SANDIA REPORT
SAND2009-6552
Unlimited Release
Printed July 2011

Regional Economic Accounting (REAcct): A Software Tool for Rapidly Approximating Economic Impacts

Mark A. Ehlen, Vanessa N. Vargas, Verne W. Loose, Shirley J. Starks, and Lory A. Ellebracht

Computational Economics Group
Sandia National Laboratories
Albuquerque, New Mexico 87185

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration, under Contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone:	(865) 576-8401
Facsimile:	(865) 576-5728
E-Mail:	reports@adonis.osti.gov
Online ordering:	http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone:	(800) 553-6847
Facsimile:	(703) 605-6900
E-Mail:	orders@ntis.fedworld.gov
Online order:	http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2009-6552
Unlimited Release
Printed July 2011

Regional Economic Accounting (REAcct): A Software Tool for Rapidly Approximating Economic Impacts

Mark A. Ehlen, Vanessa N. Vargas, Verne W. Loose, Shirley J. Starks, and Lory A. Ellebracht

Computational Economics Group
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-1138

Abstract

This paper describes the Regional Economic Accounting (REAcct) analysis tool that has been in use for the last 5 years to rapidly estimate approximate economic impacts for disruptions due to natural or manmade events. It is based on and derived from the well-known and extensively documented input-output modeling technique initially presented by Leontief and more recently further developed by numerous contributors. REAcct provides county-level economic impact estimates in terms of gross domestic product (GDP) and employment for any area in the United States. The process for using REAcct incorporates geospatial computational tools and site-specific economic data, permitting the identification of geographic impact zones that allow differential magnitude and duration estimates to be specified for regions affected by a simulated or actual event. Using these data as input to REAcct, the number of employees for 39 directly affected economic sectors (including 37 industry production sectors and 2 government sectors) are calculated and aggregated to provide direct impact estimates. Indirect estimates are then calculated using Regional Input-Output Modeling System (RIMS II) multipliers. The interdependent relationships between critical infrastructures, industries, and markets are captured by the relationships embedded in the input-output modeling structure.

Acknowledgments

The authors gratefully acknowledge the financial support of the U. S. Department of Homeland Security and to the many staff members of this organization who provided the intellectual stimulus to the development of this tool. Their probing questions and desire for quick turn-around answers to these questions were important to the development of the tool. Various staff members at Sandia National Laboratories also contributed to the intellectual environment that stimulated the tool development. Finally, editors at Sandia National Laboratory were invaluable in ensuring that descriptions of the tool were clear, crisp, and accurate. We are indebted to them but do not hold them responsible for any errors, misconceptions, or omissions. Those are the responsibility solely of the authors.

Table of Contents

Figures

Tables

Acronyms, Abbreviations, and Initialisms

Acronym	Definition
BEA	U.S. Bureau of Economic Analysis
DHS	U.S. Department of Homeland Security
GDP	gross domestic product
GIS	Geographic Information System
IMPLAN	Impact analysis for PLANning
I-O	input-output
NAICS	North American Industry Classification System
RIMS II	Regional Industrial Multiplier System II
SCPM	Southern California Planning Model

1 Introduction

The federal government's role in disaster planning, mitigation, and relief is extensive. This role has historically been related mostly to the effects of natural disasters such as floods, hurricanes, tornados, earthquakes, and wildfires, but has more recently been extended to manmade events best exemplified by terrorist actions.

For some natural disasters, particularly hurricanes, advances in meteorology provide advance warning, including prediction of severity and trajectory, allowing responsible government officials time to plan, prepare, and formulate a response. Predicting the possible economic impacts of such events in a specific locale permits timely decisions to be made about the magnitude of responses.

REAcct was developed to provide a simple tool that could rapidly provide order-of-magnitude estimates of the potential economic severity of a disaster. Some of the advantages of REAcct include that it

- Provides approximate estimates quickly;
- Is relatively easy to use, thereby lower cost;
- Is based on input-output (I-O) methodology; therefore, theoretically established; and
- Uses the Geographic Information System (GIS) to provide regional detail.

A key advantage of REAcct is that it can be used in real-time to estimate the economic impact of events, contrasting with other, more sophisticated but complex, models that require more time, preparation, and effort. However, REAcct is useful in analyzing events with duration of up to 1 year. Anything over 1-year requires the use of different models. In the case of terrorist actions, numerous hypothetical events can be examined; again, permitting analysis and comparisons of results that can support decisions or can lead to the development of more effective policies and procedures. This is the environment within which the need for a tool such as REAcct was formulated.

