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# Dynamic Modeling of the Economic Impacts of a Terrorist Attack Using a Radiological Dispersion Device

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THESIS

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AFIT/GEM/ENV/09-M07

**DEPARTMENT OF THE AIR FORCE**
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## Abstract

The purpose of this research is to model the dynamic economic influences associated with an attack using a radiological dispersion device (RDD). Specifically, this thesis seeks to identify the variables associated with the total economic impact to the local community where the attack occurs and gain better insights into how local, state and federal entities can employ various policy decisions to bring the system under control within the first year of recovery. Of primary interest to the research is the problematic behavior of exponential economic impact and how the final accumulation of fiscal cost can be reduced. Using a system dynamics research method and the dynamic modeling software STELLA©, considerations such as controlling the media's influence on public fear, consumer confidence, community resilience, and community recovery are incorporated with fiscal impact stocks such as business losses, tax revenue losses, and response costs. Once combined, the model uses historical examples of responses from the September 11 attacks, the Three Mile Island and Goiania, Brazil incidents, natural disasters, and recommendations from the latest Environmental Protection Agency Protective Action Guidance for response to radiological incidents to examine the effect on the impacted community's recovery and total fiscal impact.

*To my beloved wife and sons for their patience and understanding of my need to serve our nation*

## Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Lt. Col. David Smith, for his guidance and support throughout the course of this thesis effort. The insight and experience was certainly appreciated. I would also like to thank Dr. Michael Shelly for introducing me to systems thinking and system dynamics. The result of your teachings will serve me and the Air Force well. Finally, I would like to thank Lt. Col. Dean Vitale for teaching me that "because I said so" is not an effective tool for winning an academic argument.

Christopher B. Ledford, Capt., USAF

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# I. Introduction

## Background

Since September 11, 2001, the United States has diligently prepared for all likely scenarios of terrorist attack. The common modus operandi of notorious Islamic terrorist organizations is the use of conventional weapons and explosives. However, the desire for weapons of mass destruction (WMDs) is well documented. Al Qaeda specifically has searched for nuclear weapons, nuclear material, and the technical personnel required to create an improvised nuclear device (IND) or radiological dispersion device (RDD) since the early 1990s. (Boureston, 2002) Osama bin Laden and Muslim clerics have declared that the acquisition of WMDs is a religious duty for jihadist around the world in hopes that the ability to strike the United States with such a weapon becomes a reality. The availability of weapons grade fissile material is limited for a non-state entity, but radioactive material such as Cesium 137 is commonly found in less secure industrial or medical facilities. Consequently, it is more likely that terrorists will create an RDD or "dirty bomb" From these less secure sources. This concern has become the premiere fear of Homeland Security personnel. This fear was publically highlighted in a press conference hosted by Homeland Security Secretary Michael Chertoff, in which he stated, "As I think I have said previously, the single biggest threat we worry about, in terms of protecting this country and securing the homeland, is the threat of a weapon of mass destruction. And at the very top of the scale is a nuclear device or a radiological device." (Department of Homeland Security, 2006)

**Problem Statement**

It is generally accepted that the psychological effects from an RDD on the populace located near the attack are likely to impact the economy through fear. Economists, government personnel, and scholars have attempted to quantify the economic impacts of such an attack. Unfortunately, there is no definitive methodology for how to quantify the economic impact of such an event due to the inclusion of important, yet immeasurable considerations that are generated by an attack. Such complications of estimation efforts are due to several characteristics of a radiological event. Most notably is the public perception of radiation and the personal decisions civilians will make based on their fears. In addition, the variability in location, amount of explosive and radiological material, dispersion method, weather patterns, and response capabilities creates a multitude of possibilities. Furthermore, modeling economic influences between industry sectors has historically been difficult due to a lack of timely data from economic indicators and vague relationships between sectors. Consequently, the actual economic impact from an RDD event is commonly presented as a range of values based on educated guesses with bounded rationality.

**Research Questions**

The goal of this research is to create a simulation tool that allows researchers or responders the ability to see the impact of various policy tools on the local economy. To that end, the following research questions must be answered.

1. What variables influence an economic system that has been attacked with a radiological dispersion device?

2. How can federal government policy influence the overall cost of an RDD attack to the local community?
3. How can response agencies influence the overall cost of an RDD attack to the local community?
4. What effects do governmental agencies and regulatory bodies have upon a community's recovery?

**Research Method**

This thesis proposes the use of a systems perspective to model aggregated influences of the targeted system in an effort to gain insight to the more valuable information of how the economic impact can be limited rather than presenting a final range of financial figures. There is significant benefit in creating a dynamic model instead of generating a list of estimated expenditures. The most recent studies concerning fiscal impact of a terrorist attack are limited to estimates of losses per economic sector. Even if those analysis methods can one day determine the actual cost of a terrorist attack, what would be the effect? A ten million dollar price tag that is developed years after the event will not generate a different response from the government or populace than an attack with a ten billion dollar price tag. The development of a dynamic model that explains the influences of entities within the economic system will better serve decision makers by providing insights that can mitigate the effects of a radiological terrorist attack.

**Assumptions and Limitations**

The dynamic model presented is a simplified, macro level view of the influences related to the economic system. It will not include actual economic input data on the impacted community from sources such as the Department of Revenue. This limitation is placed on the model due to the desire for generalization across all communities instead of a specific case study. It is the argument of the researcher that economic input-output analysis of such data is irrelevant, and by no means timely, to the recovery of the community.

**Implications**

The ability for decision makers associated with the recovery efforts to understand the dynamic influences within the economic system is vital if the local area is to rebound from a radiological terrorist attack. For example, once the initial response phase ceases and decontamination operations are relinquished to the Environmental Protection Agency (EPA), the expected timetable to begin clean up is measured in months to years. By giving decision makers insight into the influences the speed of their recovery efforts have upon the public's resilience, policy changes can be made to ensure that the speed of recovery meets public demand. Having such insight might have made the results of the post Hurricane Katrina environment in New Orleans much different. The Federal Emergency Management Agency (FEMA) responded in accordance with the prepared plans for hurricane response. However, like the EPA, the timetables were measured in weeks to months and did not meet the needs of the population. Consequently, FEMA efforts were unable to restore public resilience in New Orleans and the result was approximately 50 percent of the population not returning to the city (Campanella, Spring 2006).

# II. Literature Review

## Historical Examples

### *Radiological Incidents*

The topic of radiological terrorism has received much attention since 2001 when the American public realized that terrorists really do want to kill our citizens and can reach our homeland.  However, much of the talk is speculative at best.  This is primarily due to the lack of data on such an event.  While Chechen rebels have attempted to implement an RDD and detailed plans for an RDD were found in al Qaeda training camps, no organization has accomplished an actual detonation that has been publicized by any government (Steinhausler, 2005).  Due to this lack of data on RDD affects, most data specific to radiological incidents is gathered from the Goiania, Brazil, Chernobyl, and Three Mile Island incidents.

"The tragic radiological accident that occurred in Brazil between 13 September 1987 and March 1988 is the closest event to a true RDD attack. While the parallels are not exact, study of the incident provides some insight into the possible progress of a case of radiological terrorism." (Zimmerman, 2004)  In September, 1987 two thieves stole a radioactive source from an abandoned medical facility.  After breaking it open, they exposed the radiation to themselves, their families, and friends for several days as the thieves played with the glowing blue material.  Thinking it was valuable, the thieves sold the material to a junkyard owner who subsequently spread the contamination further. After the incident area was finally locked down and treated, 5 people had died, 28 more were treated for radiation burns, and 249 others were exposed to the cesium 137 radiation.  Mass panic ensued across Goiania as the result of the incident.  Family members refused to board their evacuated relatives and Goiania residents were assaulted trying to enter other cities (Steinhausler, 2005). These effects are at the center of this research. The mass panic that ensued due to the incident is an indication of what American citizens may do once they find out that a RDD has been detonated in the local area. While only 28 people suffered from acute radiation sickness and only 5 people died, approximately 125,000 people were surveyed for possible exposure and monitored for several years after the incident (Steinhausler, 2005).

The second example, but largest radiological material release, was at the Chernobyl nuclear power plant incident. This disaster released roughly 100 times the combined radioactive material of the bombs dropped on Hiroshima and Nagasaki, Japan. As in Goiania, the perceived radioactive effects were reported by over two million people with another two million continuing to be monitored for atypical cancer rates, pulmonary complications, and other radiation symptoms. However, unlike Goiania, the Chernobyl incident complete wiped out the local economies causing nearby towns to be vacated and permanently quarantined (Steinhausler, 2005).

The most valid example of how the American media and public will react to radiological terrorism is the incident at the Three Mile Island nuclear power plant. Although no radiation exited the facility, the sensationalized media coverage and widespread public fear arguably threatened the future of the nuclear power industry. Public relations personnel from the plant and the Nuclear Regulatory Commission did not have a public information plan in place to deal with the incident (Congressional Research Service, 1999). Consequently, the quality of media coverage was less than adequate to deal with the public's lack of understanding with respect to radiation hazards. This lack of reporting quality was compounded by the sensationalized coverage by news anchors, such as Walter Cronkite, who used terms such as, “the worst nuclear power plant accident of the atomic age,” “horror” and “catastrophe” (Congressional Research Service, 1999). A positive influence cited as a counteracting the public fear created by the media was the intervention of Governor and Lt. Governor through news conferences designed to instill calm.

With the combination of these events several generalization s can be made concerning a radiological attack. First, we can expect to see mass public panic in the absence of formal information. Second, the effects of the radiation may be widely dispersed and is mitigated by the rapid diagnosis of the symptoms as being radiological or emergency responders quickly identifying that the scene is contaminated. Finally, we can generalize that the negative impacts to the local economy will be long lasting and possibly permanent if external, positive influences are not initiated by the Federal Government.

*The Attacks of September 11, 2001*

Much has been written concerning the impacts of the September 11, 2001 attack on the World Trade Center and the Pentagon. The General Accountability Office has published several studies in an attempt to quantify the attacks, yet due to the vagueness of the data and the influences on the economy, their estimates are vague. “As GAO reported previously, precisely measuring the attack’s effect on economic activity and tax revenues is inherently difficult, because it must be disentangled from other factors that also reduce tax revenues.” (General Accountability Office, 2005). A constant trend in the GAO reports is the measurement of tax revenues losses and employment numbers as a means to determine the economic impact. However, the GAO misses other considerations necessary to achieve a more true cost. For example, each of the publications found to date do not include the governmental and private investments that would decrease the bottom line cost for the local community, nor does the GAO appear to include insurance claims or the cost of displaced businesses or persons. The list of associated costs may possibly be endless once individuals or businesses in the economic chain, above or below those impacted by the attack, are included into the final cost. For example, the financial securities companies located in the World Trade Center were wiped out on September 11, 2001. Their absence in the marketplace drove cost increases to their clients who may have lost records of their investments, their time to find new brokers, and years of experience that was critical to the success of clients (Government Accountability Office, 2005). Another way of thinking about the effect on the economic chain can be found in the economic ripple effect seen in communities that have large companies go bankrupt. Not only are the jobs lost, but the jobs that supported those people are lost, suppliers no longer have a client to sell their wares to, and buyers have to go elsewhere to find the products they need for their business. In each case, such effects of a terrorist attack can be expected to impact the economies of the attack location and spread across the state, region, nation, and possibly globally.

In response to the September 11 attacks, Congress passed several appropriations acts in an attempt to control the perceived macro-economic impact. For New York specifically, financial assistance was provided to reimburse the city for emergency expenditures and debris removal, as well as direct aid to individuals and businesses, and stimulus packages designed to reinvigorate the local economy through development incentives (Congressional Research Service, 2002). In all, Congress provided $21.6 billion specifically to aid in New York's recovery.

*Natural Disasters*

The macro level economic effects of major natural disasters have been widely published since the impact of Hurricane Katrina on the Louisiana and Mississippi coast. In many ways the damage caused by the flooding generated by a hurricane is similar to the damage caused by a RDD. The flood waters invade all structures, surfaces, infrastructure and goods in its path. After the waters recede, the infected materials are generally intact and possibly reusable; however, the flood waters leave behind dangerous bacteria and pathogens that can be harmful or even fatal. Consequently, the structures or materials must be decontaminated or destroyed before the populace is allowed to use the item or structure again. For radiological contamination, the structures or goods will appear to be free from harm, but should actually be destroyed or decontaminated before use. Due to the similarities between the effects of hurricanes and radiation, estimates of post storm population growth, economic resilience, tax revenue losses and the attractiveness of the impacted cities to future business growth should be considered.

Three years after the hurricane impacted the city, roughly 46% of the New Orleans residents had not returned primarily due to lack of housing, jobs, and services (McCarthy, Peterson, & Sastry, 2006). It has also been noted that plans to restore infrastructure and housing are not likely to address the full system surrounding community recovery or the community's resilience (Campanella, Spring 2006). Consequently, in the context of community recovery following a radiological attack, the model must address not only the needs for infrastructure rebuilding, but the physical and psychological needs of the citizens if a resilient community is to be created.

**Federal Response Capabilities**

The Federal Emergency Management Agency (FEMA) is charged with response to natural and man-made disasters within the United States. If the President declares an area a major disaster, FEMA is authorized to respond with assistance in several ways. First, FEMA offers seventeen different grant programs to provide individuals and businesses with immediate assistance. Secondly, it provides disaster relief through immediate needs such as direct food, water, and shelter support and the coordination of charity organizations, such as the Red Cross, to do the same. Lastly, it provides psychological assistance for survivors needing to cope with stress and creating a personal plan to move forward (Federal Emergency Management Agency, 2009). This is positive influence on the physical and psychological needs of the community is vital for creating resilience to the attack as well as economic recovery.

