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AN UPDATED ECONOMIC MODEL FOR LEVEL-3 PRA CONSEQUENCE ANALYSIS USING MACCS2[1]

Vanessa N. Vargas,[2] Nathan E. Bixler,[3] Alexander V. Outkin,[4] Verne W. Loose,[5] and Prabuddha Sanyal,[6] Shirley Starks[7]

Sandia National Laboratories
PO Box 5800
Albuquerque, NM 87185-0748

ABSTRACT

This paper presents the preliminary findings for updating the estimation of economic consequences in MACCS2. The objective of this effort is to include a more representative set of costs in the MACCS2 economic model. The original model included the losses associated with evacuating and relocating the public, interdiction and decontamination, loss of use of property, loss of crops, and, potentially, permanent loss of property. The new economic model is intended to include those costs, but to extend them by capturing the effect of an accident on the GDP produced in the affected area to create a more comprehensive picture of the economic impacts. The team determined the GDP reductions by using the REAcct analysis tool developed at Sandia National Laboratories. This paper outlines the motivation for the proposed improvements; the economic methodology used, including a description of the REAcct tool; and an implementation outline.

Key Words: Level-3 PRA, Consequence Analysis, Economic Model, Input/Output modeling

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[2] vnvarga@sandia.gov

[3] nbixler@sandia.gov

[4] avoutki@sandia.gov

[5] vwloose@sandia.gov

[6] psanyal@sandia.gov

[7] sjstark@sandia.gov

1 INTRODUCTION

The original MACCS2 economic model was published in the 1990s (Jow, et al. 1990). Since that time more economic data, including Geographic Information Systems (GIS)-level data and better computational capabilities, have become available. Similar model development has been made in other tools that aim at estimating the economic impacts of nuclear accidents, such as COCO-2[8]. It is therefore desirable to update the MELCOR Accident Consequence Code System, version 2 (MACCS2), to use the currently available data as well as to use more current economic tools for estimating these consequences.

MACCS2 cost estimation methodology and the model are described in the MACCS Models Manual (Jow, et al. 1990). The costs are delineated by the emergency response and remedial actions and by the productive use for the affected area (farmland vs. non-farmland). The underlying economic methodology is described in Burke, et al. (1984). Specifically, the costs calculated in MACCS2 include:

- Evacuation costs
- Temporary relocation costs
- Food
- Lodging
- Lost income
- Cost of decontaminating land and property
- Lost return on investments from properties that are temporarily interdicted
- Depreciation of temporarily interdicted property
- The value of crops destroyed or not grown
- The value of farmland and of individual, public, and non-farm commercial property that is condemned

MACCS2 costs are calculated based on the type of protective actions and emergency response measures. The protective actions and emergency responses are defined in the user-input data and include evacuation, sheltering, and relocation. In addition, the long-term protective actions include decontamination, temporary land interdiction, crop disposal, control/prohibition of food production, and condemnation of property.

Our specific goals to update MACCS2 economic-impact estimates include the following:

- Calculate reduction of GDP/value added - both direct and indirect
- Identify and eliminate double counting in the new model
- Document specific MACCS2 modifications. Conduct case studies and compare new costs with MACCS2 costs using the original model
- Update economics data sources

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[8] COCO-2 is a model for estimation of economic impacts of accidents at nuclear reactors. See Higgins et al. (2008) for more information on a model developed using UK data.

2 APPROACH

The updated model is based on gross domestic product (GDP), or value added as the main measure of economic activity and its reduction in an affected area. The purpose of using REAcct is to provide the estimation of reductions in GDP (direct and indirect) for a specific region and specific period of time (usually one year), based on parameters being supplied by MACCS2.

The model uses national multipliers to evaluate indirect GDP losses for the rest of the country. This approach is consistent with COCO-2, where the multipliers used are independent of the affected area. COCO-2 also uses an attenuation function designed to take into account the size of the affected area (the larger the affected area, the smaller the indirect part of the losses). The use of the attenuation function may not be as relevant for the U.S., given the relative sizes of the U.S. and U.K. Additionally, if necessary, the multipliers for a specific area can be obtained from the Bureau of Economic Analysis (BEA), thus enabling a more precise calculation of indirect impacts. Aggregation over time (for more than a year) of the reduction in GDP will be done within MACCS2.

