SANDIA REPORT

SAND2013-6975

Unlimited Release

August 2013

Chemical Incident Economic Impact Analysis Methodology

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Acronyms and Abbreviations

ACRONYM	DEFINITION
ABM	Agent-Based Model
AWARE	Analyzer for Wide-Area Restoration Effectiveness
CFATS	Chemical Facility Anti-terrorism Standards
CFR	Code of Federal Regulations
CIRA	Chemical Infrastructure Risk Assessment
COI	Chemical of Interest
CSP	Chemical Screening Process
CREATE	Center for Risk and Economic Analysis of Terrorism Events
CSAC	Chemical Security Analysis Center
CSAT	Chemical Security Assessment Tool
CW	Chemical Weapon
CWP	Chemical Weapon Precursor
DHS	Department of Homeland Security
DTRA	Defense Threat Reduction Agency
EPA	Environmental Protection Agency
EXP	Explosives
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GIS	Geographical Information System
HPAC	Hazard Prediction and Assessment Capability
IEDP	Improvised Explosive Device Precursors
ISCD	Infrastructure Security Compliance Division
MSRAM	Maritime Security Risk Analysis Model
NAICS	North American Industry Classification System
NISAC	National Infrastructure Simulation and Analysis Center
PATH	Prioritization Analysis Tool for all-Hazards
REAcct	Regional Economic Accounting tool
RIMS II	Regional Input-Output Modeling System II
SNL	Sandia National Laboratories
STQ	Screening Threshold Quantity
WME	Weapons of Mass Effect

EXECUTIVE SUMMARY

Congress enacted Section 550 of the *Homeland Security Appropriations Act of 2007, P.L. 109-295,* which directed the Department of Homeland Security (DHS) to identify and secure the Nation's high-risk chemical facilities. Pursuant to this congressional mandate, DHS promulgated the Chemical Facility Anti-terrorism Standards (CFATS), 6 Code of Federal Regulations (CFR) Part 27, which defines the regulatory process. Within DHS, the Infrastructure Security Compliance Division (ISCD) is responsible for implementing the CFATS regulatory process outlined in the Final Rule. ISCD partnered with Sandia National Laboratories (SNL) to develop new approaches for assessing the economic consequences of an attack on one of our Nation's chemical facilities.

This document describes the methodology Sandia has developed to assess economic consequences. Economic consequences were divided into two parts, direct impacts (e.g. impacts at the location of the terrorist act) and indirect impacts (e.g. impacts that occur away from the location of the terrorist act, such as the chemical supply chain affected by a facility loss). Direct impacts include cleanup costs of the chemical and affected areas, losses to business due to safety keep-out zones, and costs incurred to repair or replace the facility or its equipment. Indirect impacts include disruptions to the chemical supply chain, both upstream (suppliers to a facility) and downstream (consumers of the chemical produced/stored at a facility). The models used to produce results for both the direct and indirect economic impacts have been in use for a number of years at SNL.

Over the next few months, SNL will begin the implementation of the methodology. The initial facilities that will be evaluated for economic criticality will be selected from the top two tiers of the current CFATS process. The next set of facilities will include a sampling of facilities that have completed the CFATS questionnaire – regardless of tier. Finally, SNL has a methodology in place that will evaluate additional facilities based upon economic and chemical supply chain metrics. This process is called the Chemical Screening Process (CSP). Ultimately, this assessment methodology will enable ISCD to identify high-risk chemical facilities based both on their potential to cause significant public health and/or economic consequences.

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1 BACKGROUND AND INTRODUCTION

1.1 Chemical Facility Anti-terrorism Standards

An essential component of the Department of Homeland Security (DHS) mission is to ensure the security of the Chemical Sector.[1] In support of this mission, Congress enacted Section 550 of the *Homeland Security Appropriations Act of 2007, P.L. 109-295,* which directed DHS to identify and secure the Nation's high-risk chemical facilities. Pursuant to this congressional mandate, DHS promulgated the Chemical Facility Anti-terrorism Standards (CFATS), 6 Code of Federal Regulations (CFR) Part 27, which defines the regulatory process. Within DHS, the Infrastructure Security Compliance Division (ISCD) is responsible for implementing the CFATS regulatory process outlined in the Final Rule.

In Appendix A of the CFATS Final Rule[2], DHS provides a list of Chemicals of Interest (COIs) that trigger preliminary screening requirements for facilities in possession of these hazardous chemicals above the indicated Screening Threshold Quantities (STQs). The COIs included in Appendix A fall into three categories, or *security issues*, based on their potential public health consequences. The three security issues currently regulated under CFATS are defined in the interim final rule[3] as follows:

- *Release* – DHS believes that certain quantities of toxic, flammable, or explosive chemicals or materials, if released from a facility, have the potential for significant adverse consequences for human life or health.

- *Theft or Diversion* – DHS believes that certain chemicals or materials, if stolen or diverted, have the potential to be used as weapons or easily converted into

[1] DHS (2009) *National Infrastructure Protection Plan*, Washington, D.C. retrieved from www.dhs.gov/xlibrary/assets/NIPP_Plan.pdf, accessed July 2013.
[2] 6 CFR Part 27, App. A, § 105 (2007) Appendix to Chemical Facility Anti-Terriorism Standards; Final Rule § 105 "Definitions" http://www.dhs.gov/xlibrary/assets/chemsec_appendixafinalrule.pdf, accessed July 2013.
[3] 6 CFR Part 27, "Chemical Facility Anti-Terrorism Standards" Department of Homeland Security, DHS-2006-0073, RIN 1601-AA41, http://www.dhs.gov/xlibrary/assets/IP_ChemicalFacilitySecurity.pdf, accessed July 2013

weapons using simple chemistry, equipment, or techniques in order to create significant adverse consequences for human life or health.

- *Sabotage or Contamination* – DHS believes that certain chemicals or materials, if mixed with readily available materials, have the potential to create significant adverse consequences for human life or health.

While the current CFATS regulatory process is focused on securing facilities with holdings of hazardous chemicals that pose public health risks (i.e., COIs listed in Appendix A), the interim final rule defines a facility as high-risk if it has the potential to cause

> "*significant adverse consequences for human life or health, national security, and/or critical economic assets if subjected to terrorist attack, compromise, infiltration, or exploitation.*"

To meet this broader regulatory goal, two additional security issues concentrating on chemicals with critical relationships to government missions and/or to the national economy are under consideration for addition to the CFATS process. To accomplish this broader regulatory scope, ISCD partnered with Sandia National Laboratories (SNL) in 2008 to develop new approaches for assessing the economic consequences of an attack on one of our Nation's chemical facilities.

1.2 Economic Consequences of a Chemical Incident

The potential consequences of chemical terrorism incidents range from immediate public health consequences resulting from exposure to hazardous chemicals, to on-going and far-term effects, including chronic health issues, environmental impacts, supply chain disruptions, or even psychological consequences. In the array of potential consequences, virtually all consequences involve an economic aspect. For example, injuries and fatalities resulting from an attack have associated medical and funeral costs, respectively, and any type of remediation effort would use capabilities and resources that come at a cost. In other words, while the total economic cost of a chemical incident can be captured in a single metric – dollars – the sources of economic impacts are vast and diverse. As a result, an analysis of economic consequences can quickly become complex and poorly defined.

To structure the analysis approach, SNL defined a framework for economic consequence based on the DHS Risk Lexicon. This framework is the foundation for the economic assessment methodology developed for the CFATS program. DHS defines an economic consequence as:

> *"[an] effect of an incident, event, or occurrence on the value of property or on the production, trade, distribution, or use of income, wealth, or commodities."*[4]

An important concept underlying this definition is that there are immediate economic impacts of an incident (property damage) as well as derivative, or cascading, impacts that may develop over time as a result of an incident (e.g., changes in production and exchange of goods). Accordingly, the DHS Risk Lexicon distinguishes these as "direct" and "indirect" consequences, respectively.[5]

Another key concept conveyed in the definition is that there can be both positive and negative economic effects of an incident. For example, there may be positive impacts in commodities and employment associated with remediation industries following an incident. To accommodate the potential for both positive and negative effects on the economy, the economic consequences are often generally referred to as "economic impacts." The economic consequence framework used in this effort includes a distinction between direct and indirect impacts and encompasses both positive and negative impacts.

1.3 Project Objectives

The objectives of the current efforts at SNL are threefold:

1. Review existing methodologies for the assessment of economic impacts after security incidents.

2. Develop an economic impact analysis methodology for use in the CFATS process to assess the potential consequences of security incidents at chemical facilities.

3. Apply the analysis methodology to a selected set of chemicals and facilities as directed by CFATS program needs.

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[4] Risk Steering Committee DHS Risk Lexicon, 2010 Edition. Retrieved from http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf, accessed July 17, 2013.

[5] See Appendix A of this report for the full definitions along with examples and annotations of direct and indirect consequences as provided in the DHS Risk Lexicon.

Analysis methods have been developed by other groups to assess the economic consequences of natural disasters, accidents, or security incidents. In particular, two other DHS analysis groups are developing economic assessment methods specifically related to homeland security concerns. These assessment methods include the:

- Chemical Infrastructure Risk Assessment (CIRA) Economic Consequences Model, developed for the Chemical Security Analysis Center (CSAC) within DHS;[6]

- Economic assessment methodologies within the National Center for Risk and Economic Analysis of Terrorism Events (CREATE), University of Southern California;[7] and

- Maritime Security Risk Analysis Model (MSRAM), developed by the United States Coast Guard.

To corroborate SNL's methods development, these existing economic analysis methodologies and others are being reviewed in parallel to the efforts for ISCD. The findings of the review will be documented separately in a later report. A review of several economic input-output models was conducted to assess potential use for assessing chemical supply chain impact.[8] The current methodology review is aimed more broadly at assessment approaches for all post-incident economic impacts.

This report addresses the second of the project objectives previously listed by describing the analysis methodology developed for estimating the economic impacts resulting from a chemical terrorism incident. At a high level, the methodology is flexible enough to

[6] "Chemical Infrastructure Risk Assessment Economic Consequences Model" Draft Report prepared for the Department of Homeland Security Chemical Security Analysis Center by Tetratech, Inc. Reston, VA, October 2010.

[7] CREATE Homeland Security Center; National Center for Risk and Economic Analysis of Terrorism Events. Retrieved on July 17, 2013 from http://create.usc.edu/research/econ_assessment.html.

[8] Vargas, V., Drake, W., Loose, V., Smith, B., Vugrin, E. (2010). Methodology for Identifying Economically Critical Chemical Facilities, Prepared for Jon M. MacLaren, U.S. Department of Homeland Security, November 2010.

address inquiries about a broad range of economic impacts. This report also outlines the analysis scope and plan for an initial set of economic impact assessments using this methodology. Currently four categories of economic impact may be evaluated using the approach defined by the methodology. These include economic consequences related to:

- Clean-up
- Business interruption
- Facility repair and replacement
- Chemical supply chain disruption

Early efforts at SNL focused on characterizing one specific source of economic consequences: supply chain disruptions. Within the last year, the SNL effort expanded to include multiple sources of economic impacts. The methodology presented in this report, along with the initial set of assessments outlined, will help to address ISCD's broadening program needs.

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2 METHODOLOGY FOR ASSESSING ECONOMIC IMPACTS

A high-level flowchart of the economic impact analysis methodology is illustrated in Figure 1. The first step in the process is to select a chemical and identify a facility in possession of that chemical (Step 1). The next step is to select the type of security issue and define the scenario (Step 2). Once the chemical, the facility, and the scenario are determined, the economic impacts (direct and indirect) resulting from the chemical incident can be assessed (Step 3). These impacts include both the surrounding area impacts and the cascading impacts. The sum of the impacts (which may consist of both economic gains and losses) can then be reported as the total economic impact in dollars (Step 4).