Similarly, the Small Business Administration (SBA) is, “a signatory to the National Response Plan (NRP), SBA is a part of the federal government’s single comprehensive approach to domestic incident management to prevent, prepare for, respond to, and recover from major disasters, terrorist attacks and other emergencies” (United States Small Business Administration, 2008). The effect of SBA disaster assistance provides individuals and businesses that were not prepared for the fiscal impact of a terrorist attack the financial means, through low or no interest loans, to recover. Following the September 11 attacks, the SBA expanded disaster assistance lending to businesses that were not physically in lower Manhattan, but could prove financial impact from the attacks (Congressional Research Service, 2002). The expansion of assistance coverage directly addresses the ripple effect of economics by adsorbing the system shock felt across the impacted industries. One potential benefit to the local economy of this expansion of coverage is the lack of need for entities serving or being served by impacted businesses to look elsewhere for products, support, or service. Consequently, the SBA disaster assistance is also vital to the immediate and long term recovery of the local economy by addressing the needs of unprepared individuals or businesses.

**Response Considerations**

RDD response is broken into three phases, early, intermediate, and late (Conklin, Proposed Framework for Cleanup and Site Restoration Following a Terrorist Incident Involving Radioactive Material, 2005). The early stage of response will be focused on life saving and containment of the radioactive material. This phase may last from a few days to several weeks depending on the complexities surrounding the detonation and deposition. It is not until the intermediate phase, measured in weeks to months, that involved stakeholders will begin charting a path to recovery. During the late phase of response, measured in months to years, considerations such as acceptable radiation levels for cleanup efforts, economic recovery plans, and public acceptability of the results should be the focus of responding agencies and stakeholders (Conklin, Proposed Framework for Cleanup and Site Restoration Following a Terrorist Incident Involving Radioactive Material, 2005). It is recommended that stakeholders should be involved in the decision making process to ensure transparency, inclusiveness, effectiveness, and shared accountability. In the context of economic impact, the inclusion of stakeholders can have a positive influence on the speed of recovery assuming that the included stakeholders agree with the recommendations of technical experts. Speeding the recovery of the community accelerates the economic forces involved would have a positive influence on the resilience of the economic system.

**Economic Resilience**

Economic resilience is defined as, "the inherent and adaptive responses to disasters that enable individuals and communities to avoid some potential losses" (Rose, Defining and Measuring Economic Resilience to Disasters, 2004). Due to the expectedly small size of and RDD, the economic resilience of a community following an RDD attack concerns microeconomic and mesoeconomic influences such as individual behavior of businesses and households, specific economic sectors, and individual markets. By employing mitigation and recovery management techniques, economic resilience can be enhanced. While mitigation management of the RDD effects would commonly take place prior to an attack, recovery management is a function of local, state, and federal responding agencies. Therefore, the disaster assistance from responding agencies creates a positive influence on the resilience of the community and ultimately the community's recovery.

**Consumer Confidence**

Immediately following the September 11 attacks, it was believed by many that the economy would stumble into a recession. However, it was later determined that the economy as a whole was already headed into a recession prior to the attacks and subsequently returned to positive growth several quarters after the attack. A noted problem with the fiscal impact estimates from terrorist attacks is the establishment of an economic baseline just prior to the attack (Government Accountability Office, 2005). Consequently, in order for this research to adjust for changes in economic baselines, the model will need to include an adjustment tool that mimics the economic trend just prior to the attack. The timeliest indicator of where the economy is headed is the Consumer Confidence Index or the Michigan Index of Consumer Sentiment and GDP growth. (Ludvigson, 2004).

Both measures are calculated from monthly surveys that ask consumers from across the country five questions concerning their outlook on the economy. Consumer confidence in the future of the local economy following a terrorist attack should be a vital concern of decision makers in the intermediate and late stages of RDD incident response.

# III. Research Method

Studies of the economic impact of RDD attacks are generally focused on specific, bounded case studies such as maritime ports or water supplies. Such boundaries must be drawn to simplify the multitude of possible attack scenarios. Unfortunately, due to the vague, yet strong influences and feedback systems between economic sectors, community resilience, and government responses, each of these studies are likely to omit significant economic impacts. Furthermore, unless governmental entities can identify and track the necessary data to encompass all fiscal losses due to a terrorist attack, all models will continue to miss the true mark. In an effort to overcome this boundary in the current literature, this research aggregates costs into more broad categories and uses a system dynamics approach to modeling the influences upon the total economic impact in an effort to gain insight into the dynamic system surrounding the attack.

## General View of the Modeling Process

System dynamics is a methodology for studying and managing complex feedback systems (Daum, 2001). Through imitation of real world processes or systems, system dynamics can explore system behavior to gain insight into the dynamic influences involved (Shelley, 2008). The modeling process includes five primary steps: problem articulation (boundary selection), formulation of a dynamic hypothesis, formulation of a simulation model, testing, and policy design and evaluation. Table 1 provides further details of the steps involved.

Although the process is presented in a step by step format, the final product is the result of an iterative effort. As demonstrated in Figure 1, the results of any one of the steps can result in insight that will yield changes to the model.

**Table 1: Steps of the Modeling Process ( after Sterman, 2000)**

| Modeling Step | Elements of the Step |
| --- | --- |
| **Step 1: Problem Articulation (Boundary Selection)** | **Theme selection**: What is the problem? Why is it a problem? |
| | **Key variables**: What are the key variables and concepts we must consider? |
| | **Time horizon**: How far into the future should we consider? How far back in the past lie the roots of the problem? |
| | **Dynamic problem definition (reference modes)**: What is the historical behavior of the key concepts and variables? What might their behavior be in the future? |
| | |
| **Step 2: Formulation of Dynamic Hypothesis** | **Initial hypothesis generation**: What are the current theories of the problematic behavior? |
| | **Endogenous focus**: Formulate a dynamic hypothesis that explains the dynamics as endogenous consequences of the feedback structure |
| | **Mapping**: Develop maps of causal structure based on initial hypothesis, key variables, reference modes, and other available data, using tools such as; model boundary diagrams causal loop diagrams, stock and flow maps, and policy structure diagrams. |
| | |
| **Step 3: Formulation of a Simulation Model** | **Specification** of structure, decision rules. |
| | **Estimation** of parameters, behavioral relationships, and initial conditions. |
| | **Tests** for consistency with the purpose and boundary |
| | |
| **Step 4: Testing** | **Comparison to reference modes**: Does the model reproduce the problem behavior adequately for your purpose? |
| | **Robustness under extreme conditions**: Does the model behave realistically when stressed by extreme conditions? |
| | **Sensitivity**: How does the model behave given uncertainty in parameters, initial conditions, model boundary, and aggregation? |
| | |
| **Step 5: Policy Design and Evaluation** | **Scenario specification**: What environmental conditions might arise? |
| | **Policy design**: What new decision rules, strategies, and structures might be tried in the real world? How can they be represented in the model? |
| | **"What if…" analysis**: What are the effects of policies? |
| | **Sensitivity analysis**: How robust are the policy recommendations under different scenarios and given uncertainties? |
| | **Interactions of policies**: Do the policies interact? Are there synergies or compensatory responses? |

**Figure 1: The Iterative Nature of the Modeling Process (after Sterman, 2000)**

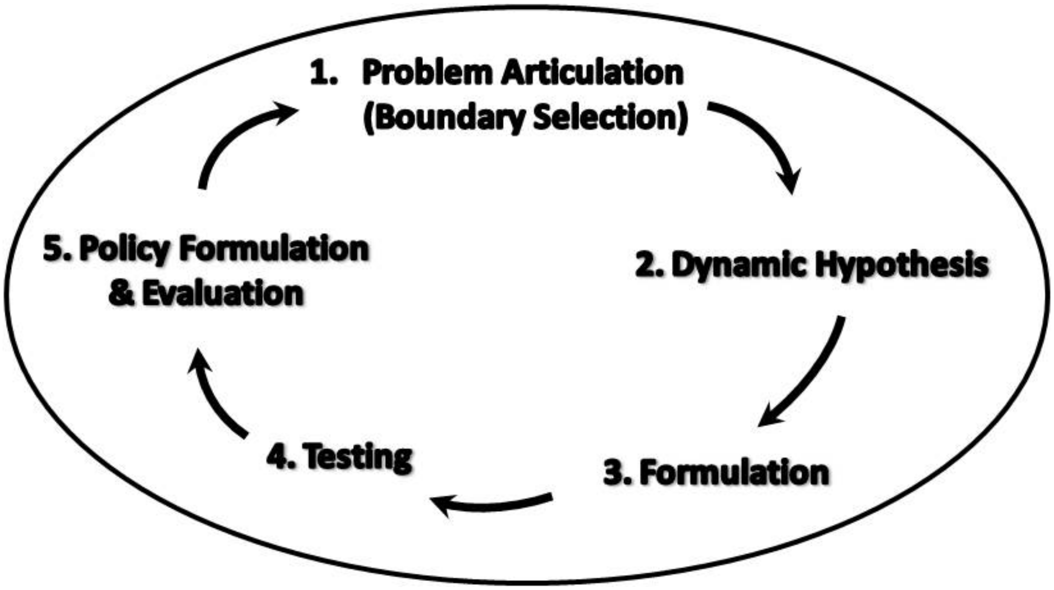
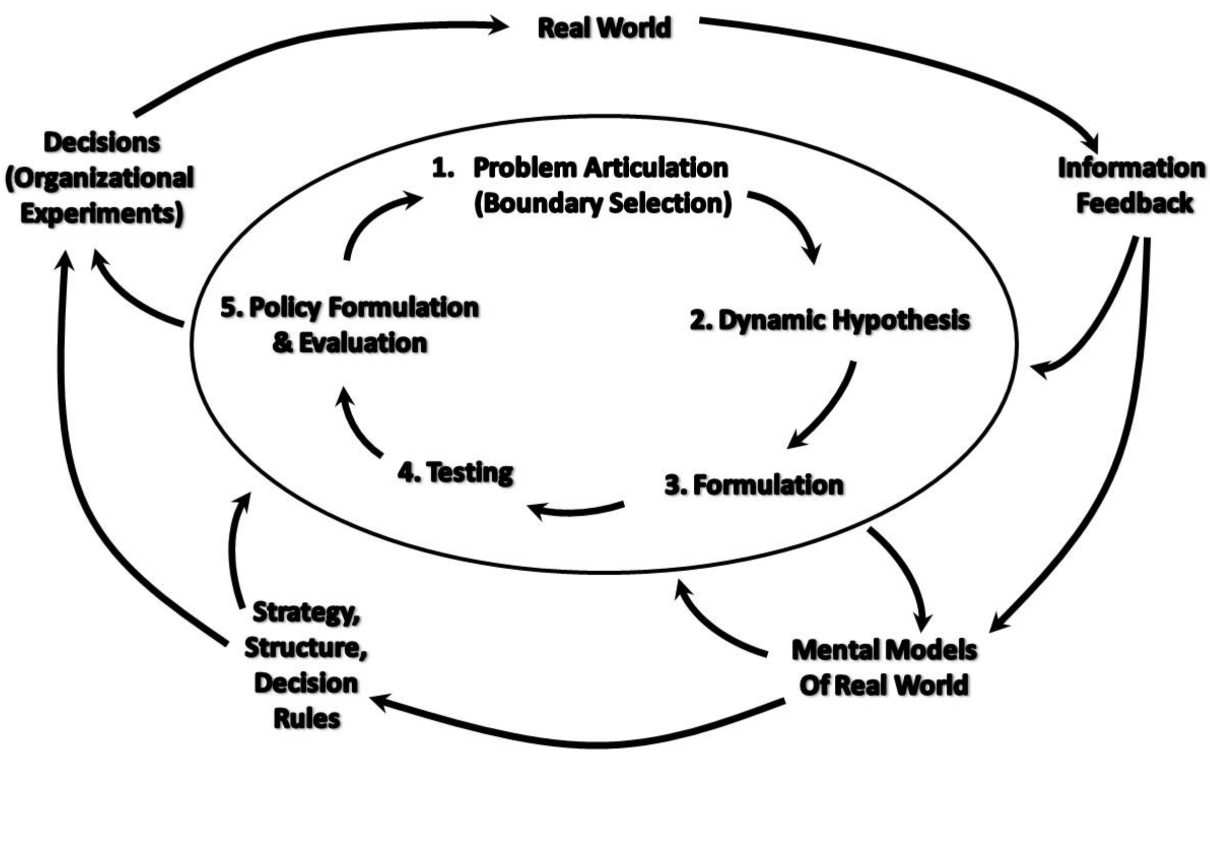



**Figure 2: Modeling is Embedded in the Dynamics of the System (after Sterman, 2000)**



**Step 1: Problem Articulation (Boundary Selection)**

*Theme Selection*

The single most important step in the modeling process is clearly defining the problem being studied. Once a clear purpose for the model has been identified, it is critical to then set boundaries on the model. Models are designed to represent a problem within a system and not the complete complex system. If a model was truly created to mimic an entire complex system, it would become as incomprehensible as the real world system surrounding the problem of interest (Sterman, 2000). In order to limit the model to the problem of interest, boundaries are established based on aggregated feedback loops of the factors considered relevant to the question at hand. The factors that influence the problem under study are identified through discussion with client teams or subject matter experts, supplemented by archived research, data collection, interviews, and direct observation (Sterman, 2000).

In the case of radiological terrorist attacks, there have not been any documented, successful attacks. The consequent lack of data leads to the formulation of theme selection through historical data from other terrorist attacks and expert opinion.