The uniqueness of REAcct lies in its ability to quickly provide impact-zone estimates of natural or manmade events. REAcct has already provided estimates for actual and hypothetical events to the U.S. Department of Homeland Security (DHS) through its extensive use in recent years, particularly during the active hurricane season in the summer and fall of 2005.

This paper begins with a brief overview of I-O literature, focusing particularly on REAcct's application to disasters. This is important because it authenticates REAcct. The authors then present and describe the REAcct methodology, including use of the GIS tools and databases that are employed in its application. This discussion is then followed by an example of how the tool would be applied to a typical analysis.

2 Pertinent Literature

I-O modeling applications have been extended to encompass both temporal and spatial considerations, adding to their customary applications to assess impacts of changes to an economy, particularly a regional economy. These recent applications, estimating the regional economic impacts of natural disasters and other unexpected events, provide new focus for the I-O modeling technique.[1] While subject to limitations well-known among economists, I-O models "are useful in providing ball-park estimates of very short-run response to infrastructure disruptions."[2]

Rose and Miernyck have provided a review of I-O literature, including applications and advancements up to about the late 1980s.[3] Some discussion of the I-O literature, pertaining to its applications for estimating the impact of natural disasters and terrorist events, can be found in a number of more recent papers, particularly Bockarjova, et al., Clower, and Okuyama.[4,5,6] Some of the more pertinent literature is discussed briefly below.

One of the strengths of the I-O technique is that it can and has been applied at almost any geographic level, subject only to the constraint of data availability. Refining the national I-O tables to incorporate a finer spatial disaggregation is necessary for many types of analysis. For example, the Southern California Planning Model (SCPM) has incorporated a level of spatial disaggregation (identifying 308 regions in the Los Angeles basin) that enables analysts to effectively study income distribution impacts in addition to the more traditional economic measures. Gordon et al., and Cho et al., emphasize that many natural disasters and infrastructure failures are predominantly local phenomena and, therefore, require modeling at the metropolitan and perhaps even sub-metropolitan level. Over the years, several techniques of varying sophistication have been developed for incorporating a spatial dimension to the national I-O data. One of the most commonly used techniques involves regionalizing the national I-O data by calculating regional purchase coefficients: one of several methods used for regionalizing an I-O model.[7]

More recent techniques focus on representing various networks or infrastructures that connect regions. For example, some I-O models include electric power infrastructure,[8,9] the airline industry,[10] and surface transportation in a sub-metropolitan region.[11,12]

---

[1] See, e.g., West et al [1994], Rose et al [1997], Rose and Benavides [1998], Bockarjova et al [2004], Haimes [2001], and Haimes et al [2005]

[2] Rose, A. (2006). "Regional Models and Data to Analyze Disaster Mitigation and Resilience," Center for Risk and Economic Analysis of Terrorism Events: University of Southern California

[3] Rose, Adam, and William Miernyck (1989). "Input-Output Analysis: The First Fifty Years." *Economic Systems Research*, 1:2, 1989

[4] Bockarjova, M., A. E. Streenge, and A. van der Veen (2004). "Structural economic effects of large-scale inundation: a simulation of the Krimpen dike breakage," in "Flooding in Europe: Challenges and Developments in Flood Risk Management, in series *Advances in Natural and Technological Hazards Research*. Summer 2004

[5] Clower, T. (in press). "Economic applications in disaster research, mitigation, and planning. In McEntire, D., *Disciplines, Disasters and Emergency Management: The Convergence and Divergence of Concepts, Issues and Trends in the Research Literature*, Springfield, Illinois: Charles C. Thomas, 2007

[6] Okuyama, Y. (2003). "Modeling spatial economic impacts of disasters: IO Approaches," in *Proc. Workshop In Search of Common Methodology on Damage Estimation*, May 2003, Delft, the Netherlands

[7] For a discussion of the methods and their limitations see, Stevens, B., G. Treyz, D. Ehrlich, and J. Bower. 1983. "A New Technique for the Construction of Non-Survey Regional Input-Output Models and Comparisons with Survey-Based Models." *International Regional Science Review*, 8: 271-286

[8] Moore, James E., Richard Little, Sungbin Cho, and Shin Lee (2005). "Using Regional Economic Models to Estimate the costs of Infrastructure Failures: The cost of a Limited Interruption in Electric Power in The Los Angeles Region," April 18, A Keston Institute for Infrastructure Research Brief, available as of 3/30/06 at http://www.usc.edu/schools/sppd/lusk/keston/pdf/powerfailure.pdf

