assessment framework might be used in future emergencies. One significant way in which the NRMC can contribute to national CI risk management is by continuing to build its analytic capabilities for the assessment and the timely communication of risk to its partners, which include sector-specific federal and state agencies. The NRMC could enhance the NCF risk assessment framework and its flexibility for use in risk mitigation by defining key failure end points for NCFs. With clear definitions of *failure* and *degradation*, analysts could more easily assess the risk-reduction potential of mitigation options and prioritize risk mitigation strategies and monitor their impact. These activities would enhance CISA's data collection, analysis and dissemination, planning and guidance, convening, and coordination roles in NCF risk mitigation strategies.

Risk assessment is just one step in a larger process of risk management. Although the NCF risk assessment framework applied to COVID-19 adopts many of the core concepts commonly used in risk assessment practice, that process, in the context of COVID-19 response, is pursued within a broader risk management framework that informs decisionmaking to address the priorities of the NRMC and its stakeholders as necessarily limited by the lack of a consistent and unified federal role in risk management. DHS has its own risk management framework, which could be adopted for such purposes, and other frameworks could be explored to address the specific management needs for the CI mission of the NRMC and CISA.

However, significant uncertainty exists about the costs, benefits, effectiveness, and sustainability of these actions. Some mitigation actions could become effectively permanent adaptations to risk. For example, the rapid expansion of working from home and even online learning in response to COVID-19 is likely to have lasting consequences as businesses, government agencies, and school systems learn from this natural experiment. By leveraging the NRMC's role as a cross-sector risk manager, the NRMC could track ongoing risk mitigation activities and evaluate their impact on risk ratings, as well as any unintended consequences, thus enhancing situational awareness and supporting the identification of mitigation actions that could be implemented in response to other threats.

The NRMC's existing engagement with other actors in public and private sectors creates opportunities for building robust risk assessment, communication, and management capabilities. These engagements are important to ground understanding

of NCF vulnerabilities, risk, and opportunities for mitigation, and expanding such forms of outreach could generate benefits for the NRMC's risk management efforts. In addition, NRMC stakeholders could play an important role in helping identify different types of risk products that the NRMC could develop to benefit risk management efforts in specific sectors. CISA could therefore enhance its internal and external risk management capacity by identifying key internal experts and external stakeholders who would be involved in planning and implementing mitigation strategies.

Potential Action Items

In light of our findings, the NRMC might consider taking the following actions:

- **Continue to invest in NRMC risk assessment capabilities.** The NRMC's role in providing information on risk to diverse stakeholders is a unique activity across the federal enterprise. Given that the NCF risk assessment framework is a relatively new risk management tool, identifying opportunities for enhancing the use of the framework in risk analysis, communication, and mitigation will boost the NRMC's value as a risk management agency and enhance the ability of diverse stakeholders to respond effectively to risk.
- **Collect information on mitigation and adaptation actions during COVID-19 to inform mitigation of future threats.** The COVID-19 experience is certainly relevant to other pandemic risks, but some mitigation actions for COVID-19 are likely relevant to other threats as well. For example, supply-chain disruptions can emerge from a variety of sources (e.g., terrorism, natural disaster, cyberattack). Preserving the institutional memory of COVID-19 risk managers in the public and private sectors could prove invaluable during the next national challenge.
- **Enhance the NRMC's stakeholder network to boost two-way flow of information** tailored to different audiences **on risks to the United States.** Enhancing the flow of information across partners and stakeholders and having the ability to analyze it rapidly to generate risk insights can benefit situational awareness. At the same time, increasing the NRMC's capacity to deliver timely risk information that is tailored to different audiences can empower actors to take mitigative actions that increase the country's overall resilience.

Concluding Thoughts

The efforts described in this report represent the first test of a new system for managing national risks in emergencies. By testing this system under fire, much was learned about how to measure, analyze, and mitigate risks. This effort also identified opportunities to improve and enhance the NCF risk assessment framework. The lessons and action items recommended for consideration could provide a road map that helps CISA, government at all levels, and both public and private risk managers better manage and respond to future contingencies and enhance risk management during steady-state operations.

Notes

[1] For CISA and other DHS materials, we searched the public-facing websites and reviewed all recent materials that included risk mitigation strategies. For academic literature, we searched using Google Scholar for "risk mitigation frameworks." We did not conduct a formal literature review.

[2] This discussion is based on an examination of the academic literature on risk analysis and economics.

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About This Report

The Homeland Security Operational Analysis Center (HSOAC) was asked to use the National Risk Management Center's (NRMC's) National Critical Function (NCF) risk assessment framework to assess risk to each NCF and complete individual risk analyses for the 55 NCFs. The NRMC also requested that HSOAC perform additional tasks, including providing a report on emerging lessons learned from risk management efforts to limit the impact and disruption that coronavirus disease 2019 (COVID-19) had on the 55 NCFs.

This report presents insights into best practices in risk assessment and management; identified challenges in the implementation of the NCF risk assessment framework to characterize risk to critical infrastructure associated with the COVID-19 pandemic; recommendations for improving the framework; and suggestions for further characterization of NCFs' interdependence, vulnerability, and geographic variation that could improve risk assessment processes. This report is intended to inform the actions of federal agencies, state and local authorities, and the private sector. In particular, this report should be of interest to owners and operators of critical infrastructure, risk managers, and others involved in COVID-19 risk assessment activities. It should also be of interest to a broader public audience who would like to understand more about how national risks are, and can be, assessed.

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The HSOAC FFRDC provides the government with independent and objective analyses and advice in core areas important to the Department in support of policy development, decisionmaking, alternative approaches, and new ideas on issues of significance. The HSOAC FFRDC also works with and supports other federal, state, local, tribal, and public- and private-sector organizations that make up the homeland security enterprise. The HSOAC FFRDC's research is undertaken by mutual consent with DHS and is organized as a set of discrete tasks.

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