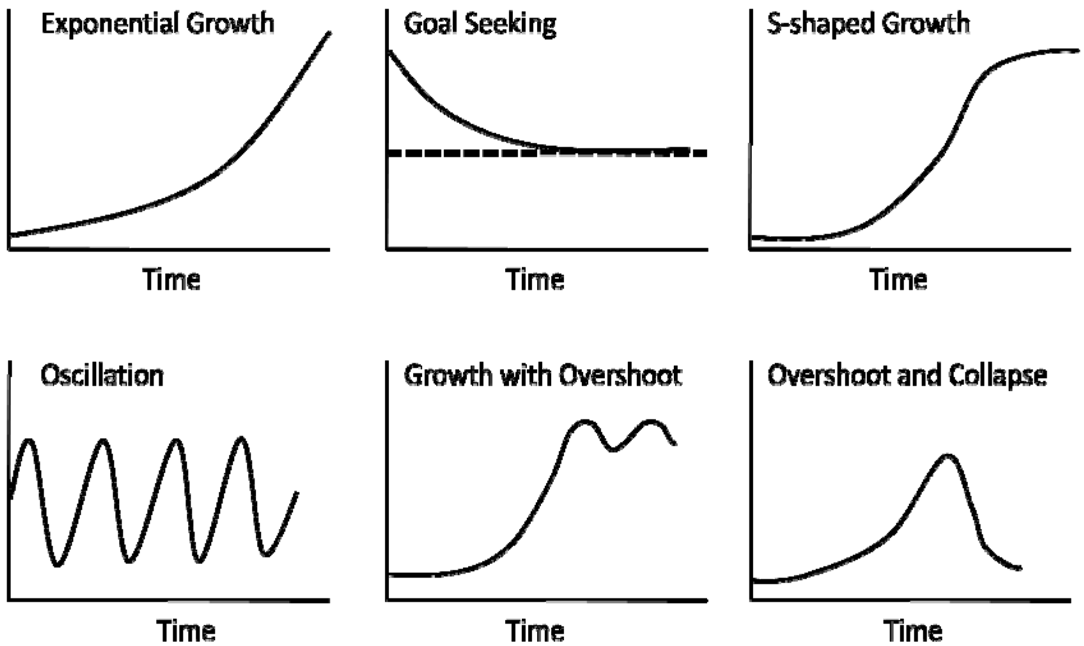
*Key Variables*

The process of defining the problem of interest must include the definitions of key variables. Variables of the problem of interest are defined by the research client or subject matter experts as being key in the system surrounding the problem.

*Dynamic Problem Definition (Reference Modes)*

A system dynamics model seeks, "to characterize the problem dynamically, that is, as a pattern of behavior, unfolding over time, which shows how the problem arose and how it might evolve in the future" (Sterman, 2000). Reference modes of behavior over time are established for each key variable in the form of graphs of behavior versus time. Reference modes are named such because the researcher must reference them continually throughout the modeling process to help the researcher and the client break away from a short term viewpoint and into a long term understanding of the cause and effect relationships surrounding the problem. (Sterman, 2000) To ensure the x-axis variable, time, is adequate, a time horizon must be established. Figure 3 illustrates common behaviors over time. Each of these reference modes of behavior are examples of real world, everyday problems we witness. For example, the media message following a terrorist attack might mimic the overshoot and collapse reference mode of behavior. The exponential growth of information and broadcasts might last until such time as another headline story becomes available. Eventually, the terrorist attack becomes a minimal topic for the evening news and is referenced less as time progresses. Such was the case following the Three Mile Island incident where there was extreme coverage immediately following the attack that dwindled over time as other topic of the day became more interesting to the public (Congressional Research Service, 1999).

**Figure 3: Examples of Reference Modes of Behavior (after Sterman, 2000)**




*Time Horizon*

The time horizon identified for the model should, "extend far enough back in history to show how the problem emerged and describe its symptoms. It should extend far enough into the future to capture the delayed and indirect effects of potential policies" (Sterman, 2000). A common mistake of decision makers surrounding a terrorist attack is to, "associate cause and effect as local and immediate" (Sterman, 2000). An example of this phenomenon was witnessed in the aftermath of Hurricane Katrina as the levee systems surrounding southern Louisiana parishes were examined. State and federal government officials immediately assumed the storm effects were too much for the designed levee system. Consequently, the Army Corps of Engineers was asked to rebuild larger, stronger levees with a corresponding increase in construction costs. Upon further investigation by the federal government, it was revealed that many of the breeched levees were the result of many years of neglect by the local levee boards.

Due to the lack of data concerned strictly with radiological terrorism, the timeline for this thesis effort will be based on the recovery efforts of other terrorist attacks on American soil and response plans from the EPA and DHS.

**Step 2: Formulation of Dynamic Hypothesis**

*Initial Hypothesis Generation and Endogenous Focus*

Once the modeler has formulated a clear problem with defined variables and reference modes of behavior, the formulation of a dynamic hypothesis is required to explain the behavior of the problematic system. The hypothesis is dynamic because it provides an explanation of the dynamics surrounding the problem in terms of the underlying feedback loops and stock and flow structures of the system. It is a hypothesis because it is always provisional, and therefore subject to revision or abandonment as the modeling process progresses and provides further insight into the problem (Sterman, 2000).

The goal of the modeling process is to develop an endogenous (arising from within) explanation for the problematic dynamics of the system. An endogenous hypothesis generates the dynamics of the system through the variables and agents represented (Sterman, 2000). Exogenous variables must be kept to a minimum since they may have negative effects on the model output. Each exogenous variable must be examined carefully to insure there are feedback loops from the endogenous variables. Should a feedback loop be discovered, then the model boundaries must be expanded to include the exogenous variable.

*Mapping: Causal Loop Diagrams*

Causal loop diagrams are, "useful tools for diagramming the feedback structure of systems in any domain" (Sterman, 2000). Simply put, they are diagrams that show the cause and effect relationships between variables within the model as well as model boundaries (Shelley, 2008). Variables in the causal loop diagrams are connected with arrows and either a positive (+) or a negative (-) symbol to indicate the link polarity between the variables. For example, the relationship between the amounts of information concerning radiation effects that are presented through the mass media will have a negative influence on public fear. As the amount of information increases, the level of public fear decreases. Further explanation of link polarity can be found in Table 2. Each endogenous variable has a causal link with the other variables in the system and a feedback mechanism. Variables that demonstrate only a single causal link, without feedback from the system, are considered to be exogenous variables.

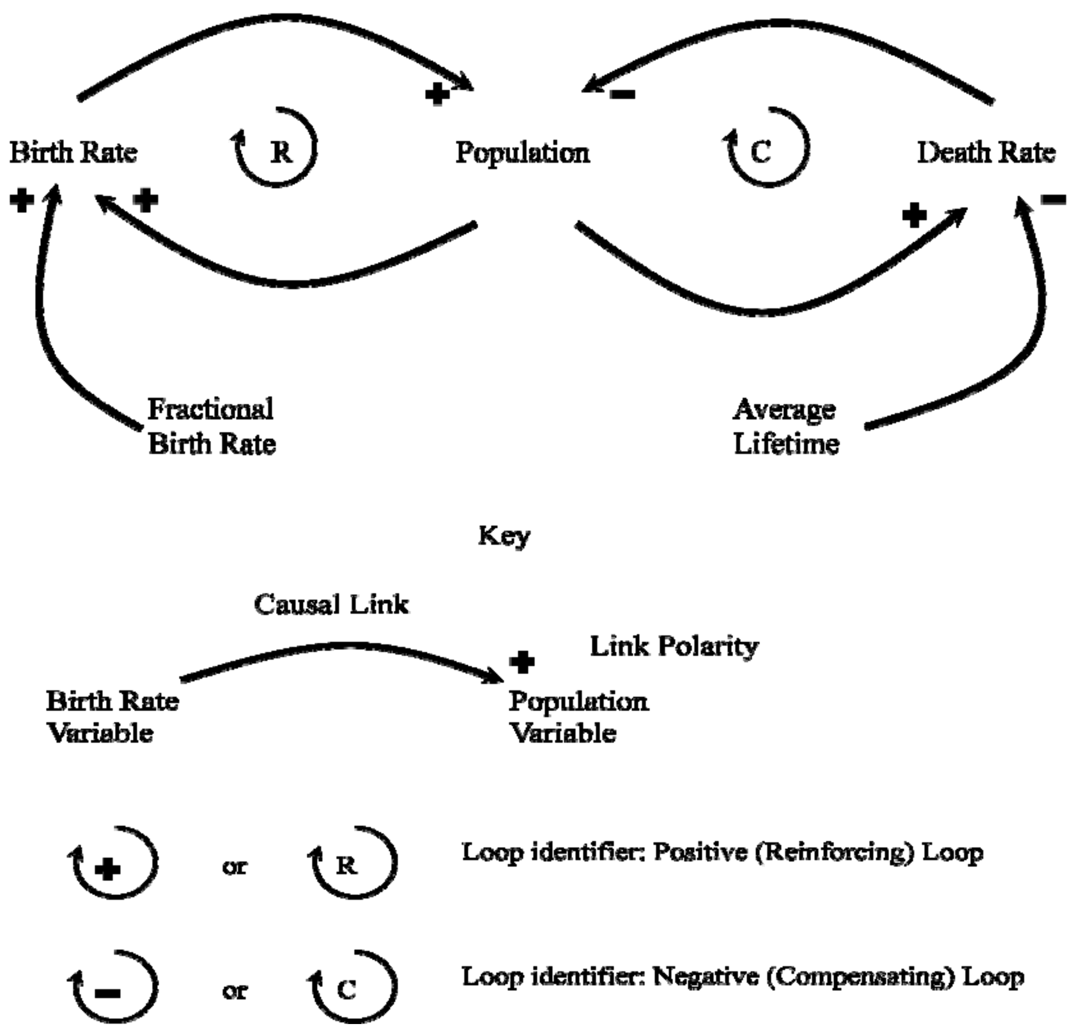
**Table 2: Link Polarity; Definitions and Examples (after Sterman, 2000)**

| Symbol | Interpretation | Examples |
|---|---|---|
| $X \xrightarrow{+} Y$ | All else being equal, if X increases, then Y increases. In the case of accumulations, X adds to Y | Product Quality $\xrightarrow{+}$ Sales |
| | | Effort $\xrightarrow{+}$ Results |
| | | Births $\xrightarrow{+}$ Population |
| $X \xrightarrow{-} Y$ | All else being equal, if X increases, then Y decreases. In the case of accumulations, X subtracts from Y | Product Price $\xrightarrow{-}$ Sales |
| | | Frustration $\xrightarrow{-}$ Results |
| | | Deaths $\xrightarrow{-}$ Population |

Within the causal loop diagram, feedback loops are presented that denote either a reinforcing behavior loop, denoted with an “R,” or a compensating behavior loop, denoted with a “C.” As illustrated in Figure 4, a reinforcing loop generates exponential growth of the behavior involved and a compensating loop generates exponential decay of the behavior involved. A feedback loop is considered reinforcing if there is an even number of negative causal polarities within the feedback loop.  Likewise, a feedback loop is considered compensating is there are an odd number of negative causal polarities within the feedback loop.

As part of the modeling process, delays in feedback between variables must be identified and added to the dynamic model.  Delays in a system create inertia, create oscillations, and commonly cause the trade-offs between the short-term and long-run effects of policies.  The model should include delays that are significant to the dynamic hypothesis or are relative to the time horizon (Sterman, 2000).

**Figure 4: Causal Loop Diagram Notation (after Sterman, 2000)**

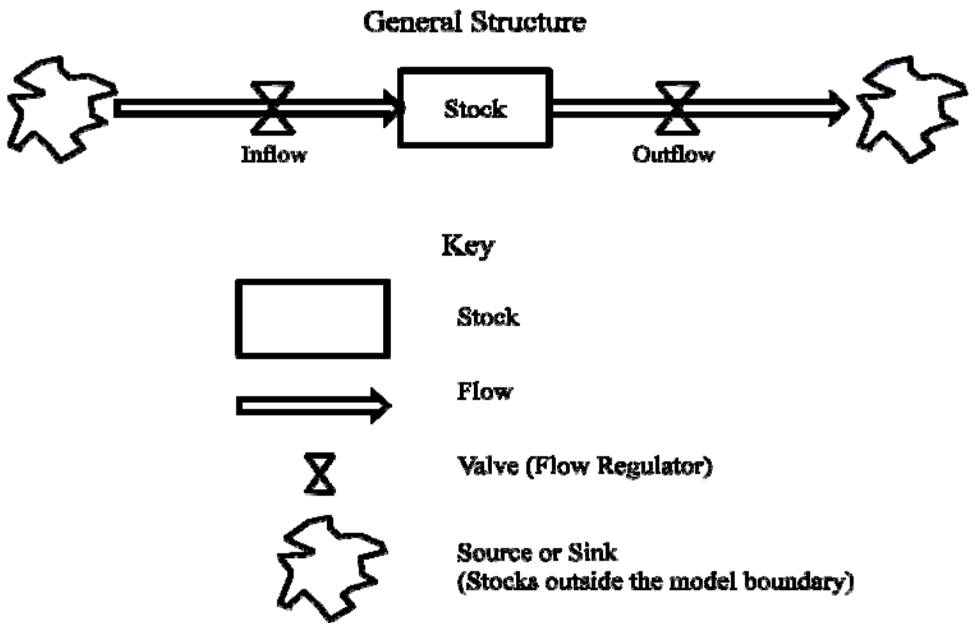


The combined behavior of multiple feedback loops within the model depends on what loop is currently dominating given the state of the system at that time. The current state of the system depends on stock levels of variables or the strength between key relationships (Shelley, 2008). During the formulation phase of modeling, the modeler undergoes numerous iterations of causal loop diagramming as the mental model of the system is refined (Shelley, 2008).