Moore, et al., use a more recent version of the same SCPM I-O model to examine the costs of a limited electric power outage at specific locations within the Los Angeles metropolitan area. Outages are allocated spatially over the region, and job and income losses are predicted from this distribution of outages. Moore, et al., were able to associate job losses with socioeconomic income groupings by using Bureau of Census data and calculating Gini coefficients,[13] both before and after the hypothetical disruption, and then determine whether the electric outage had caused a change in the distribution of income to residents of the region. They concluded that the electric power outage did not change the distribution of income.

Hewings and Roy present a model that attempts to incorporate multiple transportation paths in and out of a region. This model enables consideration of traffic congestion and improves the previously required assumption that supply from other regions is exogenous. Hewings and Roy also discuss the previous oversimplification of types of commodity flows that is often required for standard regionalization using the regional purchase coefficients.

Cheng, et al., present an I-O model that they use to estimate the economic impacts of terrorist events. They used a hypothetical event in which terrorists caused the outage of a major electric power plant serving the Washington, DC region.[14] Based on the hypothetical scenario, they concluded that noticeable economic impacts, in terms of lost output and income, could occur. In a recent article published in *The Economic Impacts of Terrorist Attacks*, Gordon and others analyze a scenario where the twin ports of Los Angeles and Long Beach are attacked by terrorists using a moderate-sized radiological bomb. They developed an embellished I-O economic model, specifically for the Los Angeles metropolitan region, that could be used to analyze any plausible attack on specific targets in the city.[15]

---

9 Rose, Adam, and J. Benavides (1998), "Regional Economic Impacts" in M. Shinozuka et al (eds.) "Engineering and Socioeconomic Impacts of Earthquakes: An Analysis of Electricity Lifeline Disruption in the New Madrid Area," *MCEER*, Buffalo, 95-123

10 Gordon, P., J. E. Moore, Harry Richardson, and Quisheng Pan (2005). "The economic impact of a terrorist attack on the twin ports of Los Angeles-Long Beach," in *The Economic Impacts of Terrorist Attacks*. H. W. Richardson, Peter Gordon, and James E. Moore II, eds., Edward Elgar Publishers, Northampton, MA

11 Cho, Sungbin, Peter Gordon, James E. Moore II, Harry Richardson, Masanobu Shinozuka, and Stephanie Chang (2001) ."Integrating Transportation Network and Regional Economic Models to Estimate the costs of A Large Urban Earthquake", *Journal of Regional Science*, 41(1): 39-65

12 Roy, J. R., G. J. D. Hewings, and G. August, (2005) "Regional Input-Output with Endogenous Internal and External Network Flows" REAL 05-T-9. Available as of 3/31/06 at: http://www2.uiuc.edu/unit/real/d-paper/05-t-9.pdf

13 The Gini coefficient measures the degree of inequality of the income distribution.

14 Cheng, Shaoming, Roger R. Stough, and Adriana Kocornik-Mina (2006). "Estimating the economic consequences of terrorist disruptions in the national capital region: an application of input-output analysis," *Journal of Homeland Security and Emergency Management*. Vol 3: 3

15 Gordon, P., J. E. Moore, Harry Richardson, and Quisheng Pan (2005). "The economic impact of a terrorist attack on the twin ports of Los Angeles-Long Beach," in *The Economic Impacts of Terrorist Attacks*. H. W. Richardson, Peter Gordon, and James E. Moore II, eds., Edward Elgar Publishers, Northampton, MA

3 The REAcct Tool

The total economic impact of a disruption is typically grouped into two categories:

- Direct impacts, which occur to those firms directly affected by the disruption; e.g., firms directly in the path of an event; and
- Indirect impacts, which occur to firms that are not in the direct path of a disruption, but that are indirectly affected (e.g., by the loss of sales to firms in the direct path).[16]

Sandia analysts use the following steps in applying REAcct to estimate total economic impacts:

1. Using the Geographic Information System, identify the number of employees directly affected by the event by establishing impact zones showing the geographic extent of the event.
2. Estimate and report the impacts (extent and duration) to firms directly affected by the change to baseline conditions. This may vary according to the previously defined impact zone
3. Estimate and report the impacts to economic entities indirectly affected by the change to baseline, using I-O multipliers.