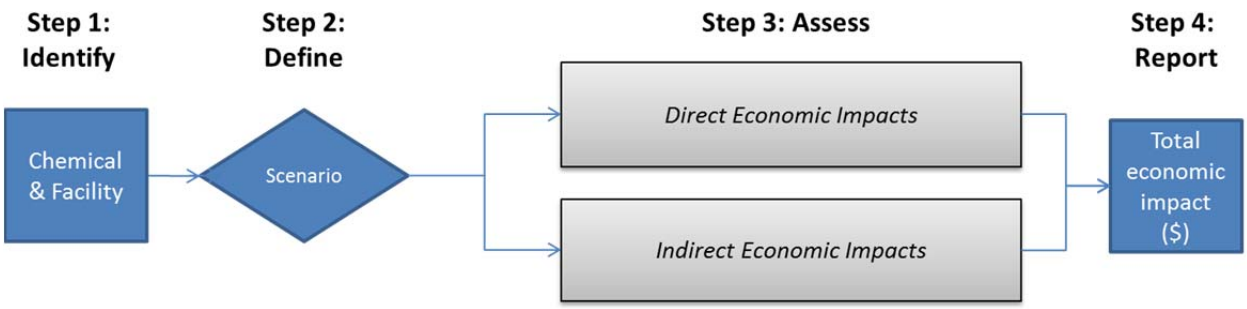

Figure 1. Steps in the economic impact analysis methodology.

Each step in the analysis methodology drives the subsequent step, ensuring consistency in the results collected across multiple assessments. For example, scenarios are not defined independently but are defined based on what would be realistic for the chemical and facility identified in Step 1. Similarly, the way the scenario is defined determines what types of economic impacts may be assessed in Step 3. Within Step 3, the direct and indirect economic impacts may be assessed in a variety of ways depending on the source of the impact being considered: e.g., models, historical data, elicited data, or subject matter expertise. The analysis approach was designed to be flexible to accommodate a broad parameter space, yet directed enough to facilitate systematic comparisons across the analysis results.

2.1 Scope for Initial Assessments

The parameter space for an economic impact analysis resulting from a chemical incident is vast, potentially leading to a wide variety of scenarios that could be modeled. In addition, a number of direct and indirect consequences could be considered. In light of ISCD's current program needs, SNL developed an approach focused on a selected set of

chemicals and facilities (Step 1), scenarios (Step 2), and economic impacts (Step 3). The general methodology for economic impact analysis was developed with the broader parameter space in mind. If a broader economic assessment is needed, the analysis methodology described here will support the expansion in scope. The scope of the scenarios and consequences to be studied in the initial set of assessments are described below.

Chemicals, facilities, and scenarios

The scope for the initial assessments will focus on facilities currently regulated under CFATS for COIs listed in Appendix A (Step 1). The narrower focus for the initial assessment facilitates the methodology development, leverages available CFATS facility data, and enables a direct comparison of public health versus economic consequences in currently regulated facilities. The CFATS facilities included in the initial assessments were identified as high-risk facilities in the current CFATS process, due to their potential to cause significant public health consequences. The initial assessments, therefore, will not identify additional high-risk facilities; rather, the economic impact assessments will add another layer of understanding to the risk posed by the currently regulated CFATS facilities.

Once the analysis approach is validated through the initial assessments, the economic impact analysis methodology will be used to assess chemicals/facilities that are <u>not</u> currently regulated under CFATS. The goal of this effort is to identify facilities that could be considered high-risk facilities due to their potential to cause significant economic consequences. For example, if a security incident at a specific facility has the potential to result in severe economic consequences but the incident would not result in severe public health consequences, the facility is not identified as a high-risk facility under the current CFATS process. To meet the stated goal, additional research is required to identify chemicals that are (1) economically critical and (2) are not included in Appendix A. This research effort is known as the Chemical Screening Process (CSP) and is described in Section 4.1 of this report. Once these economically critical chemicals are identified, the analysis methodology can be applied to facilities possessing these chemicals to determine the potential for severe economic consequences.

The types of scenarios considered in the initial assessments will be limited to those considered in the current CFATS process (Step 2). The security issues defined in Appendix A describe at a high level the scenarios leading to potential public health and economic consequences. These security issues include:

- Release – Toxic

- Release – Flammable
- Release – Explosive
- Sabotage or Contamination
- Theft and Diversion – CW/CWP (Chemical Weapon and Chemical Weapon Precursors)
- Theft and Diversion – EXP/IEDP (Explosives and Improvised Explosive Device Precursors)
- Theft and Diversion – WME (Weapons of Mass Effect)

Depending on how the scenario is defined, a pre-modeling analysis may be required to determine the area of concern that is directly impacted by an incident. Area of concern is a critical piece of information for assessing the direct impacts of an incident. For the initial assessments, the area of concern will be defined based on existing CFATS facility data. The pre-modeling analysis plans for the initial assessments are discussed in more detail in subsequent sections. For future assessments of chemicals and facilities not currently regulated under CFATS, the approach for the pre-modeling analysis will be determined by the scenario definitions.

Economic impacts

Although a single metric of Total Cost in dollars may be used to measure economic impact of a security incident in the chemical infrastructure, the sources of the impacts are numerous and complex. As described above, the economic impacts can be divided into two categories to facilitate the analysis:

- *Direct Impacts* (surrounding area impacts) - Changes in economic output that occur within the area physically impacted by a chemical incident (e.g., neighboring commercial and residential areas contaminated by a chemical plume)

- *Indirect Impacts* (cascading impacts) - Changes in economic output as a result of a chemical incident that do not necessarily occur within the physical vicinity of the incident (e.g., reduced production capacity for chemicals/products that rely on the chemical facility impacted)

The difference between the geographic area impacted directly by a chemical incident versus the areas indirectly impacted is notionally depicted in Figure 2. Cascading impacts may propagate far beyond the location of the attack. For example, if an incident in Texas interrupts the production of a specific gizmo, the supply of that product may be

reduced nationwide such that a consumer is unable to purchase the gizmo in Pennsylvania for a period of time.

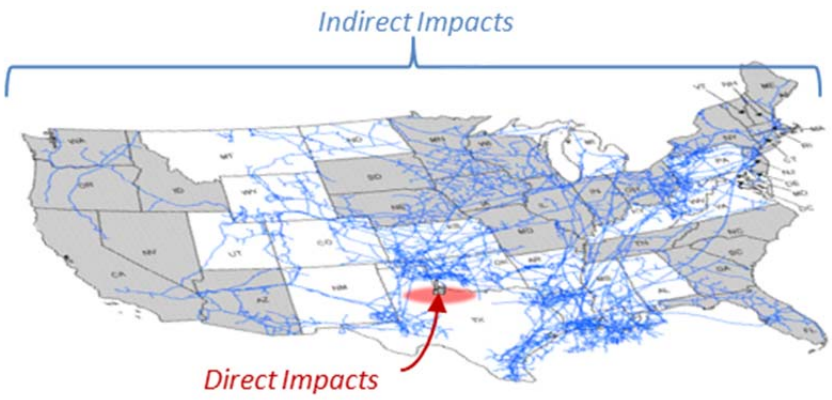

Figure 2. A notional map illustrating the difference between direct and indirect impacts. The area directly impacted by an attack is shown in red (i.e. consequences in the surrounding areas) and the areas indirectly impacted by an attack are shown in blue (i.e. cascading effects may extend nation-wide).

Several examples of direct and indirect economic impacts are listed in Table 1. The high-level analysis methodology developed for ISCD was designed with the flexibility to include multiple types of economic impact assessments (Step 3). Four sources of economic impact were selected for the initial assessments based on current CFATS program needs (clean-up, business interruption, facility repair and replacement, and chemical supply chain disruption). A brief description of each source is provided in this section, while the assessment tools for each source of impact are described in detail in Section 3 of this report. Other impacts, such as medical and funeral costs, may be considered for expanded or follow-on assessments of economic impacts.

Table 1. A list of potential sources of economic impact resulting from a chemical security incident. (Those marked with an * will be studied in the initial assessments.)

DIRECT ECONOMIC IMPACTS	INDIRECT ECONOMIC IMPACTS
Medical costs due to injuries	Disruptions in the chemical supply chain*
Funeral costs due to fatalities	Changes in consumer decisions
Clean-up costs*	Gains in industries that aid recovery
Losses due to business interruption*	Changes in technology investments
Replacement costs due to damages*	Jobs gained/lost
Damage of environmental resources	New regulations/policies impacting businesses
	Fluctuations in stock price valuations
	Changes in property valuations

Clean-up costs

Following an incident that causes contamination or damage to infrastructure, steps must be taken to remediate, or clean up, the area before people can reoccupy the area and return to business as usual. These steps include characterizing the extent of damage, developing a clean-up plan, identifying the resources (e.g., labor, equipment, etc.) and capabilities needed for clean up, executing the clean up, and ensuring that the remediation effort was effective. Depending on the scale of the incident, the clean-up effort may be accomplished with local resources and capabilities or may be complex with national resources and capabilities as well as specific expertise in hazard remediation required. The time and cost of these resources and capabilities can vary widely.

Business interruption

During a clean-up effort, business operations within the area of concern may be shut down until reoccupation is permitted. Businesses may be interrupted at different levels, depending on both the type of business and on the type incident. For example, a keep-out zone established around the area of concern would have a more severe impact on businesses that provide goods and services on-site (e.g., stores) than it would on businesses with a contingency plan that can operate remotely or have multiple sites of operation. The latter type of business may be able to function at some level during the remediation. Incidents that cause structural damage to a business may experience longer interruptions in business operations. The key factor that determines the

economic losses due to business interruption is the amount of time operations are impacted.

Replacement costs due to chemical facility damage

On-site incidents at a chemical facility may have costs associated with rebuilding, repairing, or replacing equipment. As a result, business operations at the chemical facility might not be restored until this equipment is functional. Replacement costs are incurred in addition to the economic consequences associated with remediation and business downtime costs.

Chemical supply chain disruptions

A chemical facility that incurs an incident may suffer from a number of direct economic consequences including remediation and equipment replacement costs along with losses due to business interruption during these efforts. While the operations at that facility are disrupted, the throughput of goods into (upstream) and out of (downstream) the facility may be severely reduced. As a result, the operations of businesses that supply that facility as well as those that use the goods produced by that facility may also be disrupted, thereby causing indirect economic impacts. The chemical supply chain in the United States is large and complex, and the chemical manufacturing sector supports many other sectors of the U.S. economy. In general, problems causing a decline in the economic output in one region or sector are often mitigated in large part by increases in output in another region or sector. Therefore, it is unknown whether an interruption at a single point in the chemical supply chain would have economic impacts noticeable at the National level.

2.2 Analysis Plan for Initial Assessments

As described in the analysis scope above, the CFATS facilities, their Appendix A COIs, and the corresponding security issues have been selected for the initial economic impact assessments. The first round of assessments is currently underway for a subset of these facilities, COIs, and security issues. This subset samples across the initial analysis scope to test and improve the methodology. The facilities selected for the first round of studies are primarily Tier 1 facilities that are geographically distributed across the country. All seven security issues are represented in the subset.

Before the economic impacts can be assessed in Step 3, two important variables of the scenario must be defined:

1. The area of concern, including the location and the size of the physical area directly impacted, and
2. The types of economic impacts relevant to the scenario.

Defining the area of concern

The type of chemical and the security issue combine to determine the location and the extent the surrounding areas may be impacted by an incident. The potential area immediately affected (referred to as the area of concern) is the critical piece of information that drives the economic impact modeling and analysis. The area of concern used in the economic impact analysis is the keep-out zone after an incident. The keep-out zone represents the area where people have been evacuated during clean up and operations are interrupted until the area is deemed safe for re-entry. An area of concern may be large or small, depending on the type of incident and the chemical. A number of approaches can be used to estimate the area of concern for the economic impact analysis. Three options for defining the area of concern have been considered for the economic impact analysis:

1. Leverage the existing Chemical Security Assessment Tool (CSAT) facility data, which includes contours calculated for estimating public health consequences;
2. Use an average area impacted based on historical chemical incident data; or
3. Calculate new contours using hazard modeling tools.

Each of these options is discussed briefly below.