2.1 Connecting MACCS2 to REAcct ─Macroeconomic Impacts of a Nuclear Accident

The parameters necessary to define a specific scenario and to connect MACCS2 with REAcct are defined in MACCS2 and include the affected area, the duration of disruption, and the disruption severity and countermeasures. In order to connect REAcct to MACCS2, a set of scenario-related parameters must be defined in MACCS2 and passed to REAcct.

Additionally, some of the existing parameters used in MACCS2 must be reconsidered, primarily the duration for which the losses need to be calculated. If the area is decontaminated relatively quickly, then the period needed to interdict property could be used as the time period for which the economic losses are evaluated. However, if an area is interdicted over a long period the choice becomes more difficult. The team's initial point of departure is to use the parameters as they are currently specified in MACCS2. In particular, the losses for farmland are calculated for up to 8 years (and condemned if not restored by that time) and for non-farmland up to 30 years. However, another way to look at this issue is to consider the duration of time in which the overall economy would recover if an affected area were condemned. In this case the recovery to a "normal" condition would require that the population and business from the affected area move to other parts of the country.

Therefore, the question becomes how long would it take for the overall economy to absorb the resulting migration and for the affected people to find new jobs, restart businesses, etc.[9] Additional data that can be used to evaluate time for the economy to recover includes: 1) the length of recessions and 2) past disruption events, like Hurricane Katrina. Other historical precedents include the Fernald uranium production plant (cleanup completed in 2006), Chernobyl, and the Three Mile Island accidents.

[9] For example, COCO-2 uses the maximum of scenario specific duration of countermeasures or a maximum of 2 years to calculate the lost value added.

3 AN OVERVEW OF REAcct

The regional economic accounting (REAcct) analysis tool has been in use for the last 6 years to rapidly estimate the approximate economic impacts for disruptions due to natural and manmade events. It is based on and derived from the well known and extensively documented input-output modeling technique initially presented by Leontief (1936) 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 U.S. The REAcct process incorporates geospatial computational tools, and site-specific economic data, that allow differential magnitude of disruption and duration estimates to be specified for regions affected by a simulated or actual event. Using these data as inputs to REAcct, the number of employees for the affected economic sectors is calculated and lost GDP for those sectors is aggregated to provide direct impact estimates[10]. 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.

The economic method is based on a framework of inter-industry commodity flows, often termed input-output (IO) analysis and uses a set of multipliers derived from IO analysis, and dynamic econometric models to estimate the total direct and indirect economic impacts of business disruptions[11]. The total economic impact of a disruption is typically grouped into (1) direct impacts, which occur to those firms directly affected by the disrupting event and (2) indirect impacts, which occur to firms not directly affected by a disruption but that are indirectly affected (e.g., by the loss of sales to firms directly affected).[12] See Ehlen et al. (2009) for additional information.

3.1 Input-Output Multipliers

Consider a case where a disruption halts the production of Commodity D, corresponding to column D in Table I below. The values in each column show the amount of each input commodity needed to generate one unit of the output commodity. A disruption to D's production reduces D's need for every commodity in its production recipe, specifically commodities B and C. If B and C are disrupted, then so are their inputs: looking at the B and C columns, one can see that A and B are used as inputs. Since B uses A as an input and vice versa, the production of B is indirectly impacted by its own disruption; that is, a disruption can ripple in a circular fashion

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[10] The entire economy is represented in REAcct by 39 economic sectors (including 37 production sectors and 2 government sectors).

[11] While IO multipliers require that the analyst make many strong assumptions about how disaster impacts propagate through the economy, the IO framework does not; what the framework provides is a useful, structured approach for understanding and modeling highly detailed economic processes.

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

through the economy. The input-output impact modeling approach uses this circularity to derive mathematical multipliers that estimate these system-wide circular effects.

Calculating the indirect impacts of a sector specific disruption are difficult given the circular nature of commodity flows. One can make a reasonable assumption that the linkages between sectors are tight, that is, any change in the production of a particular industry changes production in intermediate, "feeder" industries in the proportions listed in the U.S. BEA government input-output tables, and one can use an input-output multiplier technique to estimate the impacts.