The following paragraphs discuss these three steps in more detail.

3.1 Geographic Information System (GIS) Component

The first step in application of REAcct to an actual or hypothetical event in a specific area requires the specification and identification of the area within which the event occurred. Using GIS software, a GIS layer is created that depicts the specific affected area. This layer is overlaid with another GIS layer that shows the U.S. counties. Using this overlaid counties layer, the intersections of the affected area with the counties are determined resulting in a list of the counties within the affected area. The duration of the economic disruption is then determined by analysts based upon knowledge of the event and the affected area. By identifying the affected counties and the duration of the economic disruption, analysts can generate estimates of the amount of economic activity in a specific area and the impact of the event on economic activity, using key impact measures such as employment and output.

3.2 Direct Economic Impacts

Direct impacts are measured by multiplying gross domestic product (GDP) per worker-day, by industry, times the number of lost worker days. Summing this value across industries yields the total direct GDP lost.

[16] Impact analysis often separates out the induced impacts, which are the impacts to households and their expenditures resulting from lost income.

3.3 Indirect Economic Impacts

Indirect impacts are measured as indirect losses in other industries and households, through losses of input materials purchased and lost income (which affects spending across all industries).[17] Total impacts are estimated by multiplying the direct impacts by the Regional Industrial Multiplier System RIMS II[18] 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.

4 Data

The U.S. Bureau of Economic Analysis (BEA) maintains publicly available national I-O data and I-O multipliers down to the county level. Additionally, Minnesota IMPLAN Group's **IM**pact analysis for **PLAN**ning (IMPLAN) software produces multipliers for U.S. counties or other user-defined regions.[19] The national data are benchmarked every 5 years and estimated annually. At a national level, the BEA provides more detail on inter-industry relationships than is available at smaller geographic levels. See Table 4-1 for a list of required data and sources.

Table 4-1: Required data and sources

Var	Name	Source
Y_i^{US}	National annual output, by North American Industry Classification System (NAICS) industry	U.S. Bureau of Economic Analysis[20]
E_i^{US}	National employment, by NAICS industry	U.S. Bureau of Economic Analysis[21]
E_i^r	Regional employment, by industry/county	U.S. Census Bureau, County Business Patterns (NAICS)[22]
m_i^r	Output- and demand-driven multipliers	U.S. Bureau of Economic Analysis, Regional Industrial Multiplier System (RIMS II) multipliers[23]

[17] 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.
[18] U.S. Bureau of the Census, "Regional Input-Output Multipliers II (RIMS II)," http://www.bea.doc.gov/bea/regional/rims/ , 10/23/04
[19] Minnesota IMPLAN Group, Inc. (1999). IMPLAN Professional, Version 2.0, "Social Accounting and Impact Analysis Software: User's Guide, Analysis Guide, Data Guide" Stillwater, Minnesota
[20] U.S. Bureau of Economic Analysis, "Gross-Domestic-Product-(GDP)-by-Industry Data," http://www.bea.gov/industry/gpotables/gpo_action.cfm?anon=103397&table_id=24752&format_type=0, 4/26/05
[21] Ibid.
[22] U.S. Bureau of the Census, "County Business Patterns," http://www.census.gov/epcd/cbp/view/cbpview.html , 4/26/05
[23] U.S. Bureau of the Census, "Regional Input-Output Multipliers II (RIMS II)," http://www.bea.doc.gov/bea/regional/rims/ , 10/23/04

5 Application

The following sections summarize how the I-O approach incorporated into REAcct is applied to estimate the economic impacts of a hurricane, what its limitations are, and how it can be expanded to include dynamics and higher fidelity.

5.1 Hurricane Scenario

A strong hurricane is forecast to land on the Gulf Coast and dissipate over a period of 2 to 4 days. The winds from the hurricane are forecast to cause minor damage to utilities and buildings, but the ensuing rains and related conditions will require that businesses and residences either close and evacuate or close and then support local emergency activities.

5.2 Step 1: Define the Impact Areas

Given that closing and evacuating of businesses is likely to result in more lost days of economic activity than closing and supporting, analysts defined four zones of economic disruption, shown in Figure 5-1,[24] and assigned different days of economic loss to each.