Within the CFATS program an area of concern for public health consequences is calculated using the U.S. Environmental Protection Agency (EPA) model RMP*Comp in conjunction with a C-factor analysis.[9]

Figure 3 depicts the RMP*Comp region in comparison to the four C-factor fatality zones. The potential fatalities from toxic exposures[10] are then estimated based on the

[9] Selk, S. et al. "Chemical Facility Anti-Terrorism Standards Top-Screen and Security Vulnerability Analysis Tiering Methodologies" Sept. 23, 2011. Report is FOUO.

[10] This specific approach only applies to release-toxic and sabotage security incidents. However, similar approaches are used for other security incidents with flammable or explosive COIs.

population within the area of concern. The economic impact assessment could leverage either the RMP*Comp circle or the C-factor fatality zones for the area of concern, but these areas may not accurately represent the keep-out perimeter after an incident.

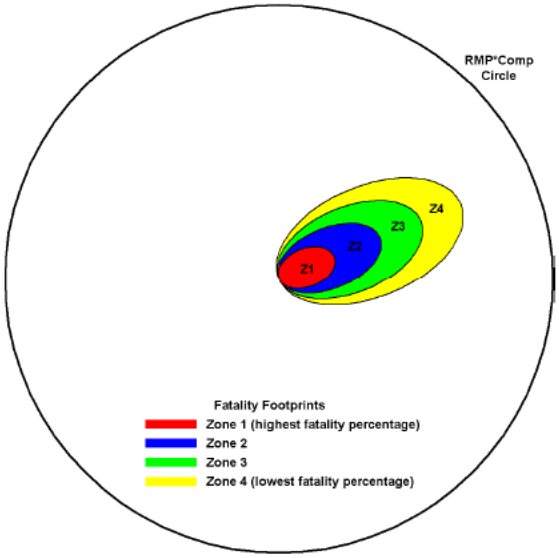

Figure 3. Notional example of RMP*Comp Circle and Plume Footprints for four C-factor fatality zones.

Another approach for estimating the area of concern is to examine historical examples of chemical incidents to identify how the clean-up and/or keep-out perimeters were defined following an incident. After reviewing numerous large-scale chemical releases (e.g., chlorine, ammonia, etc.) around the globe, it is possible make assumptions on the analysis of hypothetical chemical incidents depending on whether the chemical is persistent (low vapor pressure) or nonpersistent (high vapor pressure). For example, the majority of the historical chemical incidents reviewed (chlorine, ammonia, hydrogen fluoride, and sulfuric acid) included active remediation only within a few hundred meters of an incident (i.e., small clean-up area), even though high concentrations of the chemical in the air could drift for miles. This is a much smaller area of concern than indicated by the RMP*Comp Circle. (C-factor fatality zones are not available for comparison at this point.) Furthermore, in many of the historical incidents involving volatile chemicals, the vapor cloud dispersed over the course of a few hours, indicating that the keep-out perimeters were not maintained for long periods of time. Based on historical examples, the direct economic impacts after a chemical incident may only be incurred within a very small area of concern depending on the type of chemical and type of security issue. At the time of this report (July 2013), the historical examples approach

is the most favorable option for determining the area of concern for the economic impact assessments.

A third approach is to calculate the area of concern using hazard modeling tools. For example, the widely used Hazard Prediction and Assessment Capability (HPAC) tool developed by the Defense Threat Reduction Agency (DTRA) could be used to calculate varying degrees of contours over time for the areas impacted after an incident. This option is attractive because it would enable the analyst performing the economic impact assessment to define the area of concern rather than relying on external sources on information. However, this approach would require more time and effort for the assessments.

Select economic impacts to be assessed

As described previously, the scenario definition (Step 2) drives the types of economic assessments performed in Step 3. In particular the economic impacts assessed in the initial assessments depend on whether the area of concern defined by the security issues is on-site at a chemical facility or off-site at another location. Of the seven security issues outlined in CFATS Appendix A, three incidents occur on-site while the other four occur off-site (e.g., a chemical release in a city center). Assessment of on-site scenarios will include all four of the selected economic impacts, as shown in Figure 4.

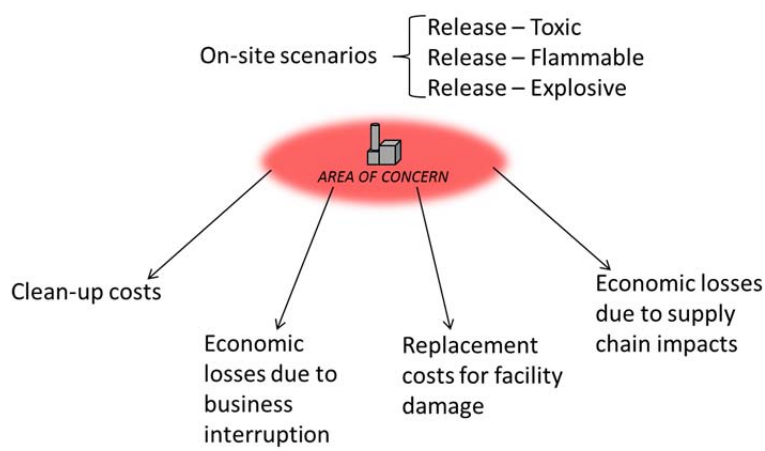

Figure 4. Economic impacts of a security incident that occurs on-site at a chemical facility.

The off-site scenarios do not necessarily impact chemical infrastructure, because the incident is located away from a chemical facility. Therefore, only two of the four selected impacts will be studied for off-site scenarios (Figure 5).

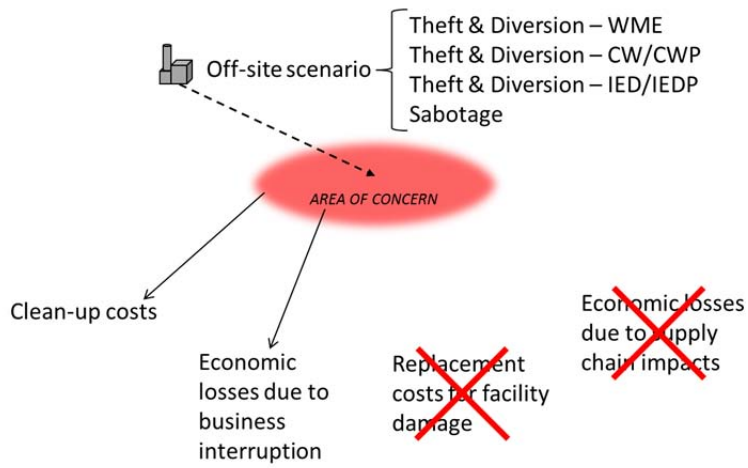

Figure 5. Economic impacts of a security incident that occurs off-site, i.e. remote from, a chemical facility.

Assessment tools to estimate each of the four types of economic impacts were identified for the initial assessments:

- *PATH/AWARE* → assessment of clean-up costs
- *REAcct* → assessment of economic losses due to business interruption
- *CSAT data* → assessments of facility repair and replacement costs
- *N-ABLE™ and Subject Matter Expertise* → assessment of economic losses due to chemical supply chain disruptions

The assessment tools were integrated into the analysis methodology as shown in Figure 6. Each tool provides an estimate in dollars of the costs/losses due to that particular type of economic impact. The PATH/AWARE tool used to assess the clean-up costs also estimates the clean-up time, which is then used in the business interruption tool REAcct. Each of the assessment tools is described in more detail in Section 3.

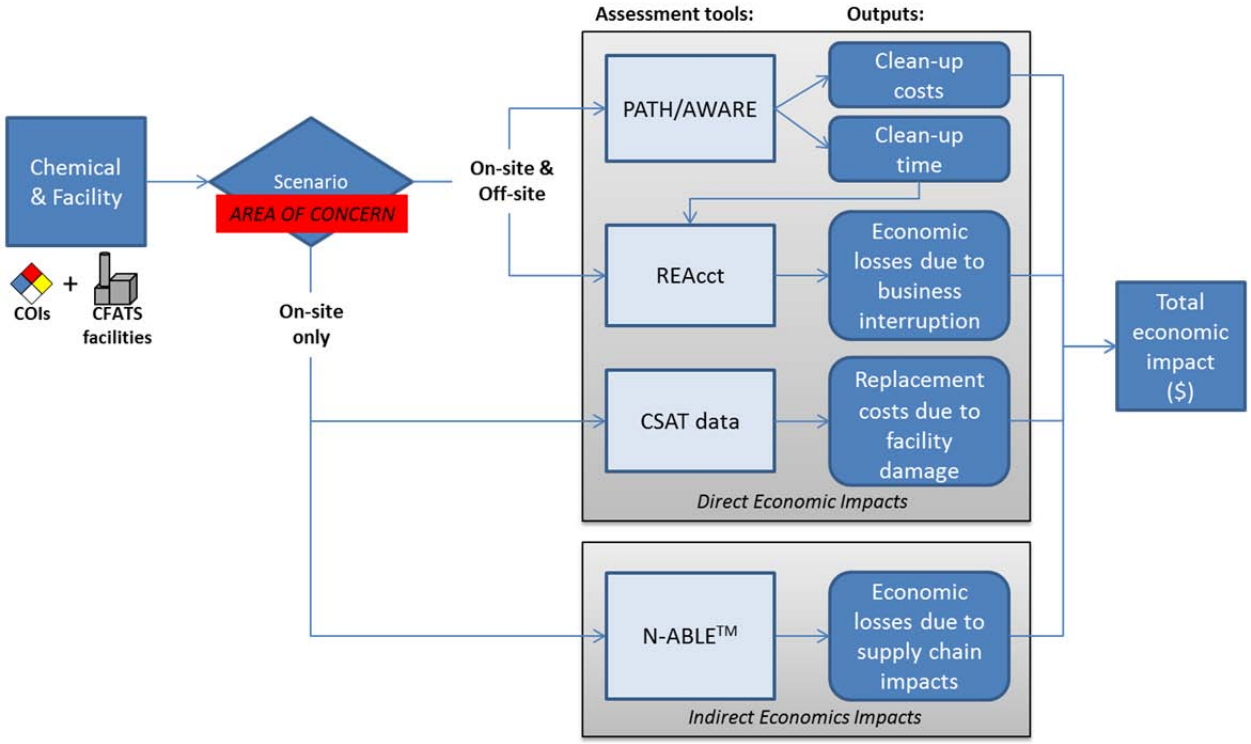

Figure 6. Multi-tool analysis approach for the initial economic impact assessments.

To summarize the approach for the initial assessments, a CFATS Appendix A COI and a CFATS facility in possession of that chemical are first identified. Then a scenario is defined based on the security issues described for the COI in Appendix A. Within the scenario definition, the area of concern is determined including the location of the incident and the extent of the area directly impacted by the incident. The relevant economic impacts are identified for assessment based on the COI, the facility, and the scenario. In particular, the location of the incident either on-site at the facility or off-site remote from the facility distinguishes what types of impacts should be assessed. Four types of economic impacts, representing both direct and indirect impacts, will be considered in the initial assessments. An assessment tool for each type of economic impact has been identified to estimate the associated costs and losses. The cost outputs from each assessment tool can then be rolled up into an estimate of the total economic impact in dollars for an incident involving that COI, facility, and scenario. This value can then be compared to the total economic impacts estimated for other COIs, facilities, and scenarios.

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3 ECONOMIC IMPACT ASSESSMENT TOOLS

3.1 Clean-up Costs: PATH/AWARE Tool

The AWARE tool, which stands for Analyzer for Wide-Area Restoration Effectiveness, is a planning tool developed at SNL to examine restoration activities following a wide area contamination incident. This tool enables estimates of both clean-up time and cost based on input of a number of restoration resources and capabilities. The AWARE tool may be used in conjunction with the PATH tool (Prioritization Analysis Tool for all-Hazards), although this capability will not be used in the initial economic assessments.

Step 1: Define hazard area

Within the PATH/AWARE tool, an analyst can outline the hazard areas using a Geographical Information System (GIS) component (Figure 7). The area of concern determined in the scenario definition will be incorporated into the tool for the economic impact assessment. The number and types of buildings (e.g., residential, commercial, etc.) within the area of concern are then acquired from the HAZUS dataset.[11] Generally, this step in the assessment provides a clearer picture of the area requiring active decontamination after the chemical incident or a better understanding of the problem at hand.