**Step 3: Formulation of a Simulated Model**

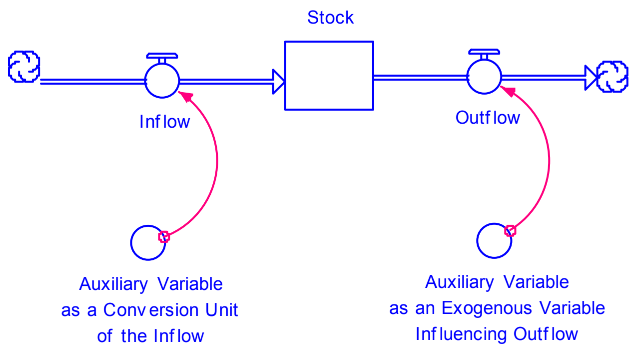
Once the dynamic hypothesis, model boundaries, and conceptual model have been created, the modeler will then test them using a stock and flow diagram created within the STELLA© software. Causal loop diagrams are effective tools for illustrating the feedback processes and interdependencies of a system. However, they are not as effective in capturing the stock and flow structure of the system. Stocks and flows, along with feedback, are the two central concepts of dynamic systems theory (Sterman, 2000). Stocks and flows can track the accumulations of material, money, information, etc… as each move through the system. Stocks accumulate the difference between inflows and outflows and include such things as inventories of populations, debt, and products. Flows are the push or pull units of stock per unit of time, or rates of increase or decrease in stocks, such as shipments, borrowing or repayment, or expenditures (Sterman, 2000). Stocks represent the state of the system and generate the information upon which decisions are made. The decisions made then alter the rates of flow, altering the stocks and closing feedback loops within the system (Sterman, 2000). Figure 5 demonstrates four equivalent representations of the stock and flow structure.

**Figure 5: Representations of Stock and Flow Structures (after Sterman, 2000)**




In addition to stocks and flows, additional variables are included in the model. As seen in Figure 6, auxiliary variables are either constants or exogenous inputs to the model. They can be are used to convert units of X into units of Y, input exogenous influences, and distinguish feedback loops (Sterman, 2000). For example, if an RDD attack involved disruptions to the power grid, an auxiliary variable of “No Electricity” would decay the outflow of the stock “Radiation Safety Information.” That is, without electricity, the outflow of information to the public would be reduced to a trickle since most mass media outlets require electricity (i.e. television and radio).

**Figure 6: Example of Auxiliary Variables within the STELLA Program**




The model is created based on the reference modes of behavior and the causal loop diagram. It is important that all variables within the causal loop diagram be represented within the model and that the output agrees with the reference modes of behavior for each stock (Sterman, 2000). Once the model produces behavior that mimics the reference mode behavior, testing of the model can begin.

**Step 4: Testing**

Validation of the model cannot be gained by any single test or set of test. Model validation comes from confidence in the model as more tests are passed and new points of correspondence between the model and empirical reality are identified (Shelley, 2008). As seen in Table 2, there are seven tests to identify problems with the model and build confidence in its accuracy.

**Table 3: Tests for the Assessment of Dynamic Models (after Sterman, 2000)**

| Test | Purpose of Test |
|---|---|
| Boundary Adequacy | Are the important concepts for addressing the problem endogenous to the model? |
| | Does the behavior of the model change significantly when the boundary assumptions are relaxed? |
| | Do the policy recommendations change when the model boundary is extended? |
| Structure Assessment | Is the model structure consistent with relevant descriptive knowledge of the system? |
| | Is the level of aggregation appropriate? |
| | Does the model conform to basic physical plans such as the EPA Protective Action Guide? |
| | Do the decision rules capture the behavior of the actors in the system? |
| Parameter Assessment | Are the parameter values consistent with relevant descriptive and numerical knowledge of the system? |
| | Do all parameters have real world counterparts? |
| Extreme Conditions | Does each equation make sense even when its inputs take on extreme values? |
| | Does the model respond plausibly when subjected to extreme policies, shocks, and parameters? |

**Table 3 (cont): Tests for the Assessment of Dynamic Models (after Sterman, 2000)**

| Test | Purpose of Test |
| --- | --- |
| Behavior Anomaly | Do anomalous behaviors result when assumptions of the model are changed or deleted? |
| Sensitivity Analysis | *Numerical Sensitivity*: Do the numerical values change significantly… |
| | *Behavioral Sensitivity*: Do the modes of behavior generated by the model change significantly… |
| | *Policy Sensitivity*: Do the policy implications change significantly… |
| | …when assumptions about parameters, boundary, and aggregation are varied over the plausible range of uncertainty? |
| Behavior Reproduction | Does the model reproduce the behavior of interest in the system (qualitatively and quantitatively)? |
| | Does it endogenously generate the symptoms of difficulty motivating the study? |
| | Does the model generate the various modes of behavior observed in the real system? |

**Step 5: Policy Testing Evaluation**

Once the model has passed each of the seven tests, the model can be explored to formulate the best policies to drive the desired behavior of the system. In the example of an attack using an RDD, the desired effect is to minimize the amount of economic harm. An effective model will present decision makers with the ability to explore the effects of Executive agency responses, Congressional interventions, and media campaigns. It is important to note that unless there is empirical data associated with the system; policy decisions should be based on behavior patterns not specific quantified outputs at a desired time. As in any model, predictions of the value of a variable at a specific point in time are likely to different than in reality due to the noise surrounding the system (Sterman, 2000).

# IV. Model Formulation and Analysis

## Problem Articulation

### *Theme Selection*

A system dynamics research model begins by clearly defining the problem and selecting appropriate boundaries. The central theme of this model is the dynamic influences within the local economy from an RDD detonation. While the system surrounding the economic influence of a terrorist attack using an RDD is complex and vague; micro-economic and meso-economic influences can be aggregated, mapped and modeled. Macro-economic effects are not likely to be realized from such a small ripple in the economic system and therefore are not of interest (Congressional Research Service, 2002).

There is common interest within the Department of Homeland Security and the Environmental Protection Agency to estimate the actual cost of such an attack; however, this thesis proposes that actual dollar estimates for economic impact are merely semantics and the true concern is how to minimize the total economic impact. To this end, the theme of this dynamic model will be on the methods with which response agencies, state and federal government, and the media can influence the financial impact and prevent collapse of the local economy.

### *Key Variables*

The dynamic system surrounding an RDD detonation consists of three primary sub-systems of interest to the total economic impact upon a local economy. These three subsystems are the Physical Impacts, Psychological Impacts, and the Federal Response. Each sub-system influences the total economic impact on the local economy through various feedback loops.

Only realized costs are accounted for within the dynamic system eliminating such losses as the expected decrease in property values.

The physical impact sub-system consists of seven aggregated variables. They are: personal losses, business losses, tax revenue losses, decontamination costs, response costs, reconstruction costs, and morbidity costs. The psychological impact sub-system variables include the mass media sensationalized message, public fear, business confidence, consumer confidence, community resilience, and community recovery. The federal government response variables include the executive response, legislative response, RDD risk education, stakeholder involvement, revitalization plans, Federal Emergency Management Agency disaster assistance loans, and Small Business Administration assistance loans. Descriptions of each dynamic variable can be found in Table 4.

**Table 4: Listing of Dynamic Variables**

| Dynamic Variables | |
|---|---|
| **Physical Impact Sub-System** | |
| **Variable** | **Description** |
| Total Economic Impact | Summation of all Physical Impact Stocks |
| Personal Losses | Accumulation of personal losses from job loss, property damage, evacuation, or injury |
| Business Losses | Accumulation of business losses from productivity interruption or property damage |
| Tax Revenue Losses | Accumulation of tax revenue reductions from sales and property taxes |
| Decontamination Costs | Accumulation of decontamination costs |
| Response Costs | Accumulation of response costs |
| Reconstruction Costs | Accumulation of reconstruction costs |
| Morbidity Costs | Accumulation of the value of statistical life of deceased victims |
| **Psychological Impact Sub-System** | |
| Mass Media Sensationalized Message | Accumulation of the mass media's sensationalized message concerning the attack |
| Public Fear | Accumulation of public fear |
| Consumer Confidence | Variable accumulation of local consumer confidence |
| Business Confidence | Variable accumulation of local business confidence |
| Community Resilience | Accumulation of the amount of resilience a community generates after an attack |
| Community Recovery | Accumulation of the level of recovery of the shocked system |

**Table 4 (continued): Listing of Dynamic Variables**

| Dynamic Variables | |
|---|---|
| **Federal Government Response Sub-System** | |
| **Variable** | **Description** |
| Executive Response | Accumulation of the level of response from the Executive Branch of the Federal Government |
| Legislative Response | Accumulation of the level of response from the Legislative Branch of the Federal Government |
| RDD Risk Education | Accumulation of the amount of radiological risk education presented by agencies of the Executive Branch |
| Stakeholder Involvement | Accumulation of the involvement of local stakeholders with agencies of the Executive Branch |
| Agreement of Cleanup Standards | A product of stakeholder involvement |
| Federal Revitalization Plan | Accumulation of Federal Funding Tools used to offset local economic impact and promote recovery |
| Federal Emergency Management Assistance Loans | Accumulation of FEMA disaster assistance loans used to assist affected individuals and local government with economic hardship caused by the attack |
| Small Business Administration Loans | Accumulation of SBA low or no interest loans designed to assist small businesses in the local area recover from the attack |
| **Exogenous Variables** | |
| Contaminated Area | Variable accumulation of contaminated area influencing costs or losses |
| Size of Weapon | Exogenous variable that influences the size of the contaminated area |
| Insurance Coverage | Exogenous variable that influences personal and business losses |

*Time Horizon*

It is expected that without assistance from the federal government the economic impacts from an RDD detonation will cripple the local economy after the first year as the total loss begins to exceed the earning potential of the local area (Rosoff & Winterfeldt, 2007, Vol. 27). Therefore, the time horizon established for this model will be one year.

*Reference Modes of Behavior*

With the dynamic variables identified, reference modes of behavior must be identified within the system. Through the literature review, several dynamic variables were identified within the system that exhibit behavior patterns over time. The identification of variables with reference modes of behavior is critical to the foundation of a useful model (Shelly, 2008). Variables with reference modes of behavior include: the contaminated area, the total economic impact, public fear, business confidence, consumer confidence, community resilience, community recovery, executive response, and legislative response.

At the onset of an RDD attack, an area of contamination is generated that impacts all cost variables. Within the time horizon of the model, it is expected that deposition of radioactive material will quickly occur and spread until response agencies begin to contain and eventually decontaminate the area. Without any external influences, the contamination area is expected to exhibit an approach to steady state behavior, such as in Figure 7, with a corresponding model structure in Figure 8.

**Figure 7: Reference Mode Behavior of the Contaminated Area**

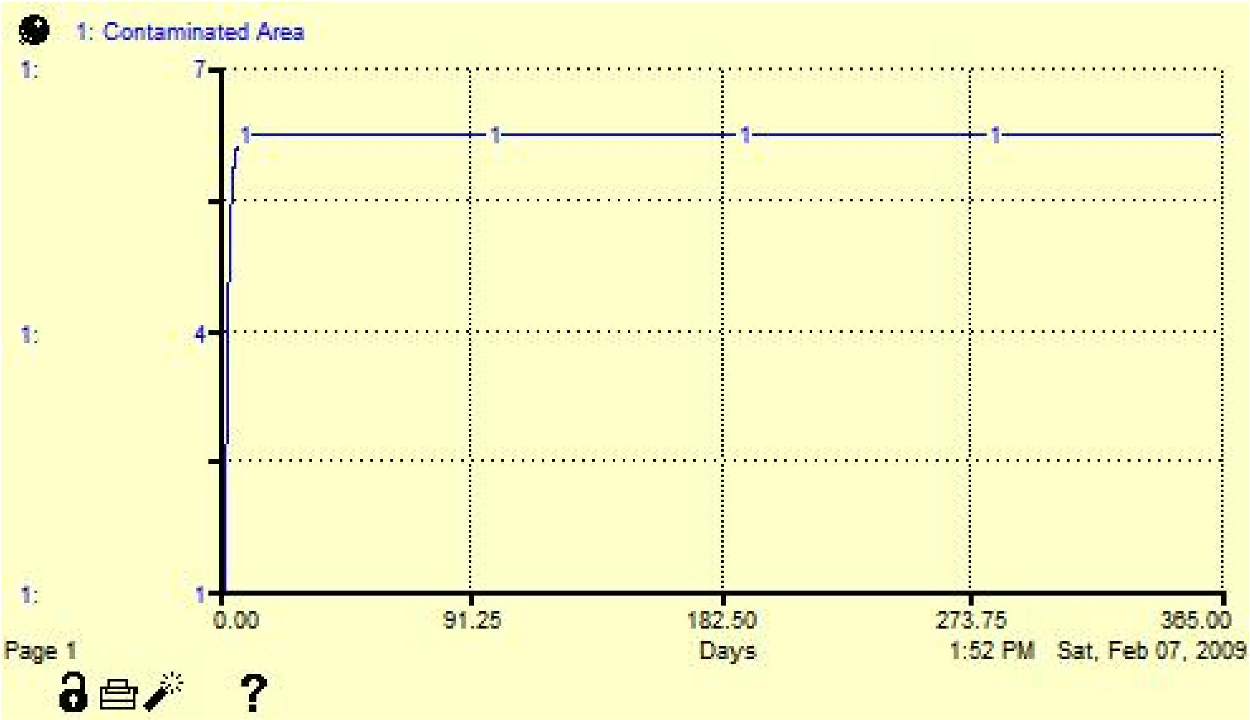
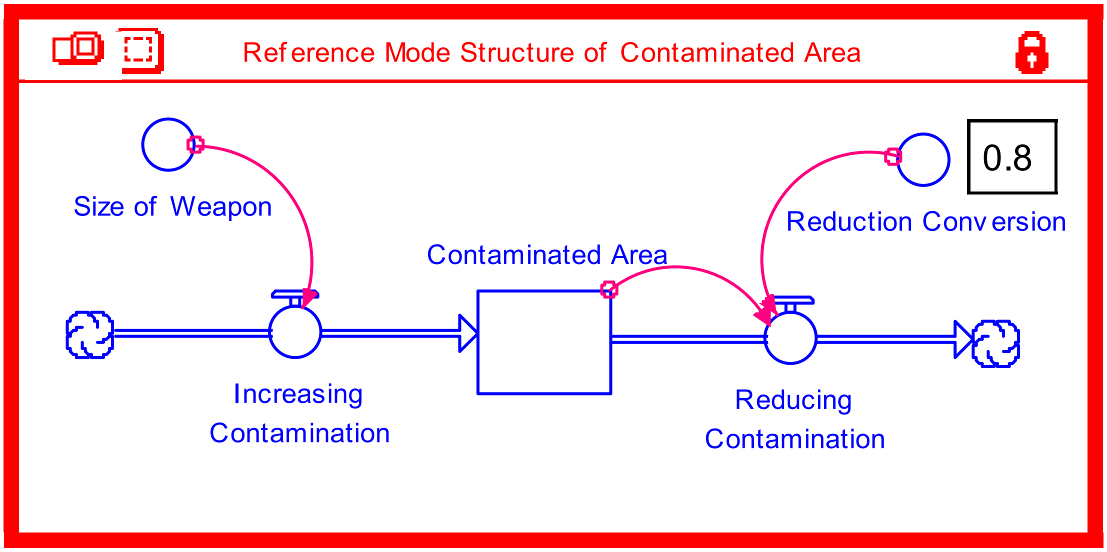



**Figure 8: Approach to Steady State Structure of Contaminated Area**



Similarly, the dynamic variable total economic impact is expected to also have an approach to steady state behavior over time as all costs are realized throughout the year. Unlike the contaminated area, the curve is expected to be more gradual as costs are expensed, paychecks are missed, and sales taxes losses are realized. This yields a reference mode of behavior as exhibited in Figure 9 with a corresponding structure such as Figure 10.