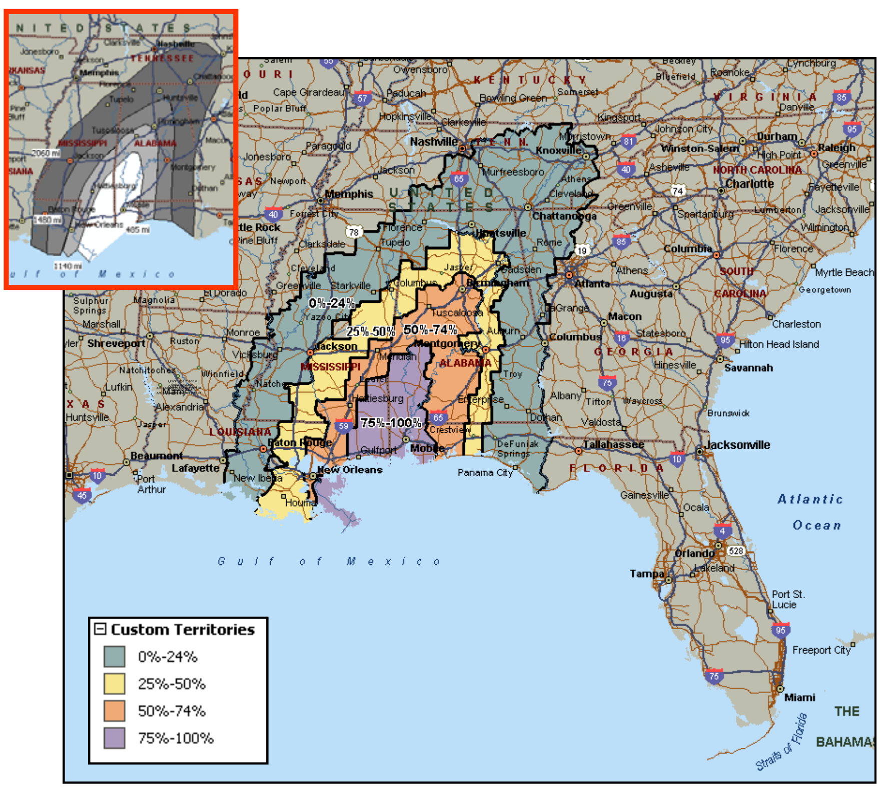

Figure 5-1: Outage areas

[24] This figure was created in Microsoft MapPoint; the purple and orange regions are created by defining MapPoint "territories," which are composed of multiple counties. These territories are exported to Excel, where they are used to filter the national county-level data to include just those counties in the analysis.

NISAC assumed that, after the outage period, economic business resumed at its pre-hurricane level, and that there were relatively few permanent economic losses. If, instead, there were significant permanent changes to the regional economy, the I-O approach would be less valid.

5.3 Step 2: Compile the Economic Data

Once the outage area has been determined, NISAC compiles the data on annual sales, income, value-added per worker, and days of impact. The recommended approach is to compile the sales and income data at the county level and then group the economic data at the 2-digit North American Industry Classification System (NAICS) industry code. Figure 5-2 illustrates the regional and industrial scope of these data.[25]