[11] HAZUS is a resource from the Federal Emergency Management Agency (FEMA) that is used in assessments of infrastructure impacts associated with natural hazard events. (http://www.fema.gov/hazus). The HAZUS dataset is fully integrated into the PATH/AWARE tool, which enables analysis of scenarios across the Nation.

Figure 7. Examples of Hazard Areas Scribed Using the GIS Component of the PATH/AWARE Tool (In this example, a high-level hazard area [red] and a medium-level hazard area [yellow] were defined. The tool estimates the clean-up time and cost within these areas.)

Step 2: Configure remediation input parameters

Once the area requiring remediation is defined, an analyst must define the resources and capabilities available for each phase of clean-up effort (e.g., screening, decontamination, etc.). For the economic impact analysis, the PATH/AWARE input parameters were selected based on information gathered over many years from various customers, workshops, and scenario analyses. An abbreviated overview of the various sections of the model and the key parameter assumptions are outlined below.

Resources

The Resources Phase involves the sampling and analysis aspect of the model. This includes the sampling capacity, such as the number of people and teams collecting samples for the Screening, Characterization, and Clearance Phases of the remediation. Lab capacities for analyses are based on the number of samples that can be analyzed by current labs scattered across the continental United States.

Screening

This phase is the first step to identify the presence of a chemical or biological species of interest. Samples are acquired few and far between to determine the areas for increased sample collection for the Characterization Phase.

Characterization

Judgmental sampling is used for characterizing areas to identify contaminated regions. Statistical sampling is not performed during this phase because time and resources are better spent on statistical sampling for the Clearance Phase to ensure the areas are safe for re-entry after the Decontamination Phase.

Waste

These parameters define the approximate quantities of outdoor and indoor waste that require decontamination, sampling for waste classification, and then transport to a disposal facility. The waste module is patterned after EPA's iWASTE tool. The metrics used in these calculations are based on defaults from the EPA tool.

Decontamination

High vapor pressure and low vapor pressure chemicals are listed in the scenarios that are under investigation for this project. For chemicals such as ammonia, chlorine, etc. (high vapor pressure chemicals), fumigation is the preferred method for interior decontamination. Those chemicals are most likely to be in a gas phase and will be diffused throughout an entire building. The best approach to access all the spaces in the building is through fumigation of a decontaminant. A liquid/foam spray would be used on lower vapor liquids and solids such as oleum and ammonium perchlorate. The use of liquid/foam spray is the only method considered for outdoor decontamination. In some cases of residential contamination, residents can elect to perform their own decontamination of their place of residence. This option was not selected for any of the scenarios analyzed.

Clearance

For the Clearance Phase, statistical sampling and judgmental sampling are both used on indoor sampling to ensure safe re-entry to buildings and residences. Justifications for only using judgmental sampling outdoors include:

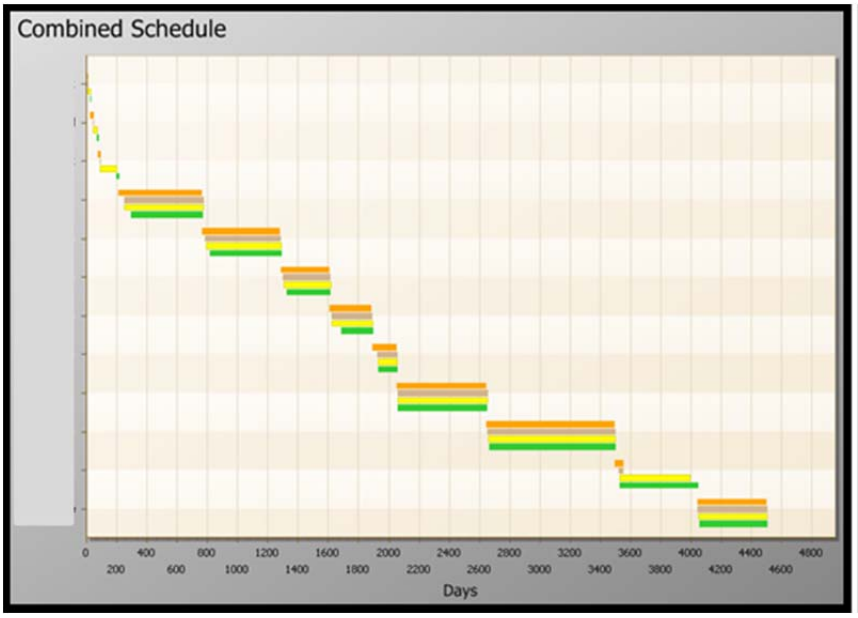
1. Weather could assist in the breakdown of chemicals,
2. Weather could assist to dissipate the chemicals to decrease concentration,
3. Indoor clearance sampling is assumed to have higher priority for reasons of habitation and working, and
4. Cost for outdoor clearance statistical sampling is astronomical.

Statistical sampling for residential space is set for 95% confidence that at least 95% of the area is clean. Increasing to higher confidence levels (e.g., 99%) increases the Clearance Phase time/cost significantly and is not considered necessary. For reasons of

public perception, statistical sampling is recommended for indoor clearance sampling as it provides quantitative information that the area is clean.

Step 3. Estimates time and cost of remediation

Once the input parameters for the area of concern and the clean-up resources and capabilities are configured into PATH/AWARE, the tool can quickly estimate the time and cost of the clean-up effort (Figure 8). The total clean-up cost is broken out by phase (e.g., characterization, decontamination, etc.) and the clean-up time is broken out into a schedule of areas within the larger area of concern. The clean-up cost is rolled up into an estimate of the total economic impact in the last step of the economic impact analysis. The clean-up time output from PATH/AWARE is used as in input into the REAcct tool for the assessment of losses due to business disruption (described in Section 3.2).



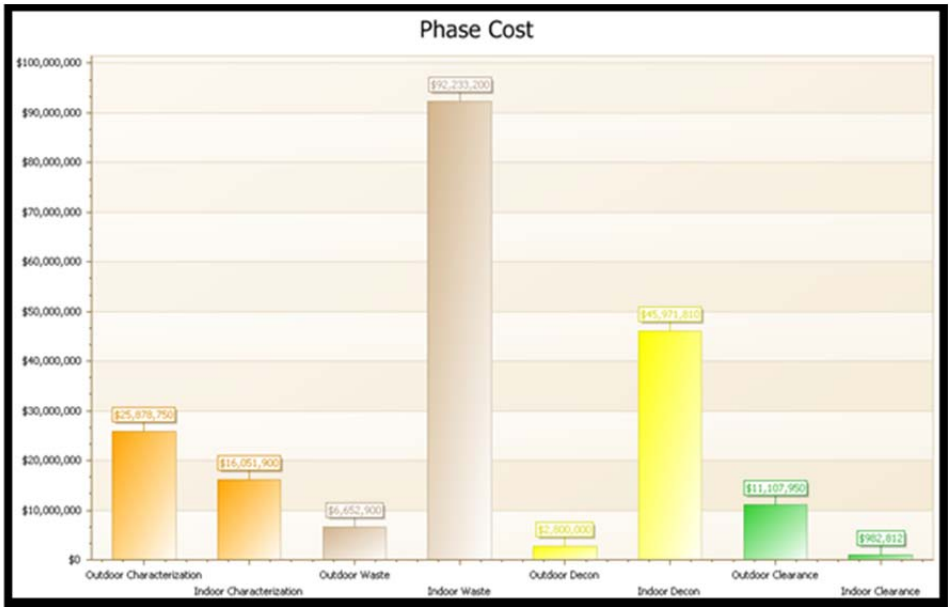


Figure 8. PATH/AWARE outputs include a remediation schedule (top) and the costs for each phase of remediation (bottom).

3.2 Business Interruption: REAcct Tool

The Regional Economic Accounting (REAcct) analysis tool is an assessment tool used for rapidly estimating approximate economic impacts for business disruptions due to natural or manmade events. REAcct provides county-level economic impact estimates in terms of gross domestic product (GDP) and employment for any area in the United States. REAcct is useful in analyzing events with durations of up to one year. Anything over one year requires the use of different models. In the case of terrorist actions,

numerous hypothetical events can be examined, thereby permitting analysis and comparisons of results that can support decisions or can lead to the development of more effective policies and procedures.

Step 1: Define the outage areas

As with the PATH/AWARE tool, the first step in an assessment with the REAcct tool is to define the area of concern (i.e., the area in which business is interrupted, or the outage area) using a GIS component of the tool. After an incident, a keep-out perimeter is typically established to prevent people from being exposed to any hazards that result from the incident. The level of business interruption within this area may vary based on the potential hazards; therefore up to four zones with different levels of economic disruption may be defined (Figure 9). Each zone may also be assigned a different duration for the disruption. This corresponds to the amount of time it takes to remediate the area and restore functions – a value calculated using the PATH/AWARE tool.

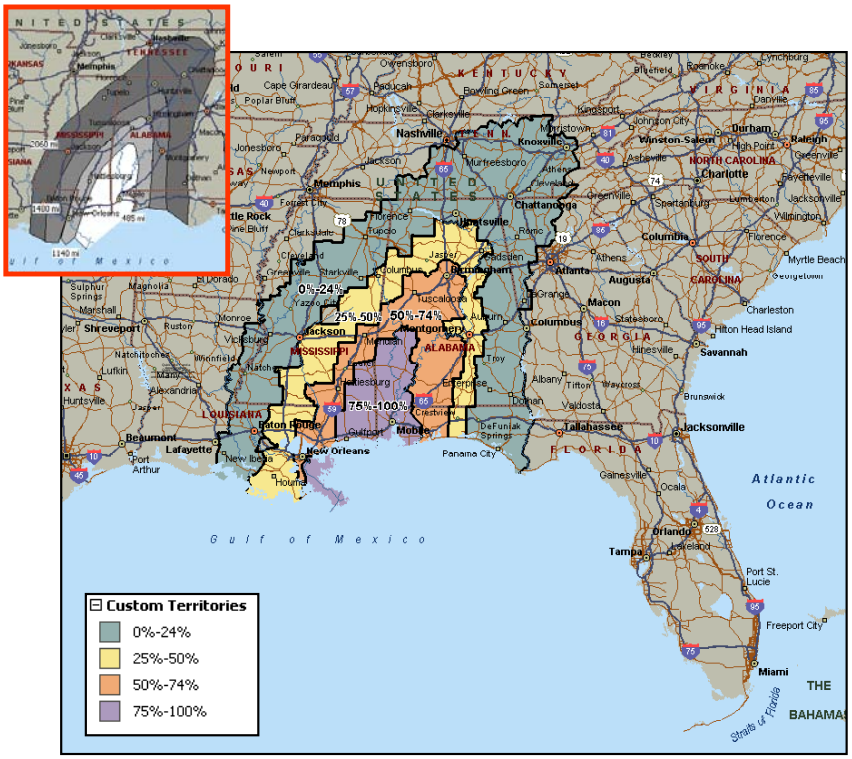


Figure 9. Example an outage area defined in REAcct with four different levels of disruption. Areas nearer to an incident may have higher levels of business disruption (e.g., up to 100%), whereas areas farther away may have less disruption (e.g., only 25%) due to fewer evacuation requirements, less infrastructure damage, etc.

Step 2: Compile the Economic Data

Once the outage area is defined and the counties impacted are identified, data on annual sales, income, value-added per worker, along with days of impact are compiled. Data are typically compiled on the county level and then categorized by industry type according to North American Industry Classification System (NAICS) codes.[12] Figure 10 is an example of the economic activity data compiled by county within the outage region.