Table I. Example of technology or use matrix

Input Commodity	Amount of Input Commodity Used to Generate One Unit of Output Commodity			
	A	**B**	**C**	**D**
A	0	x_{ab}	x_{ac}	0
B	x_{ab}	0	x_{bc}	x_{bd}
C	0	0	0	x_{cd}
D	0	0	0	0

One can formulate the above flows in Table I mathematically as $AY + D = Y$. This equation states that total demand for output Y is composed of the intermediate demand AY for the commodity by all industries and the final demand D from end users. Solving for Y, one can express total output in each industry as a function of both final demand and the industry technology matrix:

$$Y = [I - A]^{-1} D \tag{1}$$

Here, I is the identity matrix. The numerical terms in the $[I - A]^{-1}$ matrix estimate the effect of a change in end-user demand can have on the output in all industries. It can also be used to estimate the effect that a disruption in output in one or more industries has on the output in all industries, using what are called output-driven multipliers. As described in the following section, the estimates of direct economic impacts to one or more industries are used with the output-driven multipliers to estimate the indirect impacts that occur via this commodity flow-based formulation.

3.2 Estimating Direct Economic Impacts

Given a particular disruption or change that affects the baseline conditions of the economy, a subset of the overall economy is directly affected. The two primary subsets are the productive sectors (e.g. firms) and consumption sector (e.g. households), each of which is located regionally. For each day of business interruption, impacted sectors lose output or production,

resulting in lost income for their employees. The best means for estimating the direct loss in regional GDP is to directly sum up the lost GDP at each firm. Because of the lack of data at the firm level, one must instead estimate the reduction in output and income directly at the industry level as categorized by the North American Industry Classification System (NAICS)[13]. First, compute reduction in GDP as the average value added per worker nationally (or regionally[14]) times the number of employees in that industry in the disrupted region times the number of days of the business interruption.

$$GDP_{direct} = \frac{Y^{US}{}_i}{365 \times E^{US}{}_i} E^r{}_i \times d^r{}_i \tag{2}$$

Here, GDP_{direct} is the direct GDP reduction in the region, $Y^{US}{}_i$ and $E^{US}{}_i$ are the national annual output and employment for industry *i*, and $E^r{}_i$ is employment in region *r* for industry *i*. Given a set of industry sectors operating in a set of regions, the total regional economic loss (to *I* industries in *R* regions) can be estimated by summing over all industries and over all regions. It is common to assume that the number of days of disruption is the same for all industries.

3.3 Estimating Indirect Economic Impacts

Given the impacts to industries that are directly affected by the disruption, other parts of the economy are affected. Consider a regional industry that has no output for an extended period of time. The effects include the possible loss of sales to industries that provide input materials to this industry as well as the possible loss of income to the households that work in the disrupted industry. The critical assumption for estimating indirect impacts is that there are few if any production, employment, or income "leaks", or substitutions, in this flow structure. If, for example, the sales lost by this particular regional industry are offset by increased sales to the same industry in another region, and the employees in the disrupted region migrate to the offsetting region, then there are few indirect impacts. However, this type of offsetting behavior is impossible to capture in the static method being discussed.

Indirect economic impacts are estimated in the following way: given a loss of output in a specific industry sector, as calculated in previous sections, the indirect impacts are calculated using the RIMS II final-demand output multipliers. The output-driven multiplier is used to estimate the indirect impact on all industries of an industry changing its level of production. One can also use a demand-driven multiplier to estimate the indirect impact on all industries of changes in the demand for an industry's production. Since the goal is to estimate the total impact of one industry's change in production on all industries, the output-driven multiplier is used to estimate the total (i.e., direct plus indirect) impact of the output change. In equation form, if $m^r{}_i$

[13] This can be at the 2, 3, or 4 digit NAICS level, depending on the availability of data. Typically the most comprehensive data is available at the 2 or 3 digit NAICS level.

[14] This is dependent on availability of data. Some states calculate this information and it can be obtained from public sources. Some states do not calculate this and it must be estimated at the national level. In unique cases, this data may also be available at the county level.

is the output-driven multiplier (RIMSII) for industry *i* in region *r*, then the total impact of a change in output can be expressed as,

$$GDP_{total} = \frac{Y^{US}{}_i}{365 \times E^{US}{}_i} E^r{}_i \times d^r{}_i \times m^r{}_i \quad (3)$$

While the direct economic impacts occur to known regions of the country, the indirect impacts do not, because 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. Regional level multipliers can be estimated; however that is beyond the scope of this model development.