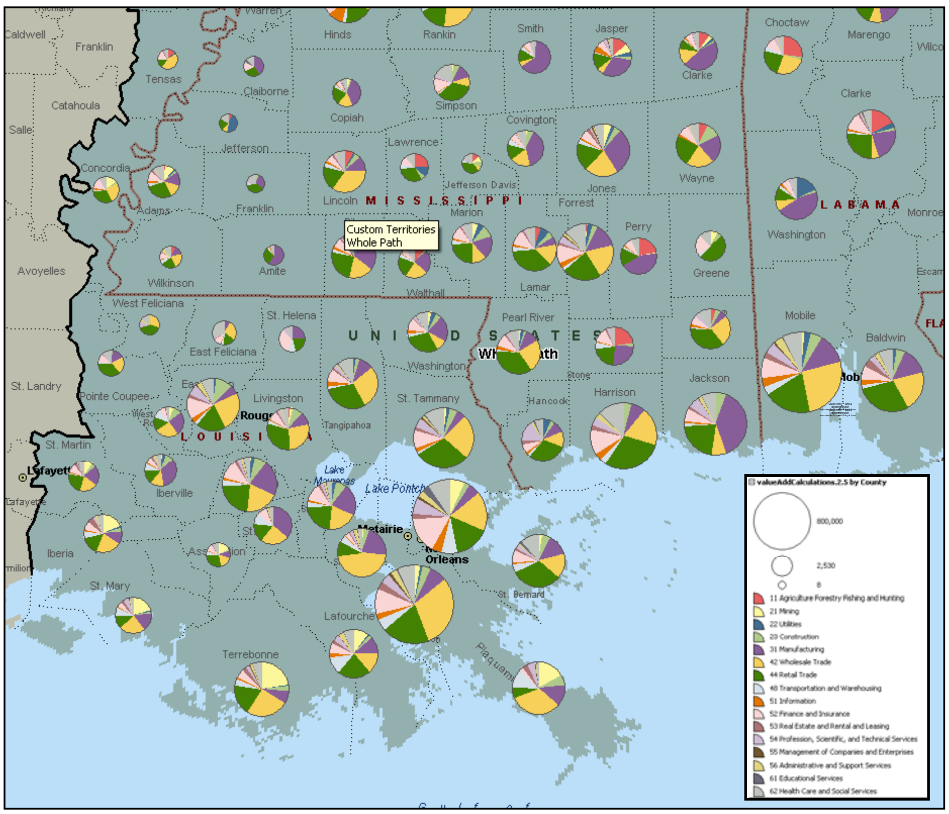

Figure 5-2: Gross domestic product (GDP) reduction, by county and 2-digit North American Industry Classification System (NAICS) industry code

5.4 Step 3: Estimating Impacts and Reporting Results

Given this regional concentration of firms and value added, NISAC then estimated the lost GDP and income that would occur due to the hurricane. Because the indirect impacts to a particular county of

[25] To create this figure, NISAC created an Excel spreadsheet of 2-digit NAICS industry code employment figures (the Excel columns) for each U.S. county (the Excel rows) and then filtered it using the territory counties described in the previous footnote. This filtered county dataset was then imported into MapPoint.

firms do not necessarily occur in the same county, it can be useful to also show the total direct and indirect losses at a higher level of aggregation, such as at the state, regional, or national level. Figure 5-3 us an example of the total impacts, shown by county.