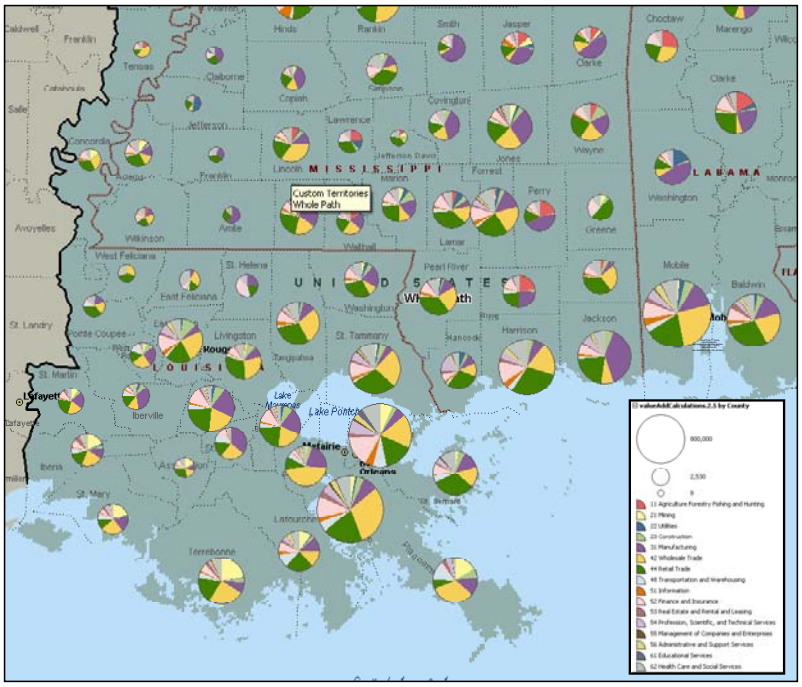


Figure 10. Gross domestic product (GDP) reduction, by county North American Industry Classification System (NAICS) industry code.

Step 3: Estimating impacts and reporting results

Based on the county-level characterization of the business activity over time, the direct GDP and income losses can be calculated for the indicated disruption time. Direct impacts are measured by multiplying the GDP per worker-day, by industry, times the

[12] NAICS codes are used to classify businesses according to their economic activity. The numbering system uses a six-digit code where the first two digits designate the largest business sector (e.g., utilities, construction, manufacturing, retail, educational services, health care and social assistance, etc.). There are 20 of these business sectors.

number of lost worker days. Summing this value across industries yields the total direct GDP lost. This value, which represents the economic losses due to business interruption within the hazard areas surrounding a chemical incident for the duration of the remediation effort, will be rolled up into the total economic impacts in Step 4 of the economic impact analysis.

Indirect economic impacts due to business interruption may also be estimated using the REAcct model. This type of indirect impact is measured as indirect losses in other industries and households, through losses of input materials purchased, and lost income (which affects spending across all industries).[13] Total impacts are estimated by multiplying the direct impacts by the Regional Input-Output Modeling System (RIMS) II[14] multipliers. Multipliers are used in regional economics to translate a dollar of direct economic impact in an industry/region into the total economic impact for that industry/region. Using the multiplier simulates the successive rounds of expenditure that take place throughout the economy as the result of a change in expenditure in an industry/region. The estimated indirect impacts are then determined by subtracting direct impacts from total impacts. Figure 11 is an example of the total impacts by county, including both direct and indirect impacts of business interruption.

[13] These income-related impacts to industry are often called induced impacts; total economic impacts are then computed as the sum of direct impacts to industries, indirect impacts to industries that supply to the directly affected firms, and induced impacts of lost income.

[14] U.S. Bureau of the Census, "Regional Input-Output Modeling System II (RIMS II)," http://www.bea.gov/regional/pdf/rims/RIMSII_User_Guide.pdf, 10/23/04

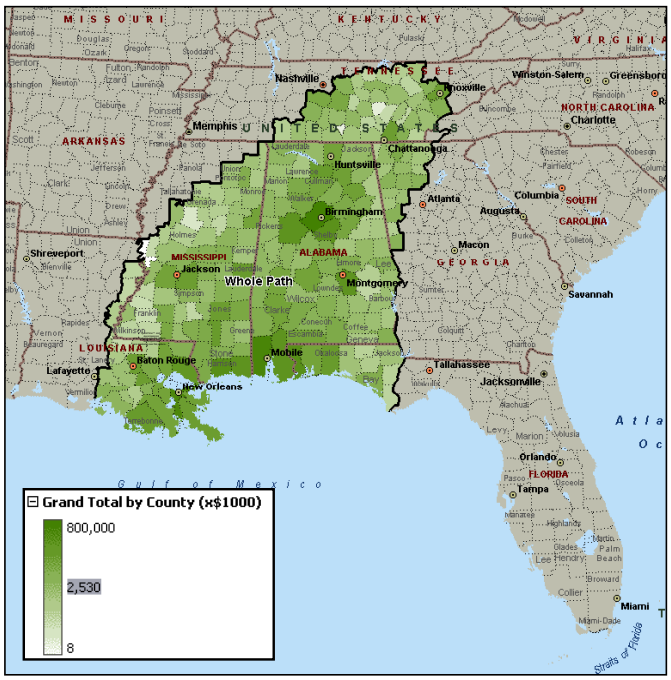


Figure 11. Total gross domestic product (GDP) reduction, by county.

3.3 Facility Damage/Replacement Costs: Top-Screen Data

For incidents that occur on-site at a chemical facility, the cost to rebuild the facility, replace process equipment, and restore operations has the potential to be an important factor in the overall economic impacts of an incident. These costs should be considered outside general remediation and restoration costs because all CFATS facilities are asked to report the estimated cost of replacement for the production units that use a specific COI in their Top-Screen survey (Figure 12). This facility-specific cost data will be incorporated in the total economic costs (Step 4).

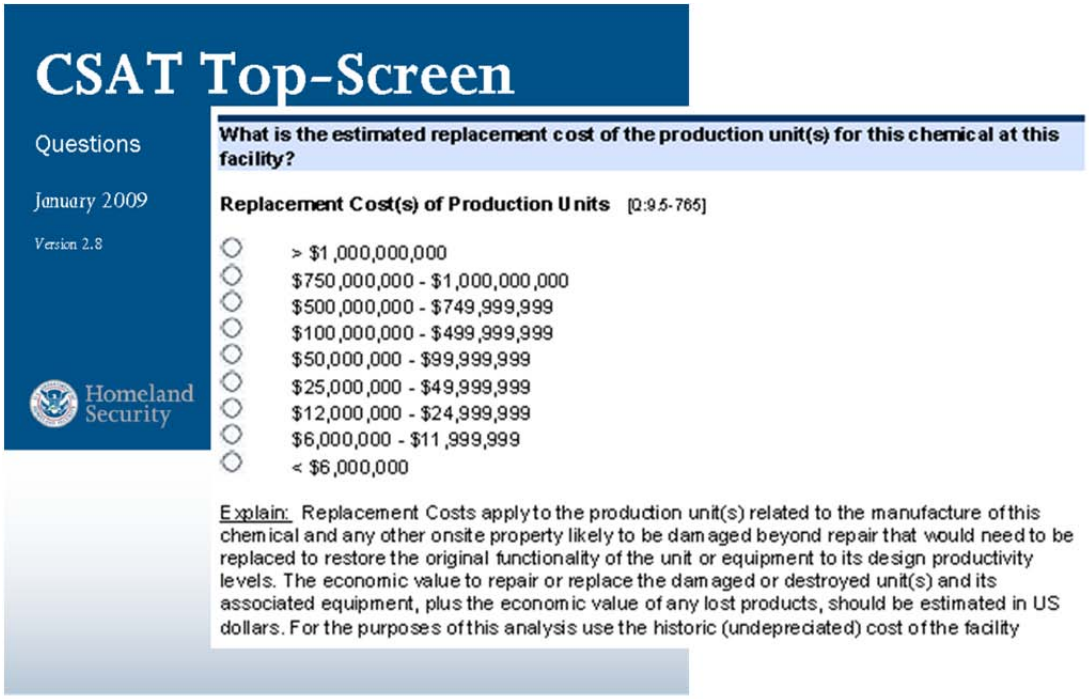


Figure 12. Screenshot of Top-Screen Question about Potential Facility/process Replacement Costs

There are pros and cons to this approach. One weakness is that the dataset collected from facilities in CSAT surveys is not vetted by DHS and therefore has the potential to be extremely inconsistent. In addition, this approach can only apply to facilities that have filled out a Top-Screen survey. Based on these concerns, other approaches were considered to estimate facility repair costs. For example, a significant amount of openly available resources and literature provide estimates of capital investments for establishing chemical processes within a chemical facility. This information could be integrated into the assessment framework or tool to render the assessment more standardized and uniform. However, the Top-Screen data have the advantage of being facility-specific, and only existing CFATS facilities are being examined in the initial set of assessments. Therefore, at this point, the use of Top-Screen data is a sound approach for estimating facility damage and replacement costs.

3.4 Assessing Impacts of Chemical Supply Chain Disruptions

The assessment of potential indirect economic impacts resulting from chemical supply chain disruptions is a complex and challenging task. Some pertinent facts affecting the attempt to identify chemical supply disruptions with national implications should be stressed at the outset:

- The U.S. national economy is large and complex—the largest in the world—at approximately $15.1 trillion in 2011 GDP.[15] The combined GDPs of China, Japan, and Germany, the next three largest economies, approximately equal the U.S. GDP.

- The 2010 GDP data, which is the most recent available for the chemical industry, shows the sector GDP to be $226.1 billion, less than 1.5% of total U.S. GDP.

- Adding the related sectors of petroleum and coal products GDP ($171.8 billion) and plastics and rubber products GDP ($66.5 billion) to chemical products sums to a total contribution of 3.1% to the national GDP.

- The 2010 input-output data for the U.S. economy demonstrate relatively low-valued inter-industry linkages between the chemical industry and other industries that it supplies. (This concept is explored in more detail in the Appendix.)

- The largest chemical company in the United States ranked by 2011 gross sales is ExxonMobil Chemical with $64.7 billion (ranked third in the world behind BASF of Germany and Sinpoec of China).[16] The ExxonMobil Annual Report shows a 2011 net profit for ExxonMobil Chemical of $4.4 billion.[17]

- Input-output data show that the dollar value of chemical product input to produce output of other industries is small, in most cases less than 5 cents. (See the Appendix for data supporting this point.)

- The U.S. economy is resilient and diverse; problems causing a decline in economic output in one region or sector are often mitigated wholly or largely by

[15] GDP by industry data obtained from the Bureau of Economic Analysis (BEA) website: http://www.bea.gov/industry/gdpbyind_data.htm, accessed (November 2012).
[16] Ranking by ICIS Chemical Business magazine. Reported at: http://www.prnewswire.com/news-releases/icis-top-100-chemical-companies-unveiled-169140386.html, accessed (November 2012).
[17] ExxonMobil 2011 Summary Annual Report Retrieved from: http://www.annualreports.com/HostedData/AnnualReports/PDF/XOM2011.pdf, accessed (November 2012).

increases in output in other regions or sectors, leaving the national economy apparently unaffected.

The facts outlined above indicate that the search for incidents of national *economic* or even regional *economic* significance resulting from disruptions in or to the chemical manufacturing sector is likely to be very difficult. This is particularly the case if the search is limited to disruptions in supply emanating from a particular plant or chemical manufacturing facility. Even where generalized disruptions (such as severe weather events) affect a significant segment of the chemical industry the identified impacts are relatively small as judged against regional impacts and virtually unidentifiable at the national level. Furthermore, attributing economic change to particular causes is problematic.[18] While impacts may be identified, these impacts must be viewed against a welter of other economic events, all of which could have exacerbated or mitigated the impacts.

Despite these difficulties, SNL spent the past several years developing robust capabilities to analyze the Chemical Sector. These capabilities enable detailed analyses of chemical manufacturing including the direct and indirect impacts to domestic chemical supply chains resulting from disruptions to chemical production capabilities. In particular, the N-ABLE ™ Chemical Supply Chain Model is built on the NISAC[19] Agent-Based Laboratory for Economics (N-ABLE™) framework.