3.4 Data

The Bureau of Economic Analysis (BEA) maintains publicly available national input-output data and input-output multipliers down to the county level for purchase. The national data is 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. The U.S. Census Bureau provides the number of business establishments and employment by industry and county annually as part of its County Business Patterns Data program. Industry employment data are also available quarterly from the U.S. Bureau of Labor Statistics. The final demand output-driven multipliers, RIMS II, are available for varying fees from the BEA. Finally, private data sources such as the Dunn & Bradstreet database maintains establishment and employment data for purchase, although this dataset is known to have methodological drawbacks and other anomalies.

3.5 Advantages and Limitations of Approach

While this approach is simple to understand and implement, it is based on a number of strong assumptions and related limitations.

3.5.1 Advantages

Disruptions in an affected region affect industry sectors in different ways. The REAcct method allows the user to apply business disruptions to specific industries and for varying disruption lengths. In the case of a nuclear reactor accident, disruptions are likely to affect all industries equally, which simplifies implementation of the model.

The REAcct method is based on well established, theoretically sound, and empirically tested IO methodology. Because of REAcct's simplicity, the CPU time required to generate estimates of economic impacts is small. REAcct can also be linked to Geographic Information Systems (GIS) to incorporate impact zone information in the impact estimate.

3.5.2 Limitations

The REAcct method cannot capture the highly complex interactions between firms and industries. Depending on the type of business disruption, the actual economic disruption and related restoration can be highly dynamic processes. Individual firms within the affected industries have different levels of on-site and in-transit inventories as well as varying production

processes. There is also the general assumption that business returns to normal levels once the disruption is over, however this is likely not the case. Some firms may return to pre-event levels gradually over months or years and some smaller firms may actually disappear due to their inability to adapt to difficult economic conditions.

There is extensive literature examining the use of input-output consequence analysis. However, traditional input-output consequence analysis calculates only direct economic impacts (the change in production or GDP at a particular level of the supply chain) and upstream economic impacts (the change in production or GDP at preceding supply chain levels that produce commodities which are eventually used at another level of the supply chain).

Downstream impacts are dependent upon firm and consumer decisions and have proven very difficult to predict due to substitution of firms and consumers. Interactions influenced by market processes (prices) determine how a disruption propagates downstream. Traditional input-output analysis does not account for these market interactions.

A critical assumption is that there are few, if any, production, employment, or income leaks or substitutions in this structure given the static nature of the model and its application to short-term impacts. If, for example, the sales lost by a particular regional industry are offset by increased sales to the same industry in another region, and the employees in the disrupted region migrate to the offsetting region, these impacts are not captured in the REAcct method.

3.6 An example of using REACCT Step-by-Step

The first step in application of REAcct to a hypothetical event in a specific area requires the specification and identification of the area within which the event occurs. The specific areas affected in this application would be determined by the MACCS2 code; they would be those areas considered too heavily contaminated to be used immediately, i.e., the areas that would be interdicted for some period of time. The duration of the economic disruption is then determined by the length of time it would take to restore habitability and farming. This allows calculation of the impact of the event on economic activity using key impact measures, such as employment and output.

3.6.1 Step 1

Scenario or event definition is established. Conditions may require that businesses and residences close, evacuate, or stop production in general as a result of accident conditions. Duration of the event is established and the affected region is determined, as illustrated for a hurricane scenario in Fig. 1.