**Figure 9: Reference Mode Behavior of Total Economic Impact**

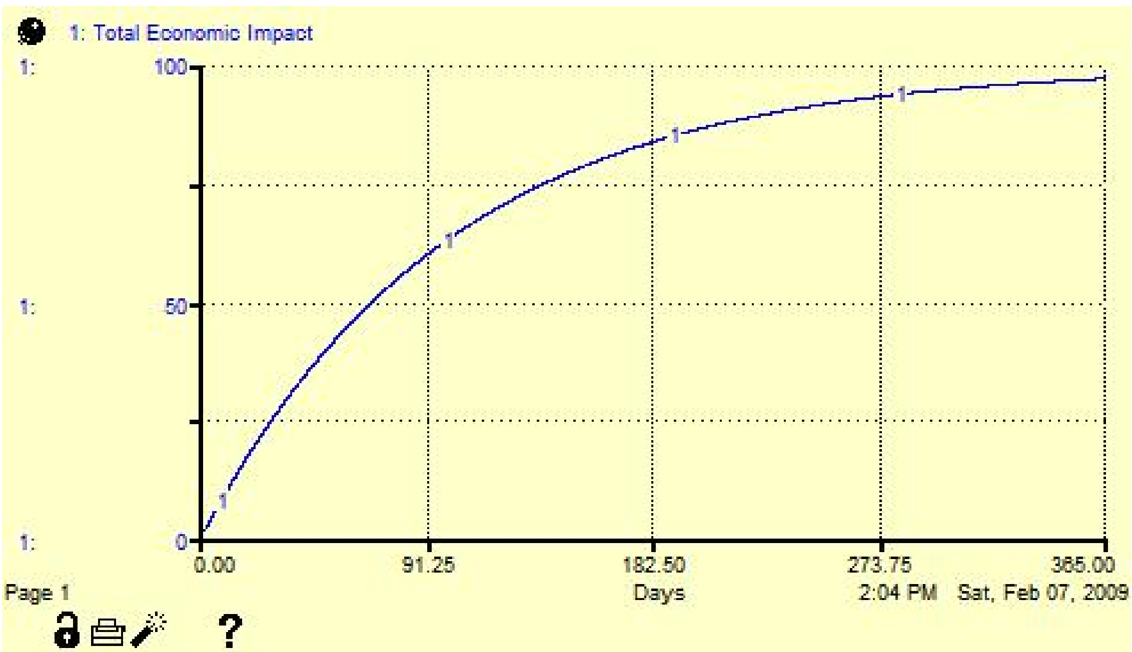
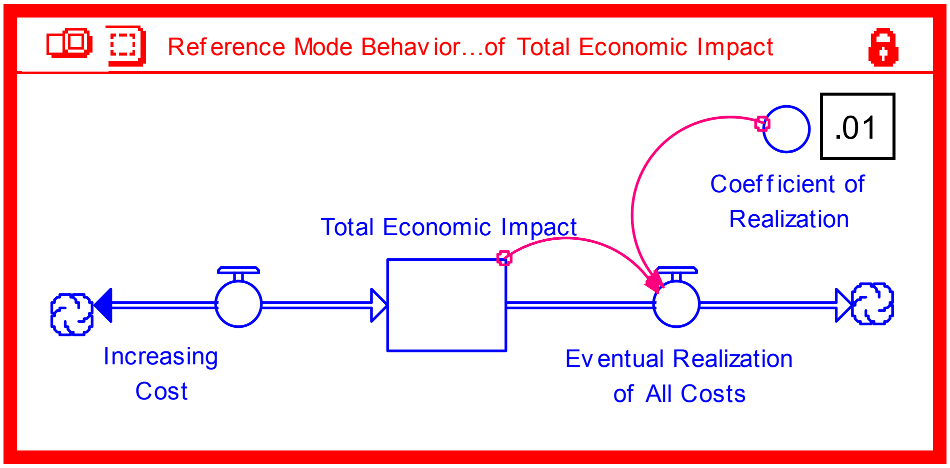


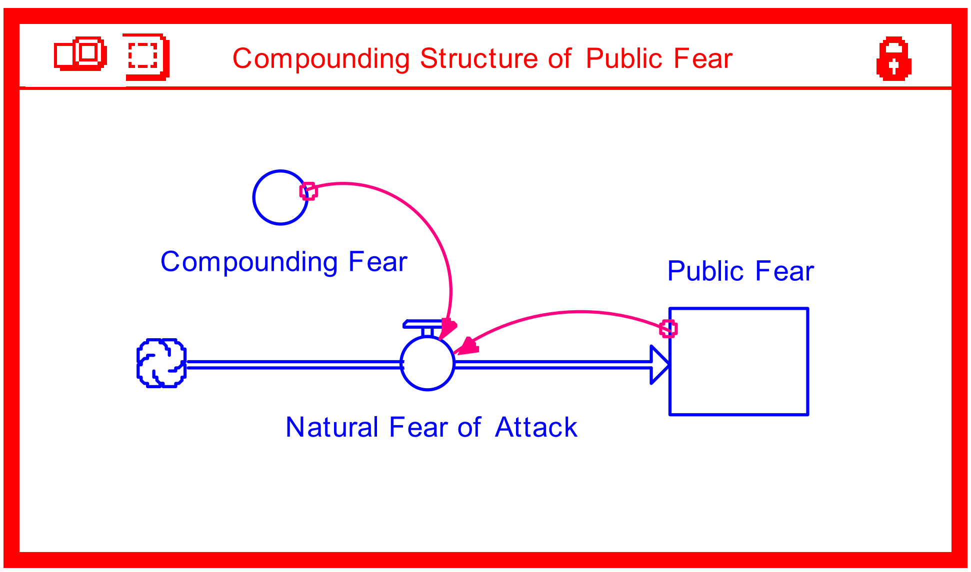
**Figure 10: Approach to Steady State Structure of Total Economic Impact**




In the examples of Three Mile Island and Goiania, Brazil provided in chapter two, the public perception of radiation rapidly generates public fear. Without any external influences on the public's fear of the risks imposed by an RDD detonation, it is expected that the fear will compound over time as in Figure 11. The compounding behavior translates into a compounding structure in the STELLA modeling program. (Figure 12)

**Figure 11: Reference Mode Behavior of Public Fear**


**Figure 12: Compounding Structure of Public Fear**



The most likely scenario involving the detonation of an RDD will occur in a major metropolitan area (Department of Homeland Security, 2008). The local area surrounding the attack site will likely include businesses that rely on customers. For those businesses fiscally impacted by the attack, their level of confidence in the ability of the local economy to recover is critical. Similarly, the confidence of consumers supporting these businesses is equally vital in the recovery of the area. Both of these dynamic variables present reference modes of behavior that can be modeled. At the moment of attack, all else equal, the levels of business confidence and consumer confidence represent the benchmark for which full recovery will be based upon. Without any external influences, both variables are expected to drain over time until there is no confidence in either variable that the local economy will recover. This reference mode of behavior is exhibited in Figure 13 with corresponding draining structure in Figure 14.

**Figure 13: Reference Mode Behavior of Business and Consumer Confidence**

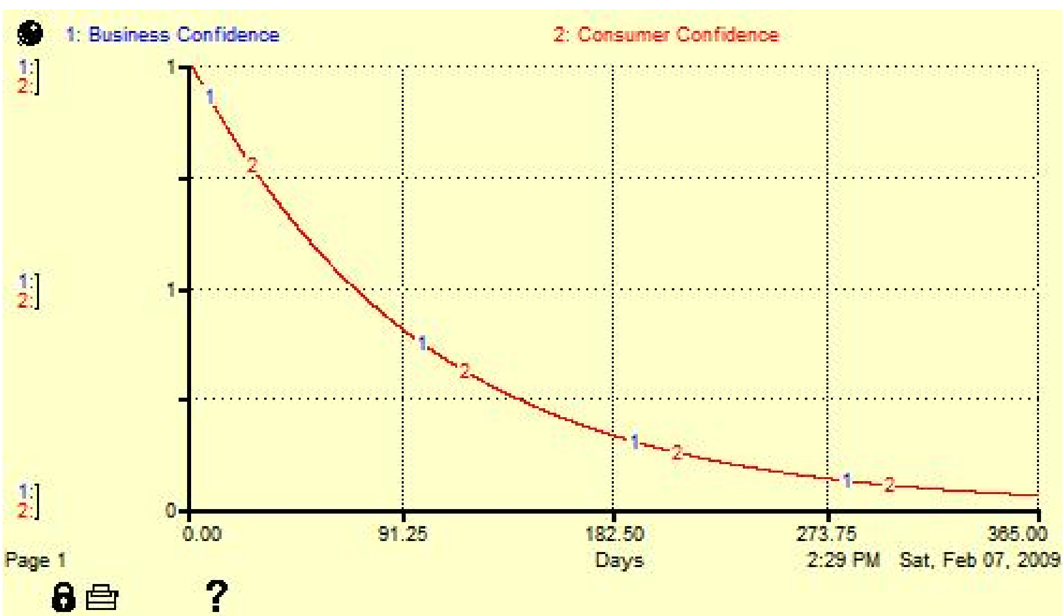
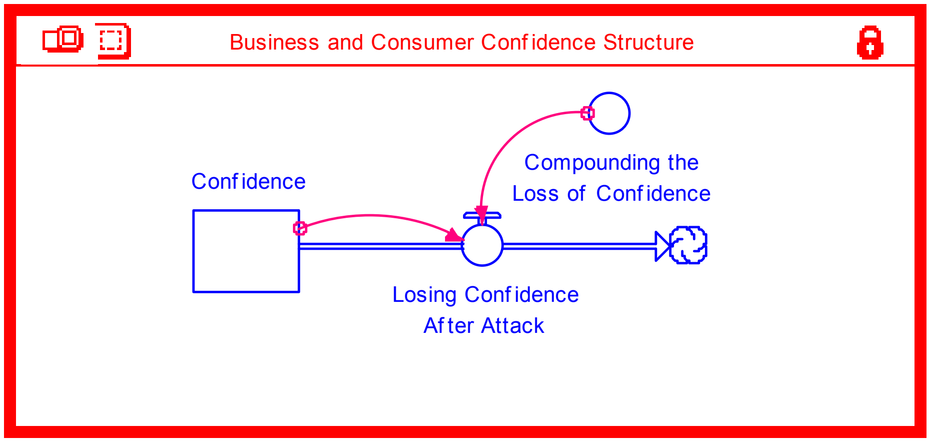


**Figure 14: Draining Structure of Business and Consumer Confidence**




Dynamic resilience is defined as the loss reducing effect of hastening recovery over time (Rose, 2007) (Rose, Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions, 2007). In the context of economic resilience, the community is dependent upon confidence from consumers and businesses that the community will recover. Consequently, the positive influence of business and consumer confidence will hasten the community's resilience to rebound from the attack and eventually recover. Without these confidence variables influencing community resilience, a community's resilience is expected to drain over time. This reference mode of behavior, Figure 15, is also modeled as a draining structure, Figure 16.