3.5 N-ABLE™ Chemical Supply Chain Model

N-ABLE™ is an agent-based model (ABM) of supply chains and value chains. It was developed to analyze how manmade and natural disasters impact large numbers of interconnected economic firms, whether they are chemical plants, food manufacturing facilities, or retailers and household consumers. These firms are interconnected through both the markets for goods and services they buy or sell and the transportation networks over which they transport these goods and services. Compared with other modeling approaches, N-ABLE™ simulations provide data on when, where, and how portions of

[18] This raises the statistical conundrum of correlation versus causation.
[19] National Infrastructure Simulation and Analysis Center (NISAC). http://nisac.sandia.gov, accessed July 2013.

the economy outside the disruptive event are impacted by the event itself. N-ABLE™ based estimates of impacts often include:

- Lists of the number and locations of firms directly or indirectly impacted by the disruption;
- Estimates of how long it takes for firms outside the disruptive event to experience indirect impacts, and how long it takes for the entire supply chain of firms to return their operations to normal;
- List of the commodities significantly impacted (and by how much); and
- Quantitative estimates of the change in aggregate (all firms) and per-firm levels of goods purchased, on-site, and in-transit inventories; production; sales; and shipments.

N-ABLE™ provides these estimates by conducting simulations based on detailed supply chain models of individual firms, their markets, and their supporting infrastructure (e.g., transportation). In the context of analysis of Chemical Sector-specific problems, the N-ABLE™ Chemical Supply Chain Model is designed to model the interactions of chemical production units, representing their purchasing, sales, and production decisions as economic agents in a cross-enterprise model of the Chemical Sector.

The N-ABLE™ Chemical Supply Chain Model is designed to foster user development of a chemical network incorporating subsets of the set of chemicals of specific interest to the problem being addressed. Thus, if preliminary analysis of a geospatial damage contour (i.e., the area of concern) using FASTMap[20] and the Loki Chemical Network Model[21] suggest that a certain subset of chemicals may be of interest for further examination, a model using these chemicals (and chemicals related to them) can be built using the N-ABLE™ Chemical Supply Chain Model. Through the development and

[20] FASTMap application reference: http://www.sandia.gov/nisac/analyses/fast-analysis-and-simulation-team-fast/fastmap/, accessed July 2013.
[21] Loki Chemical Network Model application reference: http://www.sandia.gov/CasosEngineering/amti.html, accessed July 2013.

processing of the model by chemical and economics subject matter experts, the resulting model will have a well-structured, balanced baseline that can then be perturbed using the same disruption contours. The result allows a comparison of baseline to disrupted conditions, which enables analysts to understand more complex interactions among market players for chemicals, identifying:

- Chemicals that cannot be produced to meet demand;
- Delays in the onset of disruptive effects at indirectly affected chemical production units due to in-transit and on-site storage;
- Mitigative effects for potentially indirectly affected chemical production units, such as purchasing from alternative sellers, and the added costs associated with these mitigation measures, and
- Time for systemic recovery of chemicals manufacturing following restoration of physical plant and infrastructure service.

Each of these values brings a better understanding of the levels of systemic impact than can be gained in a straight-line measure from Loki, and each is beneficial in the estimation of resilience effects for subelements of the Sector or for the Sector as a whole, providing a gauge for prioritization of restoration.

The N-ABLE™ supply chain model is composed of three main submodels:

1. An enterprise model of an economic firm,
2. A market model of buyers and sellers in these firms who purchase and sell goods, and
3. A transportation model of shipments of these goods between the economic firms.

Each of these submodels is described in the following subsections.

Enterprise model

Each economic firm in an N-ABLE™ simulation is modeled as an enterprise that purchases, receives, and stores input materials in a warehouse and uses these input materials in one or more productions that are often connected in serial or parallel to produce output materials that are then stored and ultimately sold in markets.

N-ABLE™ models the real world buyer, seller, and production operations within the firm, subject to realistic constraints on production capacity, warehouse capacity, market prices, and shipping. Moving from the left side of Figure 13 to the right, there are three fundamental operations within a firm: first, for each chemical that needs to be purchased for use by the firm, there is a buyer agent assigned to ensure that there is an adequate but not excessive amount of the chemical in the warehouse ready for use. Second, the set of productions within the plant are scheduled and coordinated by a supervisor agent, which uses a linear-programming technique described in Ehlen *et al* (2011) to set production unit levels so that final chemical production levels meet targeted levels as closely as possible. Targeted production levels are set based on current inventory levels (if inventory levels are low, then the plant will produce enough to meet expected demand) and demand in the market for the particular chemical (if the firm has little on hand but the market is asking for it, the firm will increase production to attempt to meet that unmet demand).

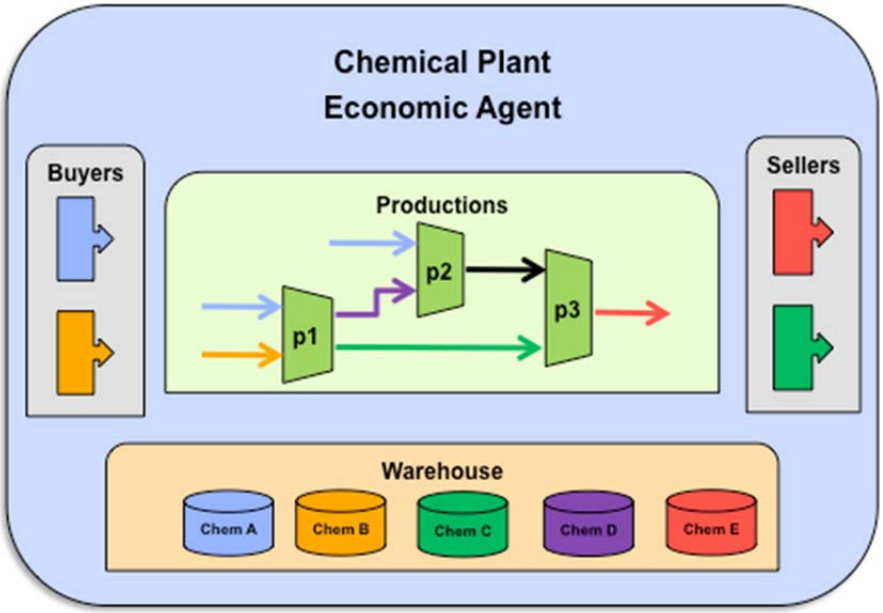


Figure 13. N-ABLE™ Enterprise Model.

Finally, one or more sellers sell each chemical in one or more markets (e.g., a domestic market and foreign market). Each seller can set different prices for its product, where higher prices tend to reduce sales and lower prices tend to increase sales. The seller agent also has the potential to learn over time what price maximizes its profit, or revenues minus costs.[22]

Market model

There are many types of economic markets from which to construct an agent-based chemical market, including competitive, monopolistic, monopsonistic, monopolistic competitive, oligopolistic, auctioneer, and others. For disruption analysis, N-ABLE™ uses a variant of the traditional competitive model, in which many buyers and sellers compete in the market and no particular firm exerts significant market power (ability to control price and market share) over other selling and buying firms. Firms can compete with one another based on price and buyers can shop for lower-priced suppliers.

Because most if not all N-ABLE™ supply chain models are directed – i.e., there are source or upstream productions and sink or downstream end-consumers for which and for whom there are no industry data. For example, N-ABLE™ chemical supply chains include plants that sell chemicals to nonchemical industries: e.g., shoe manufacturers. Because the CDM does not include data on these nonchemical firms, surrogate economic firms are created that can both provide non-CDM feedstock chemicals and other inputs to CDM plants, at the source side of the directed supply chain and use the CDM chemicals for nonchemical industry purposes. Beyond the basic purpose of then completing their associated markets (an N-ABLE™ market will not work if it has sellers of chemicals but no buyers), these surrogates are designed with the following properties to support the supply chain simulations and disruption analysis:

[22] See Ehlen, M.A., Loose, V.W., Smith, B.J., Vargas, V.N., Warren, D.E., Downes, P.S., Eidson, E.D., and Mackey, G.E. (2010) Economics Definitions, Methods, Models, and Analysis Procedures for Homeland Security Applications, Sandia National Laboratories Report SAND2010-4315, July 2010, for a detailed discussion of the GALCS algorithm used to set prices. For analytical reasons, the N-ABLE™ chemical supply chains constructed in the project hold prices constant and instead focus on the regional and temporal rationalization of supply and demand via search.

- There are sufficient numbers of each type of surrogate firm (e.g., firms that purchase nitric acid for nonchemical industry purposes) to represent the random nature of buying and use by these firms;

- These surrogates are distributed spatially/regionally to represent the effects of distance on shipping inventories and costs and to capture how a regional disruption (e.g., a hurricane) will impact portions of the chemical supply chain; and

- In the case of end-consumer firms, technology data on what chemicals go into which economic sectors were used to estimate the numbers and locations of firms in the United States.

Transportation network model

Once a seller is contacted for an order and completes that order, the seller ships the chemical using a particular mode of transportation (e.g., rail, road, water, or pipeline). The transportation model used is a large-scale multi-modal and intermodal network, where shipments can travel over one or more modes, shipments can transfer from one mode (e.g., rail) to another (road), shipments can be required to pass through specific nodes (e.g., Ports of Entry, rail yards), and resulting shipping routes can change due to homeland security-related changes in transportation infrastructure (e.g., disruption to the rail transport of chemicals).

The transportation model comprises network graphs of North American rail and road transportation and U.S. and international water transportation from Peterson (2000), shipping components that track the fixed and variable costs of shipping of each transportation mode (truck, rail, water), and network algorithms to compute the actual shipping route of a particular shipment between a particular seller and buyer. Each of the transportation modes specified by a buyer or seller is meant to reflect the physical transportation capabilities of its plant, and each is constructed as a collection of shipping component and transportation subgraphs (e.g., rail), which can be added separately or in intermodal fashion.

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4 EXPANDING ECONOMIC MODELING AND ANALYSIS

This report describes an economic impact analysis methodology that meets the needs of the current CFATS program. Specifically, the methodology presently includes the capability to assess four sources of economic impacts. At each step in the methodology, there is an opportunity for expanding the analysis capability. Such options were explained throughout the report. For example, in the first step, in which the chemical and the facility are identified, the current assessments are limited to the COIs currently regulated in CFATS Appendix A. One significant way to expand the analysis capability is to look beyond this list of chemicals that are considered because of their potential health hazards toward a broader list of chemicals that may be important specifically for their role in the economy. This effort, known as the CSP, is described in the next section (4.1).

Another opportunity for expansion is to improve the scenario definition, which is Step 2 in the methodology. In the section Defining the area of concern, three approaches were described for identifying the areas impacted after an incident. All three approaches exhibit shortcomings related to understanding the fate and transport of the hazard after the incident. Section 4.2 proposes an approach for determining the impact over time – i.e., modeling deposition contours.

The third step of the methodology, the impact assessment step, is yet another area in which the analysis capabilities could be expanded. Several other types of economic impact, including both direct and indirect sources, could be assessed in addition to the four currently included in the capability. The review of existing economic impact assessment methodologies (e.g., MSRAM, CIRA, and CREATE) will provide insight into these options.

4.1 Chemical Screening Process: Looking Beyond CFATS Appendix A for Economically Critical Chemicals

Chemicals on the CFATS Appendix A list represent primarily physical hazards. Disruption to the supply of these chemicals may or may not have significant economic impact. We SNL developed the CSP to help identify chemicals that are mostly likely to cause severe economic loss through supply disruption. These chemicals may or may not already be listed in CFATS Appendix A. Two questions help identify such chemicals:

1. Is the chemical economically important ?
2. Is supply of the chemical vulnerable to disruption?

If a chemical is not of economic consequence, loss of supply is unlikely to cause significant economic loss. If a chemical supply is not vulnerable, significant loss of supply is unlikely. As implied by the name, the purpose of the CSP is to screen a relatively large number of chemicals into a more manageable set, which can then be subjected to more detailed analysis. This multistep approach enables a more efficient commitment of resources to the problem.