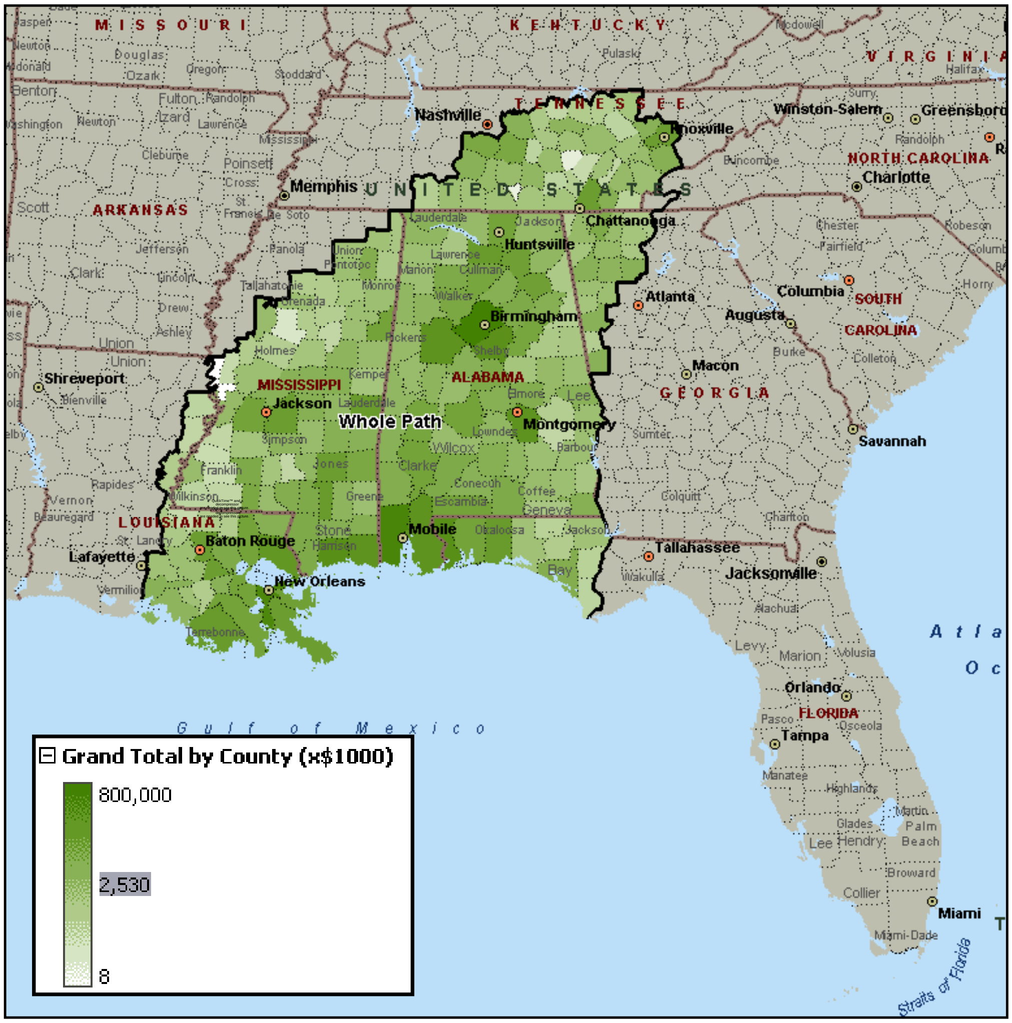

Figure 5-3: Total gross domestic product (GDP) reduction, by county

6 Verification and Validation Issues

The calculation methodology upon which REAcct is based is firmly rooted in the mathematics of I-O analysis. Input data are obtained from the publicly available sources and are verified as accurate through standard data validation techniques. The authors have verified that the equations at the core of REAcct are calculating the variable values correctly by ensuring that the variables are correctly specified and that REAcct is accessing the correct data in the database. This can be performed by using sample calculations. Due to the nature of this type of modeling, it is difficult to develop direct validations of the estimates provided by REAcct. Often the application of the methodology is for hypothetical events and incidents so there is no real-world analog to the scenario evaluated. Anecdotally, Sandia analysts have compared REAcct impact estimates with IMPLAN estimates and have found that they are within 10 percent of each other. The most current, documentable validation opportunity, to date, has been with GDP estimates for all industries published on the BEA web site.[26] Sandia analysts performed a simulation of REAcct under business-as-usual conditions, using the RIMS II final demand output multipliers. The aggregate GDP estimates for all industries for a whole year varied by only 0.16 percent.

7 Summary

A key advantage of REAcct is that it can be used in real-time to estimate the economic impact of events, contrasting with other more sophisticated, but complex models that require more time, preparation, and effort. REAcct is currently in use for rapid response studies requested by the DHS, but enhancements may be made to the tool. For example, more information about business resilience to disasters, either due to their continuity plans or the type of business operations, could be incorporated to adjust the direct impact by industry.

8 Bibliography

Chang, Shaoming, Roger R. Stough, and Adriana Kocornik-Mina (2006). "Estimating the economic consequences of terrorist disruptions in the national capital region: an application of input-output analysis," *Journal of Homeland Security and Emergency Management*, Vol 3: 3

Gordon, Peter, Soojung Kim, James E. Moore, II, Jiyoung Park, and Harry W. Richardson, (2005). "The Economic Impacts of a Terrorist Attack on the U. S. Commercial Aviation System," October, University of Southern California, available as of 3/30/06 at http://www.usc.edu/dept/create/events/2005_01_31/Gordon.pdf

Haimes, Y. Y., B.M. Horowitz, J. H. Lambert, J. Santos, K. Crowther, and C Lian (2005). "Inoperability Input-Output Model for Interdependent Infrastructure Sectors, II: Case Studies," *Journal of Infrastructure Systems*, vol. 11: pp. 80– 92

Haimes, Y.Y., and Pu Jiang (2001). "Leontief-Based Model of Risk in Complex Interconnected Infrastructures," *ASCE Journal of Infrastructure Systems*: 7(1):1 – 12

Rose, A., J. Benavides, S. Chang, P. Szczesniak, and D. Lim (1997). "The Regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions," *Journal of Regional Science*, 37:437-58

Stevens, B., G. Treyz, D. Ehrlich, and J. Bower (1983). "A New Technique for the Construction of Non-Survey Regional Input-Output Models and Comparisons with Survey-Based Models," *International Regional Science Review*, 8: 271-286

West, Guy R., "Notes on Some Common Misconceptions in Input-Output Impact Methodology," University of Queensland, Department of Economics. Available at http://eprint.uq.edu.au/view/person/West,_Guy_R.Html

[26] U.S. Bureau of Economic Analysis, "Gross-Domestic-Product-(GDP)-by-Industry Data," http://www.bea.gov/industry/gpotables/gpo_action.cfm?anon=103406&table_id=24752&format_type=0 4/26/05

Appendix A: REAcct Industry Sector Categorization and Associated NAICS Industries