**Figure 15: Reference Mode Behavior of Community Resilience**

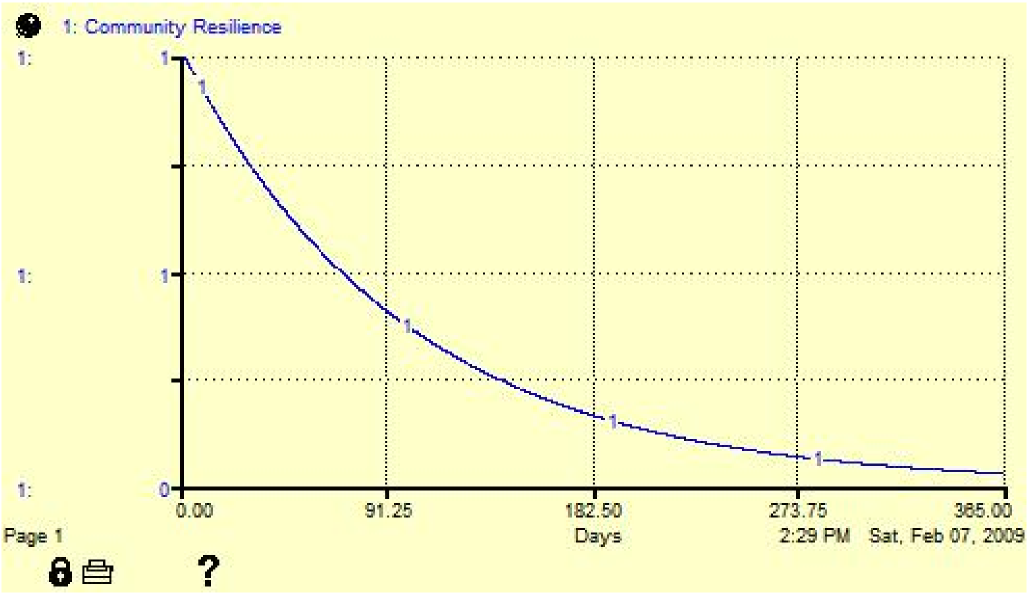
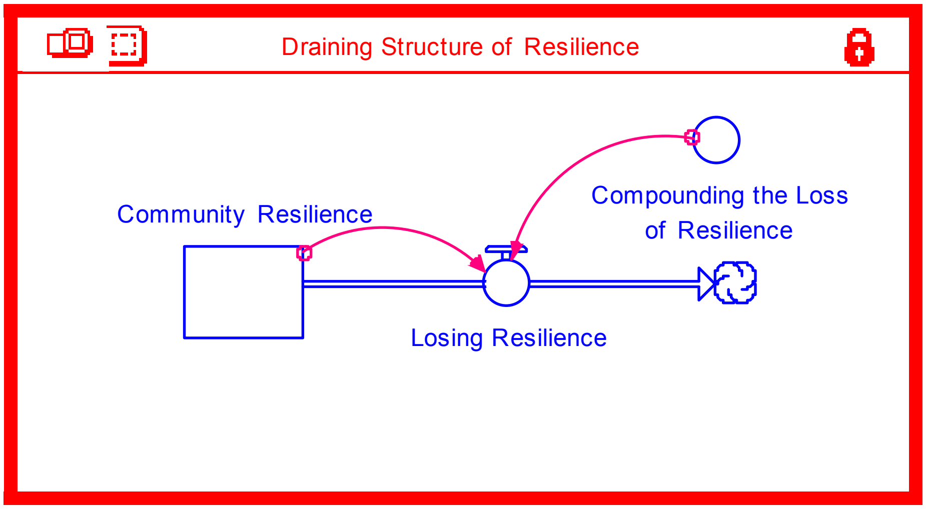
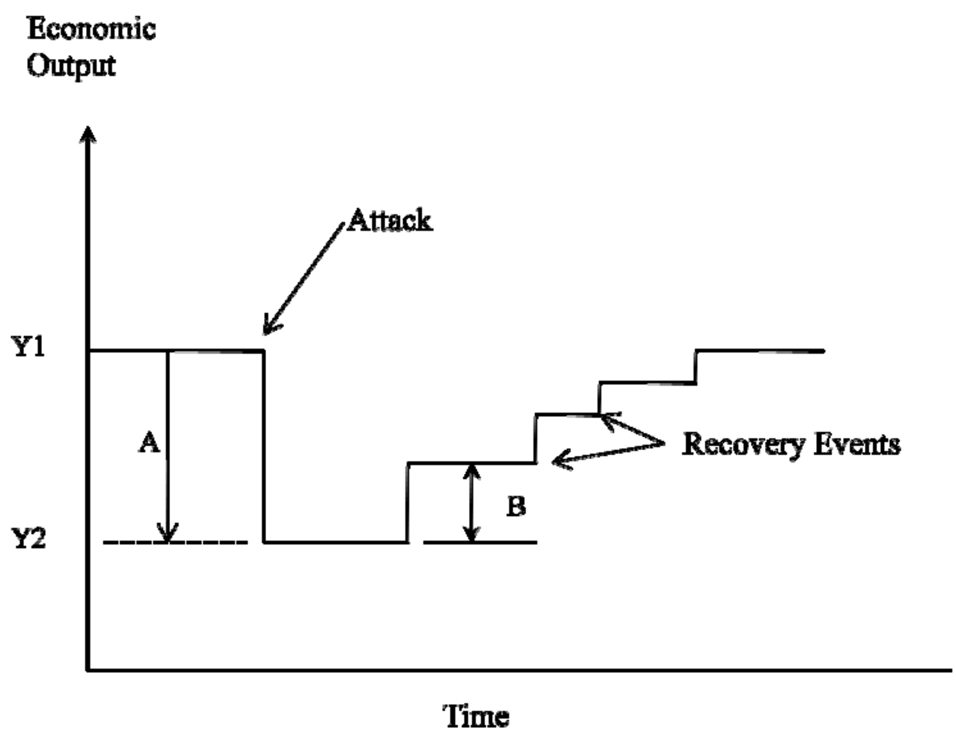



**Figure 16: Draining Structure of Community Resilience**



As presented by Adam Rose in Figure 17, the recovery of the impacted system resembles that of an S-shaped curve for each recovery effort over time. This seems logical to the researcher and consequently the dynamic variable of community resilience is modeled with an S-shaped reference mode of behavior in Figure 18.

**Figure 17: Static and Dynamic Resilience in the Context of Business Interruption (after Rose, 2007)**




A Economic Impact from Attack

B Increase in Community Resilience from Recovery Events

**Figure 18: Reference Mode Behavior of Community Recovery**


While local responders will be the first to respond to an RDD attack, they will quickly be replaced by the federal government as soon as the incident has been identified as an act of terrorism. There will be an initial steep curve as responding federal agencies mobilize and become operational within the first few days of the response followed by a steady state of response. This expected behavior yields an approach to steady state reference mode of behavior. Similarly, if the example of the legislative response following the September 11 attacks holds true, the legislative branch will respond in support of the executive branch as well as the economic areas impacted by the terrorist attack. However, this response is likely to be fiscally more costly than the executive branch response as well as delayed in action as presented in Figure 20. The reference modes of behavior for each variable are presented in Figure 19.

**Figure 19: Reference Modes Behavior for Executive and Legislative Responses**

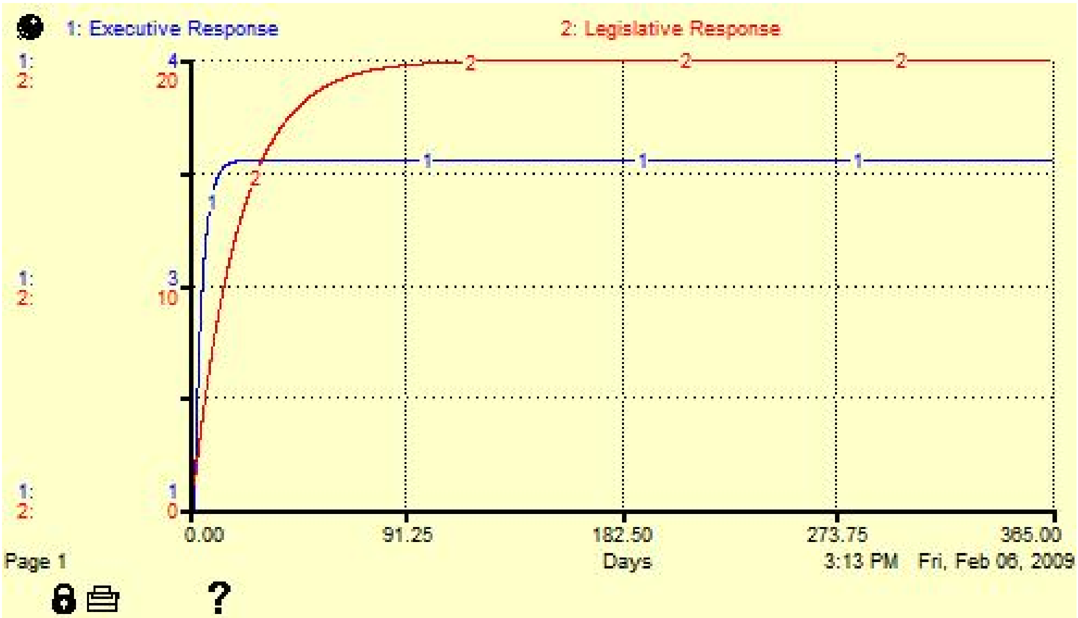
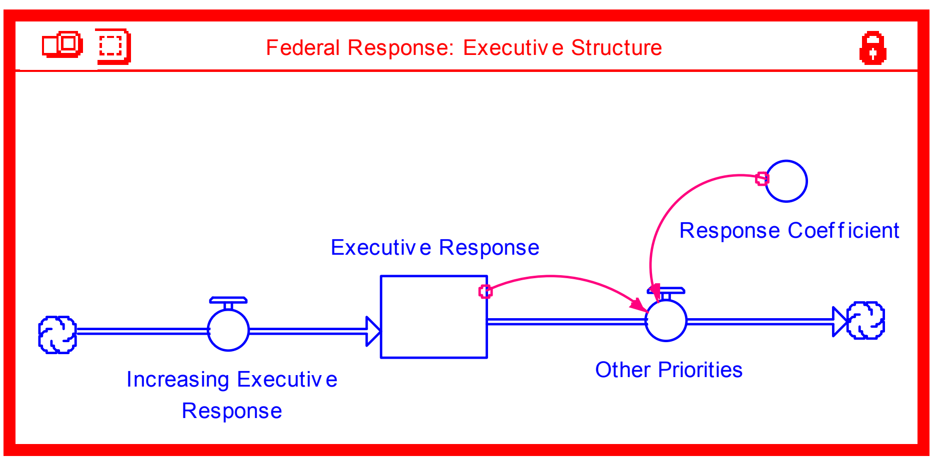



**Figure 20: Approach to Steady State Structure of Executive and Legislative Responses**

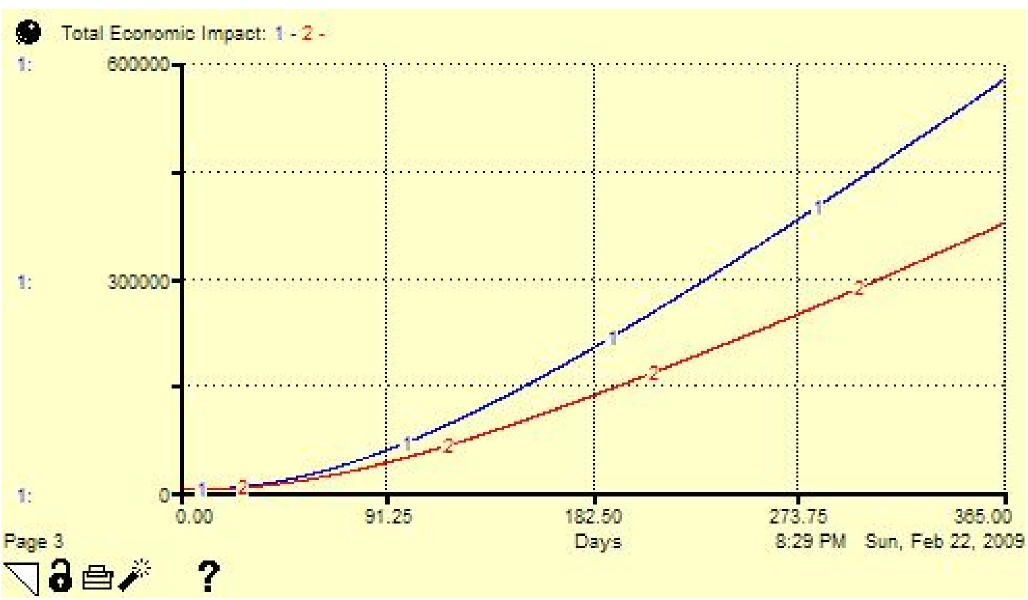


**Dynamic Hypothesis**

*Problematic Behavior*

As stated in the problem definition, this research seeks to understand the economic system surrounding an RDD attack with the intent of finding ways to reduce the total fiscal impact to the local economy. Therefore, the problematic behavior of interest to this research is the final value of the total economic impact and the tools available to decision makers to reduce the maximum y-axis value of the total economic impact. In Figure 21, curve one represents the uninfluenced behavior over time and curve two represents the implementation of various policies that have been used in historical examples of terrorist attacks or natural disasters.