A chemical may be economically important if it is a critical part of a large, strongly coupled chemical and manufacturing supply chain. Loss of supply of such a chemical could then result in severe economic loss due to cascading supply chain failure. For cascading supply chain failure to occur, suppliers must lack alternate customers or production options and/or production must require specific chemical inputs. If suppliers and producers are easily able to adjust to a supply disruption, propagation of the supply disruption will be limited.

In addition to economic importance, the supply of a chemical must be vulnerable in order for it to pose significant economic concern. Indicators of supply vulnerability include:

- Low sourcing diversity
- Unreliable source(s)
- Low backup inventory
- Raw material scarcity
- High utilization of production capacity

The ability to identify economically important chemicals with supply chain risk is limited by the availability of accurate, high-resolution economic and supply data. A complete and quantitative network describing material flows into, out of, and within the chemical industry would provide the clearest picture of the likely economic importance and supply vulnerability of a given chemical relative to other chemicals. High-quality data of this resolution and extent are not practically available at this time. Therefore, alternative options must be considered.

Because economic data describing the chemical industry are readily available, SNL explored evaluating chemical economic importance in terms of aggregated economic sectors, as opposed to discrete chemicals and manufactured products. The primary assumption with this methodology is that a chemical is more likely to be economically important if it belongs to an economically important sector. A further implied assumption is that important chemicals should not exist in unimportant sectors. To

avoid bias, SNL excluded sector-level indicators of economic importance that scaled with the number of chemicals in a chemical sector (e.g., total shipments, total value-added, total employment), because dividing a sector in half should not change the inherent importance of the chemicals in that sector. To very briefly summarize the findings, the remaining scale-independent indicators of chemical sector economic importance that explored tended to be strongly correlated and very similar in value between different sectors. In short, aggregation into chemical sectors obscures the economic importance of individual chemicals, limiting the usefulness of such data in the present analysis. For these and other reasons, SNL does not use sector-level data as part of the CSP.

Because detailed and comprehensive data describing material flows within the chemical and manufacturing supply networks is not practically available, and because sector-level data lacks sufficient resolution, an intermediate approach for use in the CSP was adopted. More specifically, SNL uses chemical prices in conjunction with measures of supply risk to create an indicator that combines economic importance and supply risk into a single measure. It is assumed that data describing chemical prices is at least as available as data necessary to describe supply risk.

SNL calculates indicators of supply risk and economic importance used in the CSP for individual chemicals. The core principles behind the indicators described below are not new. The measure referred to as *fraction of supply at risk* is fundamentally equivalent to the Herfindahl-Hirschman Index, which is a measure of concentration or competition within economic markets and is used by the U.S. Department of Justice and Federal Trade Commission in applications of antitrust law. In the same sense that having many independent firms competing in a market is generally more economically healthy than monopolistic control, having many independent suppliers of an important chemical can reduce supply risk.

The CSP uses the following data to calculate relative indicators of supply risk and economic importance for each chemical:

$R_{i,k}$ = Risk associated with source i for chemical k

$A_{i,k}$ = Amount of chemical k supplied by source i

C_k = Domestic consumption of chemical k

P_k = Price of chemical k

The fraction of supply at risk for chemical k is defined as

$$F_k = \frac{1}{C_k} \frac{\sum_i (A_{i,k} R_{i,k})^2}{\sum_i A_{i,k} R_{i,k}}$$

This indicator is a relative measure of the fraction of the supply of a given chemical that could be lost following the complete loss of a typical supplier. A low number of suppliers or a significant fraction of the supply coming from one supplier or a significant number of high-risk suppliers will all increase risk according to this measure. SNL assumes that a large potential lost supply fraction indicates greater potential for significantly harming related elements of the supply network.

The *value of supply at risk* for chemical *k* is defined as

$$V_k = P_k \frac{\sum_i (A_{i,k} R_{i,k})^2}{\sum_i A_{i,k} R_{i,k}}$$

This indicator is a relative measure of the value of the supply of a given chemical that could be lost following the complete loss of a typical supplier. As with the previous fraction of supply indicator, a low number of suppliers or a significant fraction of the supply coming from one supplier or a significant number of high-risk suppliers will all increase risk according to this measure. Additionally, a high chemical price will also increase the value of this indicator. In addition to greater supply risk, SNL assumes that a large potential lost supply value indicates greater economic importance through the effect of price, which is a general economic measure of the perceived relative value of a given item, material, or service. Regardless of the actual fraction of supply lost, SNL assumes it is worse to lose $1,000,000 of supply than $1,000 of supply.

If the input data described above are not readily available, further simplification and reduction of data requirements are possible. For example, if assignment of varying levels of risk to different chemicals/suppliers is not desired, set $R_{i,k}$ = 1 for all chemicals/suppliers. Further, if detailed supplier information is not available, make the simplifying assumption that all suppliers of a given chemical are of equal size. Mathematically, $A_{i,k} = A_k$ = average size of producer of chemical *k* = total production of chemical *k* divided by the number of producers of chemical *k*. Other simplifications are also possible. Using this approach, the CSP could be applied in multiple steps, using the coarsest data with the full set of chemicals to be screened and using more detailed (and more costly) data at subsequent steps.

Figure 14 below shows the results of testing the CSP on a set of approximately 150 chemicals, using data extracted from the Chemical Economics Handbook. To reduce

data collection requirements, this analysis used the simplifying assumptions described above: namely, that all chemical suppliers have identical relative risks and each supplier of a given chemical is of equal size. The figure shows that the two indicators, fraction of supply at risk and value of supply at risk, are generally uncorrelated, thereby allowing use of both indicators in the CSP. Fraction of supply at risk can take values greater than 1.0. This is typically the case when there is only one domestic producer of a chemical and a large portion of that production is exported – loss of that one facility would then result in a loss of supply greater than domestic consumption. Chemicals identified as requiring more detailed analysis would generally be those scoring high on either or both axes of the figure.

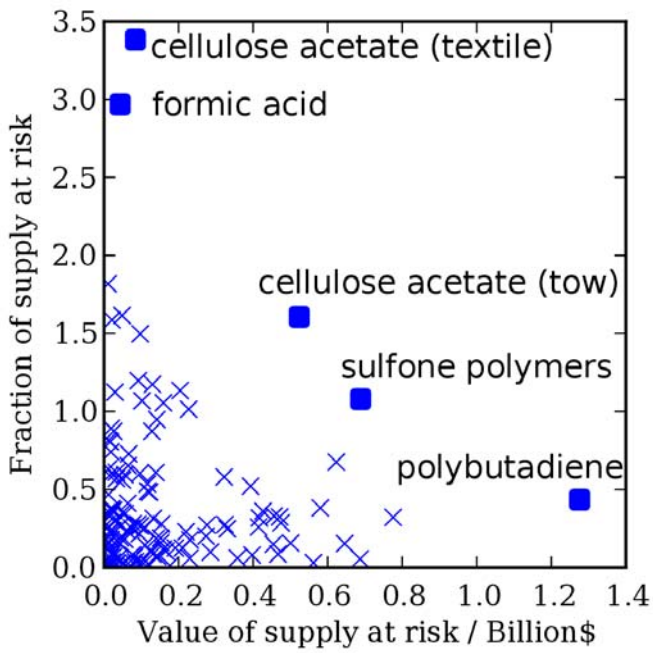

Figure 14. Example of CSP Modeling Results. (Each X represents a chemical.)

Several potential indicators of supply risk are not used in the CSP. These omitted indicators include, for example, production capacity utilization (i.e., amount produced as a fraction of the amount that could be produced) and stockpile availability (e.g., days of supply available). Production capacity utilization would be a very valuable indicator, and if such data become readily available, incorporation as another indicator in the CSP would be straightforward. Similarly, stockpile availability would be useful for evaluating scenarios in which production of a chemical is lost for a particular amount of time. The CSP does not preclude using this or other information to identify chemicals that are likely to cause significant economic loss if supply is lost. Instead, the CSP is only an early step in the identification of such chemicals.

4.2 Modeling Deposition Contours to Determine Impact Area Versus Time

In the initial analysis of economic consequences following a chemical release, SNL considered the *area of concern* to be an area that includes anything that has any chance of being impacted by the incident at any point in time after the incident. Natural dispersion and degradation of the chemical over time have not been explicitly modeled. This omission of natural attenuation mechanisms can lead to a significant over-estimation of the area requiring active remediation. Consequently, estimates of the time and cost required to return an area to service following an incident would also be greatly overestimated. For example, release of a volatile chemical such as chlorine or ammonia affects a relatively large area initially, but its tendency to vaporize and disperse also limits the area requiring active remediation to something much less than the initially affected area. More accurate estimation of the economic consequences of a chemical release requires explicitly including chemical fate and transport in the analysis.

Numerous chemical fate and transport models, ranging from simple to complex, were developed to predict the movement and behavior of chemicals in the environment. For example the EPA uses such models for Risk-Based Corrective Action decision-making.[23] Similar to EPA practices, SNL would link fate and transport modeling to chemical hazard data (e.g., toxicity) to predict the area affected by a chemical release as a function of time following the incident. By combining chemical fate and transport modeling with SNL's PATH/AWARE and REAcct remediation models, development of more realistic and efficient remediation plans would be possible, relative to the simplified clean-it-all assumption used in this initial analysis. The resulting analysis would account for both natural attenuation and active remediation to predict the area denied following a chemical release as a function of time. In addition to improving remediation planning and cost prediction, more accurate estimation of the time required to return an area to service also enables more accurate estimation of secondary losses resulting from business closure, displacement of people, disabled infrastructure, etc.

[23] Foster Wheeler Environmental Corporation; 1998. American Society for Testing and Materials, Technical and Professional Training Risk-Based Corrective Action Fate and Transport Models; Compendium and selection guidance; retrieved from http://www.epa.gov/oust/rbdm/rbcafntm.pdf on July 17, 2013.

Inputs to chemical fate and transport models include properties of the chemical, distribution and properties of materials in the environment, prevailing weather and climate, etc. The most challenging part of the model system described above is the collection of data and assignment of parameters required to drive the models. To attain useful results more efficiently, initial analysis should focus on determining which chemical and environmental properties most strongly influence chemical fate and transport. This knowledge would reduce the need to model every potential combination of chemical and release environment. Further, it would permit a better estimation of the level of uncertainty in model predictions.

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APPENDIX A: SUPPORTING INFORMATION

Definitions Used in Economic Consequence Framework[24]

	DIRECT CONSEQUENCE	INDIRECT CONSEQUENCE
Definition	An effect that is an immediate result of an event, incident, or occurrence	An effect that is not a direct consequence of an event, incident, or occurrence, but is caused by a direct consequence, subsequent cascading effects, and/or related decisions
Sample usage	Property damage and loss of life were among the direct consequences resulting from the hurricane.	In the following months, decreased commerce and tourism were among the indirect consequences resulting from the hurricane.
Annotation	• Can include injuries, loss of life, on-site business interruption, immediate remediation costs, and damage to property and infrastructure as well as to the environment. • To distinguish direct and indirect, an analysis should: - capture the likely effects – be they designated as direct or indirect, - clearly define what is contained as part of direct consequences and what is part of indirect consequences, and - be consistent across the entire analysis	• Can include the enactment of new laws, policies, and risk mitigation strategies or investments, contagion health effects, supply-chain economic consequences, reductions in property values, stock market effects, and long-term cleanup efforts. • May have greater and longer-lasting effects than the direct consequences. • Sometimes referred to as ripple, multiplier, general equilibrium, macroeconomic, secondary, and tertiary effects.

The variety of consequences is highly dependent on the type of attack. For example, a contamination attack in the subway system of a metropolitan area could potentially result in a significant number of injuries and fatalities. There could be a lengthy clean-up effort after the incident at significant costs. Furthermore, people may be averse to

[24] Risk Steering Committee DHS Risk Lexicon, 2010 Edition. Retrieved from http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf on July 17, 2013. Repeat of Reference #3

taking the subway in that city, or even in other cities after the chemical incident. This would result in decreased revenue for public transportations regionally and/or nationally. On the other hand, a chemical incident where a terrorist might target a chemical facility or group of facilities in an attack would have a different set of consequences. If the facility is not in a densely populated area, the immediate public health consequences would be less severe than the first example, but damage to the facility operations and business disruptions could have economic consequences that reach far beyond the chemical sector.