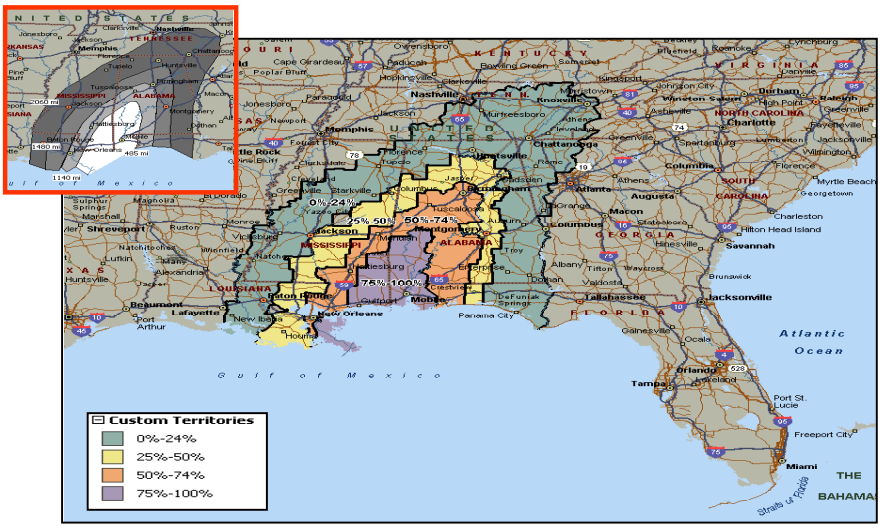

Figure 1. Example of GIS overlay

3.6.2 Step 2

Economic data are compiled within the REAcct tool. Data are government-collected, and therefore consistent and verifiable. This step is illustrated in Fig. 2. Counties are evaluated regarding industry sector makeup or regional uniqueness.

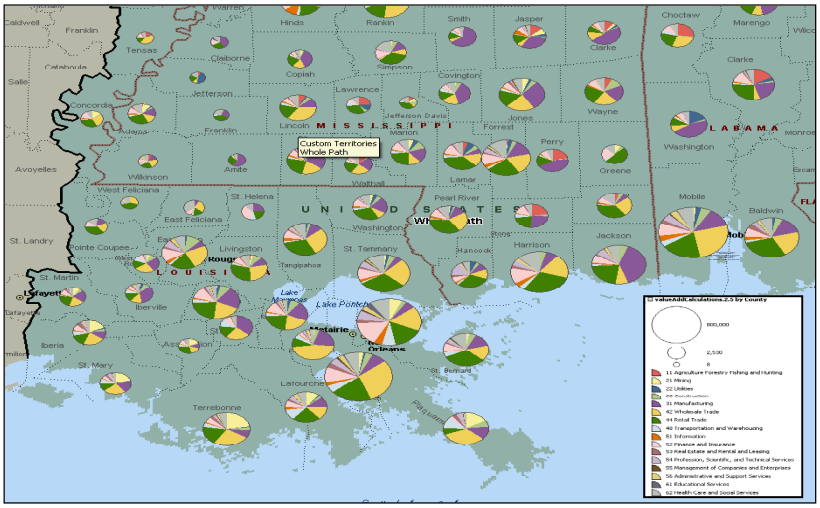

Figure 2. Example of industry distribution at the county level

3.6.3 Step 3

Economic impacts for the affected region, whether for one county or a group of counties, are calculated and reported. The metric of concern is reduction in GDP, which can be reported at the industry, county, and region level, as illustrated in Fig. 3.

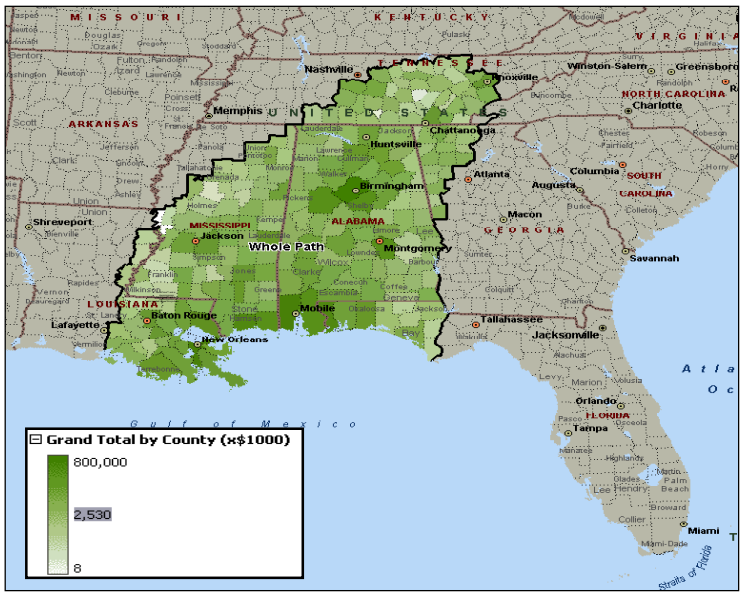

Figure 3. Total GDP loss

4 CONCLUSIONS

This paper presents an updated approach to estimating economic impacts in MACCS2 by using reduction in GDP as the main measure of the economic impact. This approach is implemented through a Sandia-developed tool called REAcct. The authors present the motivation for the proposed improvements, the economic methodology used, including a description of the REAcct tool, and an implementation outline. Differences between this and traditional models must still be evaluated to see what impacts the updated model would have on estimated economic consequences.

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