**Figure 21: Problematic Behavior of Interest**

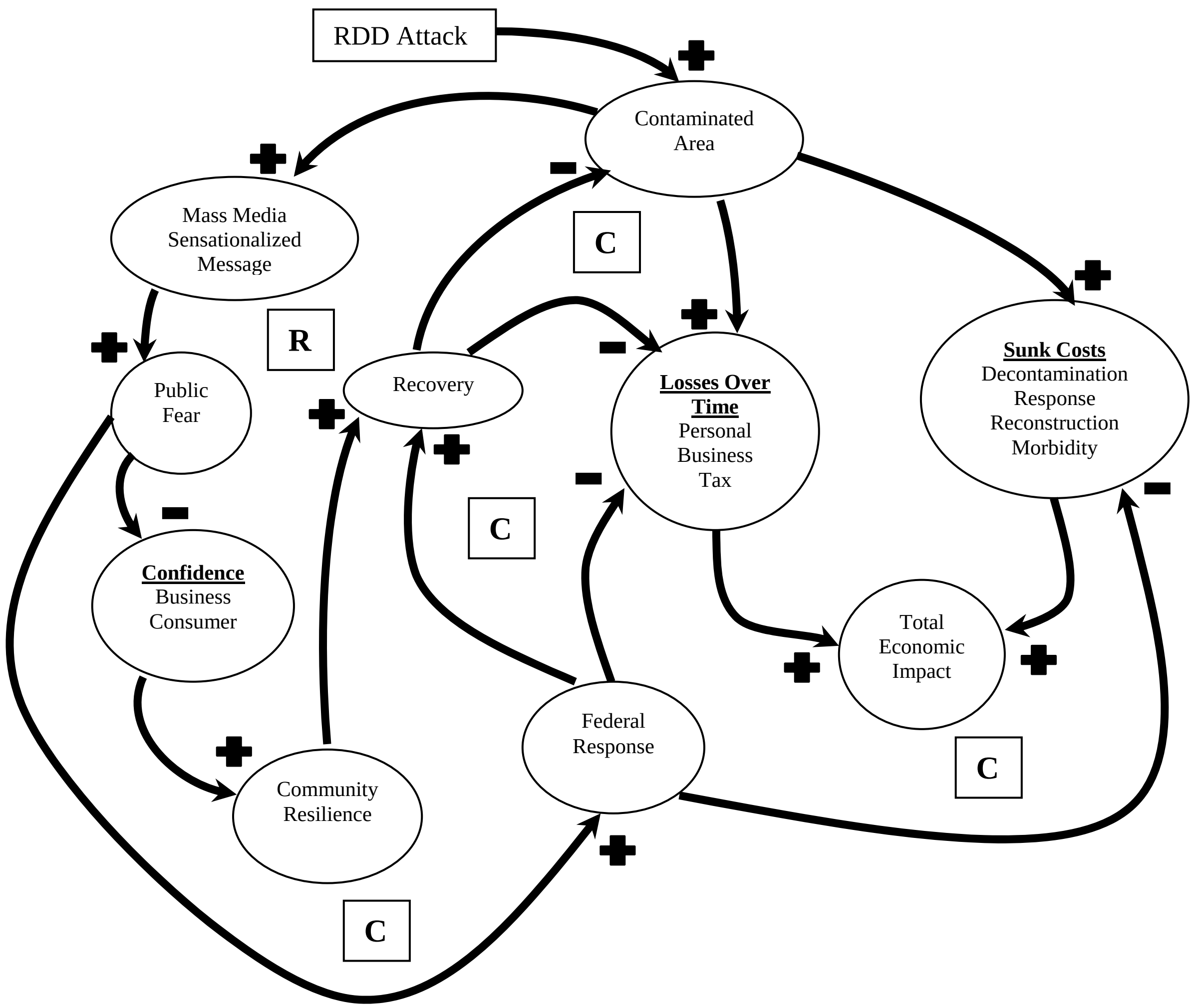


*Causal Loop Mapping*

The behavior over time of the total economic impact is influenced by a system of interconnected variables. Figure 22 demonstrates the various influences surrounding the problematic behavior and the polarity of each influence.

The event of a successful RDD attack generates a positive influence on the area of contamination; that is, as the size of the attack increases so does the size of the contaminated area. The generation of a contaminated area creates influences on eight endogenous variables. Within the physical impact sub-system of the model, there is a positive influence of the size in contaminated area upon the personal losses, business losses, tax revenue losses, decontamination costs, response costs, reconstruction costs, and morbidity costs. As the size of the contaminated area increases, so does the amount of costs incurred within each variable. Similarly, as in the Three Mile Island example, a positive relationship exists between the existence of a contaminated area and the subsequent sensationalized mass media message covering the effects of the attack (Congressional Research Service, 1999).

**Figure 22: Causal Loop Diagram**




Following the Three Mile Island incident, an "extraordinary" amount of broadcast time was devoted to coverage of the incident with words such as "horror," "specter," and "catastrophe" being used by media figureheads (Congressional Research Service, 1999). The media influence on the public generated uneducated fear of radiation both locally and nationally (Congressional Research Service, 1999). This is represented as a positive influence within the causal loop diagram. The generation of localized public fear creates a negative influence on the confidence of the community. Specifically, business confidence and consumer confidence are both influenced by the perceptions of the impact of the attack on the community and the ability of the community to recover. Similarly, the generation of widespread public fear generates a positive relationship on the federal response to the attack. An example of this feedback loop was witnessed in the year following the September 11 attacks on the world trade center. Families of the deceased were given money by Congress. As word spread, the pressure on congressmen from their constituents to increase funding for families increased until eventually another appropriation was passed that encompassed families impacted by the attacks (Government Accountability Office, 2005).

Adam Rose defines economic resilience as, “the ability of an entity or system to maintain function (e.g., continue producing) when shocked.” To influence the economic resilience of a community, supply-side and demand-side phenomenon must be addressed (Rose, 2007) (Smith, 2008). The demand-side of economic considerations involves the inputs from consumers and their willingness to spend or demand services within the impacted area. Consumer attitudes are measured by the Consumer Confidence Index, a five question survey administered monthly to determine the amount of consumer confidence within the economy. While this survey is administered as a macro-economic snapshot, the fundamental assumption that consumer confidence leads to consumer spending which stimulates the economy is the basis for the existence of a consumer confidence variable within the model. Consequently, by influencing consumer confidence, the resilience of the system can be positively influenced. Likewise, business confidence, the supply-side phenomenon, can also positively influence the community’s resilience.

Recovery of the impacted system is achieved once the economic output of the system returns to pre-attack levels.  For each increase in the community's resilience, the economic system takes incremental steps towards recovery.  This translates into a positive influence between community resilience and community recovery within the model.  Finally, each unit of recovery has a negative influence on the amount of contaminated area.  For example, one unit of recovery may represent the containment of the contamination which will decrease the size of the cordon area where contamination was thought to be present.  The negative relationship between community recovery and contamination area provides an important feedback loop within the system and allows decision makers the ability to bring the system under control once policies can be made to manipulate the variables within that particular reinforcing loop.

Without external influences, a local economy may never recover (Smith, 2008).  With the exception of some of our major cities, most of the small to medium sized cities within the United States do not have the internal expertise to deal with radiological terrorism.  Consequently, as in other United States terrorist attacks, the federal government is likely to respond through numerous agency efforts as well as legislative funding support.  The federal response variable provides the necessary compensating feedback to bring the local economic impact under control and potentially accelerate the economic output above that of pre-attack levels.

**Formulation of Model**

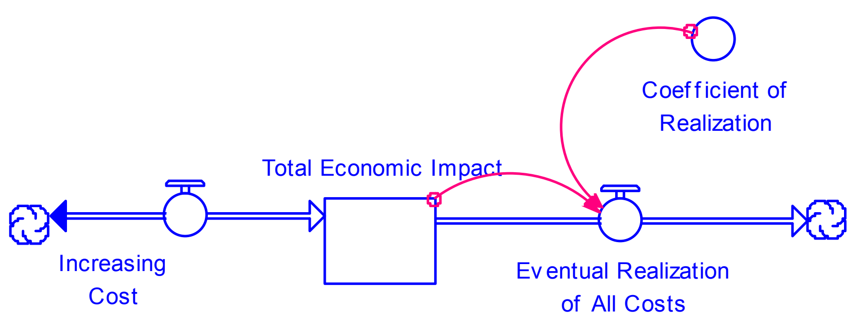
With the reference modes of behavior identified as a baseline and a causal loop diagram as a roadmap, formulation of the model within the STELLA program can begin.  It is important to again note that this model represents the influences within the perceived system and not numeric calculations of specific costs as found in other economic impact research papers.  To standardize the structures in the model, all conversion units have a value of .1 unless an adjustment is required to represent the specific logic embedded within the output graph.

The modeling process begins with creating stock and flow structures that create the reference mode of behavior for each variable that has an identified behavior over time. Due to the size and complexity of the model, the three sub-systems are represented independently before influences between them are connected. This gives the researcher further insight into the model as well as another opportunity to incrementally test the modeled behavior against the expected behavior.

*Physical Impact*

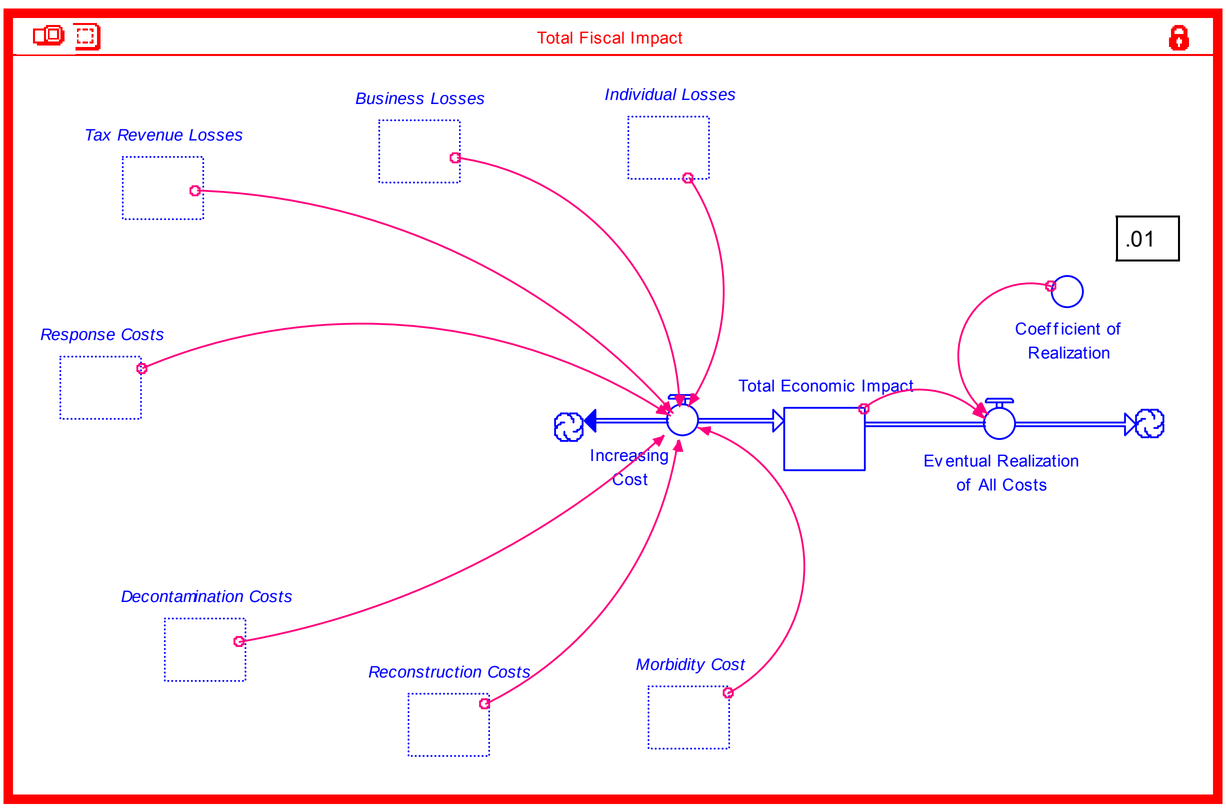
Within the physical impact sub-system, only the total economic impact variable has an expected behavior over time. This behavior is represented as an approach to steady state with a model structure resembling that of Figure 23. The "coefficient of realization" is a conversion unit that represents the rate at which costs are realized. Adjusting this conversion unit adjusts the total economic curve. It is also important to note that the inflow is bidirectional. This allows the model the potential to not only recover, but to recover to a better state of economic output than found prior to the attack.

**Figure 23: Total Economic Impact Structure**



Within the literature review, eight variables were identified as aggregated representations of the expected fiscal accumulations. The eight variables that influence the total economic impact on the local economy do not have an expected behavior over time and are represented simply as stocks, or accumulations, of losses or sunk costs over time. The summation of each of these variables equals the total economic impact. The complete physical impact structure is represented in Figure 24.

**Figure 24: Physical Impact Structure**



*Psychological Impact*

The variables within the psychological sub-system are critical variables for decision makers to consider when faced with the establishment of a path to recovery, yet they are difficult to measure and analyze for a proper response. Fortunately, all of the variables, except mass media sensationalized message, exhibit individual expected behaviors over time without external influences. While the mass media sensationalized message may generally increase over time following the attack, the influences on such behavior cannot be standardized across all spectrums of media due to competing stories, political bents in coverage, and personal biases of editors. Consequently, this variable exists as a mere stock that is influenced by other variables. Once the reference mode behaviors are translated into model structures, as in Figure 25, the influences between the psychological impact variables are modeled and result in the structure represented in Figure 26.