Data Sources for Chemical Supply Chain Models

Models and analytic capabilities designed to support analysis of the Chemical Sector require a wide range of information to serve as a basis for analysis. This includes information such as:

- Plant facility information, including plant name, geolocation, and street address;
- Facility production information, including the names of chemicals produced at a site, the processes involved in their production, and the quantities of production that are physically possible given the production and storage equipment at the facility;
- Infrastructure dependencies, including identification of transportation types accessible to the facility (rail, pipeline, highway, waterway), and identification of energy dependencies (electric power, natural gas, petroleum products);
- Input consumption information, including chemical categories used as inputs to processes, the quantities necessary to support acquisition, and storage levels on site; and
- Import and export information, identifying the level of movement of chemicals to and from the United States and, where possible, the points of production.

These information requirements must be met for a wide range of chemical families. The capability currently encompasses data on over 8,000 producers, over 1,300 reactions, and over 580 chemicals, in the following areas of chemical production:

- Petrochemicals
- Chlorine and Ammonia

- Industrial Acids
- Industrial Gases
- Select Inorganic Chemicals
- Pesticides, Insecticides, and Herbicides
- Agricultural Fertilizers
- Select Plastics and Plastics Precursors

For this purpose, the project has drawn on a wide range of resources for data on chemical production, handbooks on the fundamentals of chemical manufacturing, and other data sources for infrastructure, trade, and demand data.

Table 2 highlights the principal sources of Chemical Sector data used in this project.

Table 3 highlights the handbooks that are used to provide a fundamental understanding of the processes involved. Table 4 shows the infrastructure, economic, and trade data used within the scope of the effort. Additional discussion is warranted for several of the sources.

Discrepancies among data sources are addressed in the construction of the data model, described in the Data Model section of this appendix.

Table 2. Chemical Sector Data Sources.

CHEMICAL DATA SOURCES	PROVIDER	SUBSCRIPTION
World Petrochemicals	IHS Global	Annual
Directory of Chemical Producers	IHS Global	Annual
Chemical Economics Handbook	IHS Global	Annual
Ullmann's Online Encyclopedia of Industrial Chemistry	SNL Technical Library	Bi-annual
Kirk-Othmer Online Encyclopedia of Chemical Technology	SNL Technical Library	Bi-annual
ACS Guide to Business of Chemistry	American Chemical Society	Annual
ACS Resin Review	American Chemical Society	Annual
E-PLAN	U.S. Environmental Protection Agency	public
OSHA hazardous chemical list	Occupational Safety and Health Administration	public
NIST	U.S. Department of the Interior	public
Materials Safety Data Sheet	Company websites	public
Peer-reviewed journal articles	Journal websites	public and private

Table 3. Chemical Sector Handbooks.

HANDBOOK	PROVIDER	PUBLICATION DATE
CRC Chemical Processing Handbook	SNL Technical Library	1993
The Agrochemicals Handbook	Royal Society of Chemistry	1991, purchase
Handbook of Commercial Catalysts	SNL Technical Library	2000
Petroleum Engineering Handbook	SNL Technical Library	1987
Shreve's Chemical Process Industries	SNL Technical Library	1984
Perry's Chemical Engineering Handbook	SNL Technical Library	2008

Table 4. Infrastructure, Trade, and Economic Data Sources

NAME	SOURCE
United States Census 2000	U.S. Census Bureau
County Business Patterns 2007	U.S. Census Bureau
County Business Patterns Employees Estimation 2007	U.S. Census Bureau
Geographic Names Information System	U.S. Geological Survey
IMPLAN States Summary 2002	Minnesota IMPLAN Group
International Trade Statistics 2007	U.S. Department of Commerce
2005 Commodity Flow Survey, Department of Transportation	2005 Waybill Sample, Surface Transportation Board
2007 Class I Railroad Statistics, Association of American Railroads	2007 Producer Price Index, U.S. Department of Labor

IHS Global Data Sets

Three data sets, *World Petrochemical* (WP), the *Directory of Chemicals Producers* (DCP) and the *Chemical Economics Handbook* (CEH) are essential elements to this capability, providing an array of the Chemical Sector-specific data across the spectrum of chemicals included in the data set. These are acquired on a subscription basis from IHS Global and are updated accordingly.

WP provides supply/demand and capacity analysis for 55 petrochemicals and plastics and 12 refinery products worldwide. Each report is organized by product, with detailed

capacity, production, consumption, and trade data by region and country. Each country section includes a review of the local markets and producers and a product balance by company, location, and country.[25]

DCP offers a unique view of global chemical industry producers, and covers more than:

- 14,000 chemical companies
- 20,000 chemical manufacturing sites
- 21,700 unique chemical products.[26]

CEH is the leading source of global chemical business analysis for over 300 industrial chemicals. The coverage includes:

- Detailed supply/demand analysis of current markets for individual chemicals or groups of chemicals, future growth with five-year projections, and historical data
- Evaluation of the size and nature of specific end-use markets and trends
- Industry production, producer locations, and capacities
- Commercial manufacturing processes
- Price histories and factors affecting prices
- International trade, detailed supply/demand analysis of current markets for individual chemicals or groups of chemicals, future growth with five-year projections, and historical data.[27]

[25] HIS Chemical Company Analysis http://www.ihs.com/products/chemical/companies/analysis/index.aspx, accessed July, 17, 2013.
[26] HIS Directory of Chemical Producers http://www.ihs.com/products/chemical/companies/producers.aspx, accessed July 17, 2013.
[27] Chemical Company Handbooks , HIS Chemical at http://www.ihs.com/products/chemical/companies/handbooks/index.aspx, accessed July 17, 2013.

Data Model

The Chemical Data Model, or CDM, reflects the assembly of information from the above-identified data sources into a single environment accessed by a variety of analysis capabilities. The schema for the CDM is shown in Figure 15.

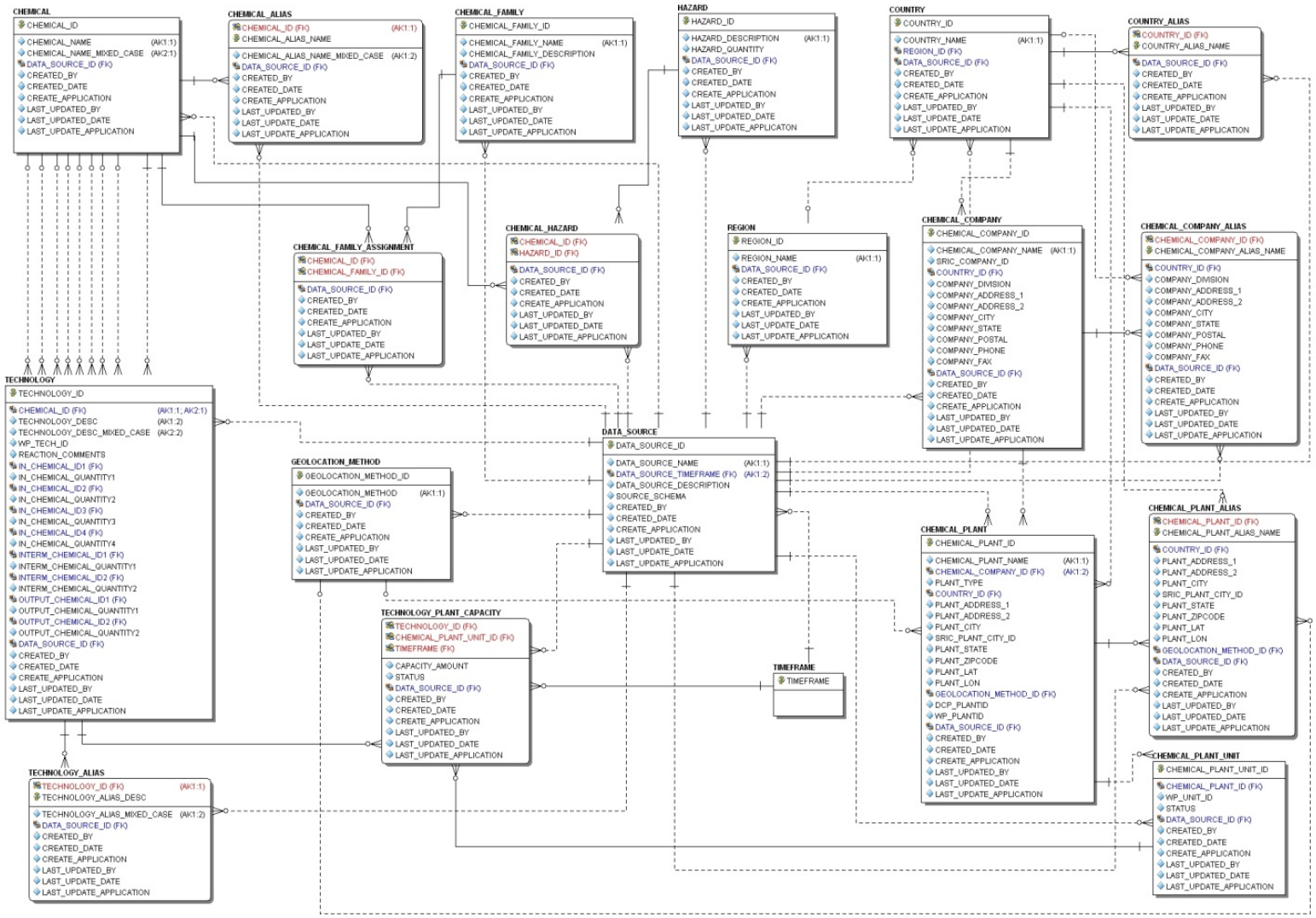

Figure 15. Chemical Data Model Schema.

The CDM is a normalized data schema consisting of the chemical facilities, chemicals, and technologies used in the Chemical Model. An individual chemical facility in the CDM is generated either from a single input source or by combining data from multiple sources and verified by a subject matter expert (SME) during the process of chemical facility creation using the Chemical Data Review (CDR) tool discussed below.

The design of the CDM allows the Data Development and Processing SME to identify quickly which technologies are used to create a given chemical as well as where the same chemical is produced and which chemicals are used to produce that chemical. The normalized data structure enables the quick retrieval of data from any one section of the database that relates to data from any other section of the database.

The main schema design elements are:

Chemical: Contains each of the chemicals as well as known aliases.

Chemical Plant: Contains each identified chemical facility and the production units for the facility. Production units may produce one or more chemicals and must have an identified technology.

Technology: Contains the technologies used to produce a chemical. Technologies must contain at least one input chemical and one output chemical as well as the ratios required to produce the output chemicals.

CDM Building Process

The CDM building process is iterative and allows flexibility and information validation. The steps of the building process are as follows:

Data Gathering: New data are acquired from current or new data sources.

Processing and Integration: Data are assembled, using CDR and Chemicals Sector subject matter expertise.

Cross-checking: Checks are performed on the assembled data to determine existence of one of a variety of potential inconsistencies, including

- *Fixing chemical nomenclature records:* Spelling inconsistencies of chemical names exist within data sets, which can lead to the creation of multiple chemical records where only one exists.

- *Consolidating redundant facility records:* Records from different sources for the same chemical plant can have inconsistent name, address, and other identifying information, which can lead to the creation of multiple facility records where only one exists.

- *Process addition:* When new chemical families are added to the CDM, often reactions addressing the making of these chemicals are not in the model. Chemicals Sector SMEs consult the literature to identify these reactions and add them to the CDM.

Documentation: Changes and inconsistencies, as identified, are documented for future reference.

Testing: New versions of the CDM are tested against current iterations of the models that draw on them to determine whether additional inconsistencies have arisen from updating the CDM. Revisions to the CDM or the individual models can be made based on the judgment of the Chemicals Sector SME and model experts. Further revisions can also result from inconsistencies in mass balance across the CDM for a given chemical or chemical reaction, from industry feedback, or from the incorporation of new markets or transportation mechanisms.

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