Number	Industry Description	Associated NAICS Industries
3	Agriculture, forestry, fishing, and hunting	11
8	Mining (except oil and gas extraction)	21
10	Utilities	22
11	Construction	23
14	Wood Products	321
15	Nonmetallic mineral products	327
16	Primary metals	331
17	Fabricated metal products	332
18	Machinery	333
19	Computer and Electronic products	334
20	Electrical equipment, appliances, and components	335
21	Motor vehicles, bodies and trailers, and parts	3361,3362, 3363
22	Other transportation equipment	3364, 3365, 3366, 3369
23	Furniture and related products	337
24	Miscellaneous manufacturing	339
26	Food and beverage and tobacco products	311, 312
27	Textile mills and textile product mills	313, 314
28	Apparel and leather and allied products	315, 316
29	Paper products	322
30	Printing and related support activities	323
31	Petroleum and coal products	324
32	Chemical products	325
33	Plastics and rubber products	326
34	Wholesale trade	42
35	Retail trade	44, 45
36	Transportation and Warehousing	48, 49
45	Information	51
50	Finance, insurance, real estate, rental, and leasing	52
56	Real estate and rental leasing	53
58	Professional, scientific, and technical services	54
62	Management of Companies and Enterprises	55
63	Administration and waste management services	56
66	Educational services	61
67	Health care and social assistance	62
71	Arts, entertainment, recreation	71
74	Accommodation and food services	72
77	Other services, except government	81
79	Federal civilian	92
81	State and local government	92

Appendix B: Mathematical Description of REAcct

Given a particular disruption or change that affects the baseline (i.e., disruption-less) conditions of the economy, a subset of the overall economy will be directly affected. The two primary sectors are the productive sectors (e.g., firms) and consumptive sector (e.g. households), each of which is located regionally across the country.

For each day of economic disruption, affected industries lose economic output or production, resulting in lost income for their employees. The best means for estimating the direct loss in gross domestic product (GDP) is to directly sum up the reduced GDP at each firm. Due to the lack of such data, however, the authors must instead estimate the reduced output indirectly. First, the authors compute reduced GDP as the average value added per worker nationally, multiplied by the number of employees in that industry in the disrupted region, multiplied by the number of days of economic disruption; or

$$\text{Direct GDP reduction for industry } i \text{ in region } r = \frac{Y_i^{US}}{365 \times E_i^{US}} \times E_i^r \times d_i^r \quad , \qquad \text{(Eqn. 1)}$$

Where, Y_i^{US} and E_i^{US} are national annual GDP and employment for industry *i*, Y_i^r is GDP in region *r* for industry *i*, and d_i^r is the number of days of economic disruption in region *r* for industry *i*.

Given a set of industries operating in a set of regions, the total regional economic loss (to *I* industries in *R* regions) can be estimated as

$$\text{Direct GDP reduction for } I \text{ industries in } R \text{ regions} = \sum_{r=1}^{R} \sum_{i=1}^{I} \frac{Y_i^{US}}{365 \times E_i^{US}} \times E_i^r \times d_i^r \quad , \qquad \text{(Eqn. 2)}$$

A common simplifying assumption is that d_i^r is the same in all industries and regions.

To estimate these indirect impacts, the authors use the Final demand, output-driven multipliers calculated by BEA for the RIMS. Output-driven multipliers are used to estimate the indirect impacts on all industries, of an industry changing its level of production (the Y in $Y = [I - A]^{-1} D$). Analysts can use the output-driven multiplier to directly estimate the total (i.e., direct plus indirect) impact of the output change because this equation measures the total impact of a change in one industry's production on all industries (including itself). In equation form, if m_i^r is the output-driven multiplier for industry *i* in region *r*, then the total impact of a change in output can be expressed as

$$\text{Total GDP reduction for } I \text{ industries in } R \text{ regions} = \sum_{r=1}^{R} \frac{Y_i^{US}}{365 \times E_i^{US}} \times E_i^r \times d_i^r \times m_i^r \qquad \text{(Eqn. 3)}$$

While the direct economic impacts occur to known regions of the country, the indirect impacts do not. Not all of the intermediate industries that sell to the industries in the disrupted region are also in the disrupted region; likewise, not all of the workers that receive income from the disrupted industries spend their income on commodities produced in the disrupted region.

Distribution

1	MS0899	Central Technical Files	9536 (electronic copy)

Sandia National Laboratories