**Figure 25: Psychological Impact Variables in Reference Mode Structures**

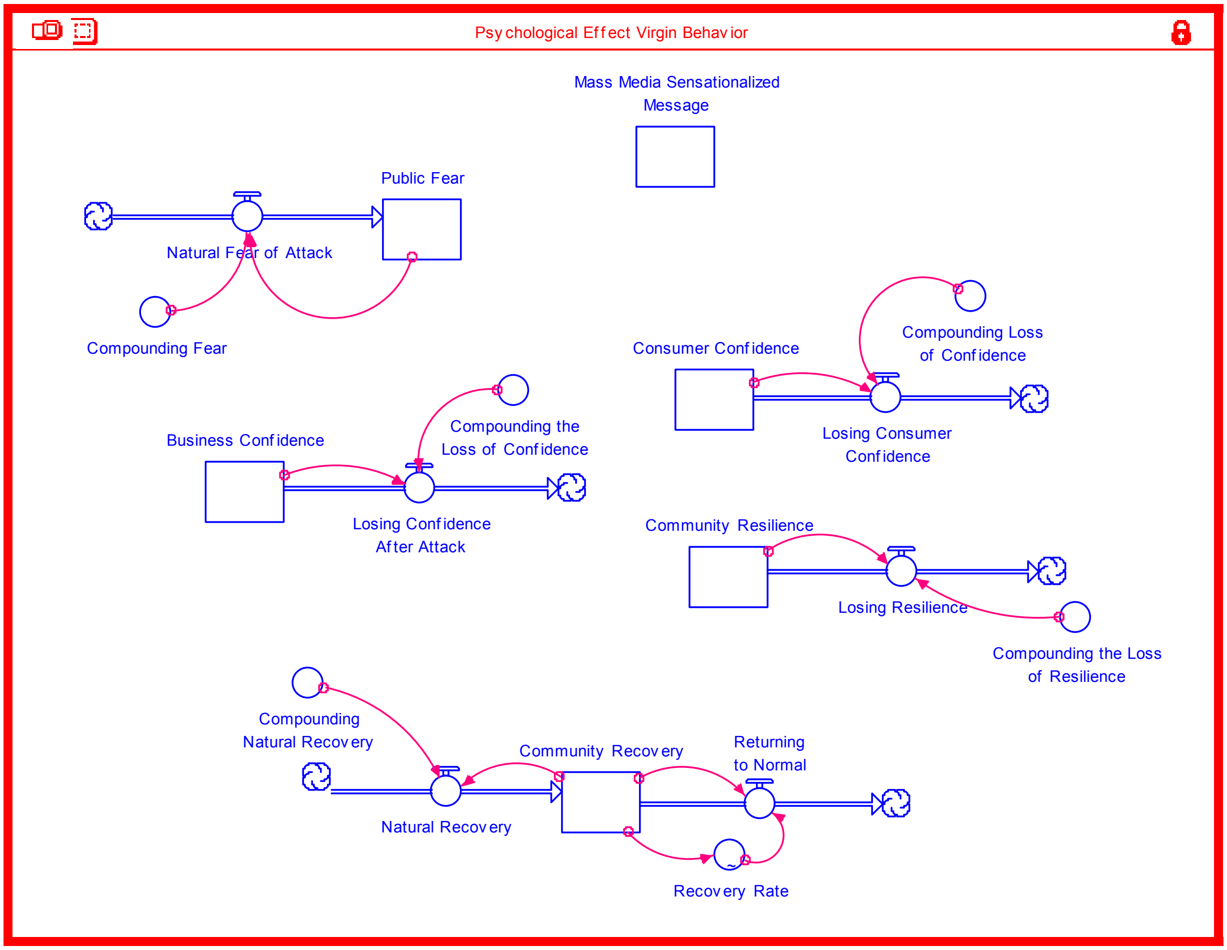
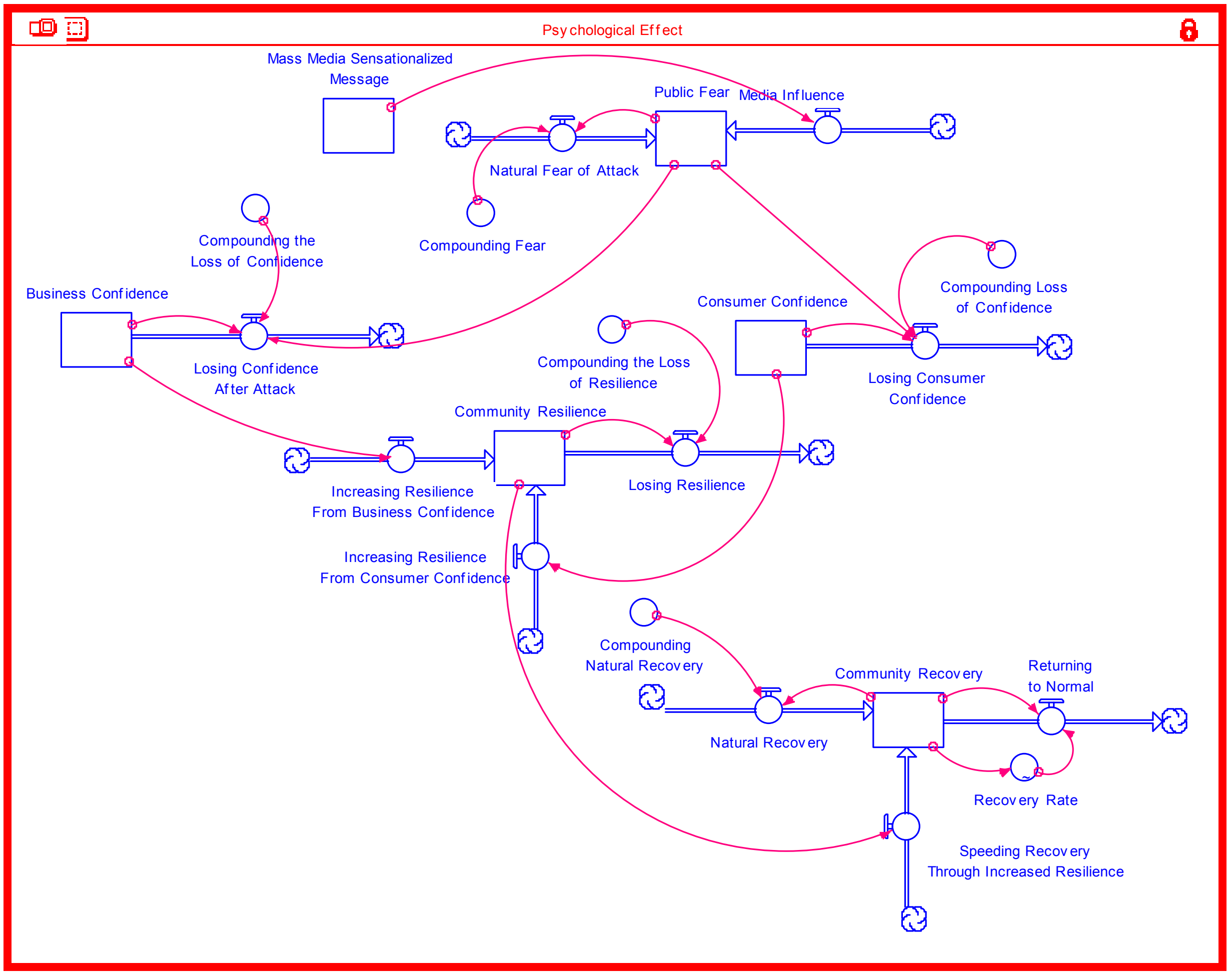


**Figure 26: Psychological Impact Structure**

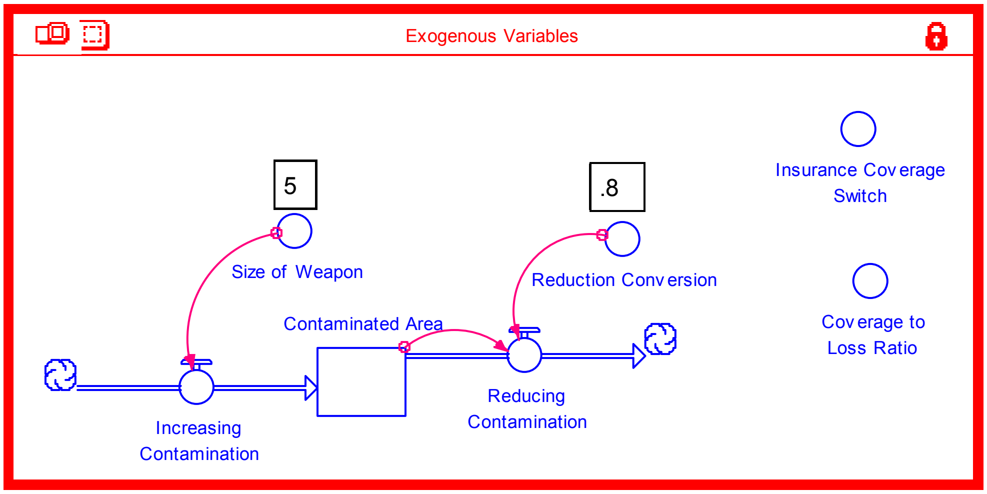



*Exogenous Variables*

There are three exogenous variables to consider within this model. The size of the weapon used in the attack generates a relative size of contaminated area. The existence of a contaminated area is the impetus for the system of study. While the size of the weapon used in the attack is a fixed variable in this study, the contaminated area does have a reference mode of behavior in which the contamination quickly spreads until it is contained. As demonstrated in Figure 7, an assumption of the model is that the contamination will be identified and contained within the first week following the attack. To achieve this expected behavior over time, the draining rate converter, Reduction Conversion, was changed from the uniform model standard of 0.1 to 0.8 as seen in Figure 27. By doing so, the contamination curve rapidly ascends within the first days until it levels off and persists until recovery actions can begin to decrease the contamination.

After the attacks of September 11, 2001, insurance companies were faced with the unexpected option of insurance claims following a terrorist attack. At the time, risk analysis models did not exist for insurance companies to formulate their coverage options. Consequently, some insurance companies have since removed coverage of claims caused by acts of terrorism (Congressional Research Service, 2002). The decision to cover claims lies outside the realm of control for the stakeholders involved in the restoration efforts following an attack. However, the influence of insurance coverage over personal and business losses has a direct effect on the losses sustained by those in the impacted economic system. Consequently, insurance coverage is an exogenous variable within the model that can be turned on and off to compare the effects of coverage on individuals and businesses. An assumption of the model is that insurance policies, even if they provided coverage, would not cover all losses realized by victims. Consequently, the model includes a converter named coverage to loss ratio of 0.8, meaning that if there is coverage of claims, the policy would only cover 80% of the total losses. If this assumption is undesirable, the model includes the ability to adjust this ratio to any desired value. However, the 80% coverage to value ratio is the standard for FEMA's national flood insurance program and therefore perceived as a valid assumption (Federal Emergency Management Agency, 2009).

**Figure 27: Exogenous Variables**




*Federal Response*

As in other terrorist attacks, it is expected that there will be a federal response from both the executive and legislative branches. In Figure 19, the reference modes of behavior of fiscal response for each branch of government are illustrated. It is important to note that while the executive response will occur before the legislative response, the legislative response historically involves far more financial assistance. In the recently published FEMA protective action guide for response to RDD and IND incidents, the education of the populace on the risks of radiation hazards, stakeholder involvement, and agreement on acceptable decontamination standards were noted as having influence on recovery efforts after the attack (Department of Homeland Security, 2008). Each of these variables is enacted by executive agencies, namely the Department of Homeland Security and the Environmental Protection Agency. Therefore, each of these variables is included in the executive response model, Figure 28, as influencing variables within the psychological sub-system. These influences will be discussed further in the complete model discussion.

As reported by the GAO, following the September 11 attacks and numerous natural disasters, the legislative branch authorized funding through numerous outlets to assist in the recovery. This funding was provided through several different mechanisms. Some assistance was provided through low or no interest loans and distributed by the Small Business Administration. Other funds were distributed by FEMA through disaster assistance grants, response reimbursement for equipment and labor, or payments to families of the dead—as was the case following the September 11 attacks. For more long term recovery considerations, special tax incentive zones were created to stimulate business growth in the local economy. Not only did this funding offset some of the physical losses, but it also generated positive psychological influences on businesses and consumers through reassurance of recovery as seen in lower Manhattan today. Within this model, these psychological influences translate into a positive influence on business and consumer confidence.

**Figure 28: Executive Response Structure**

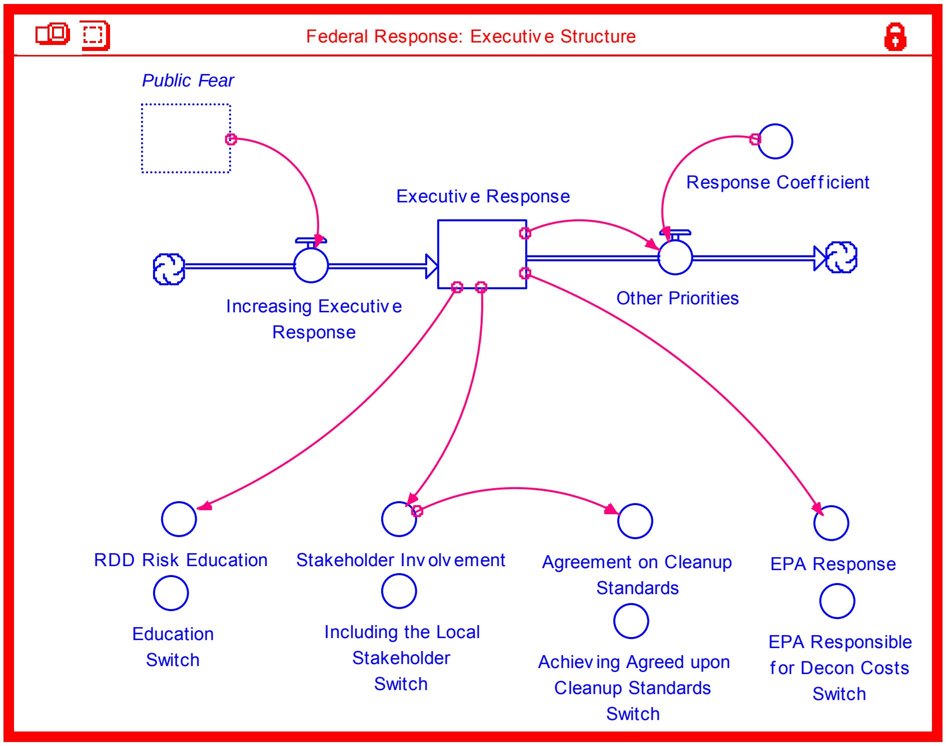
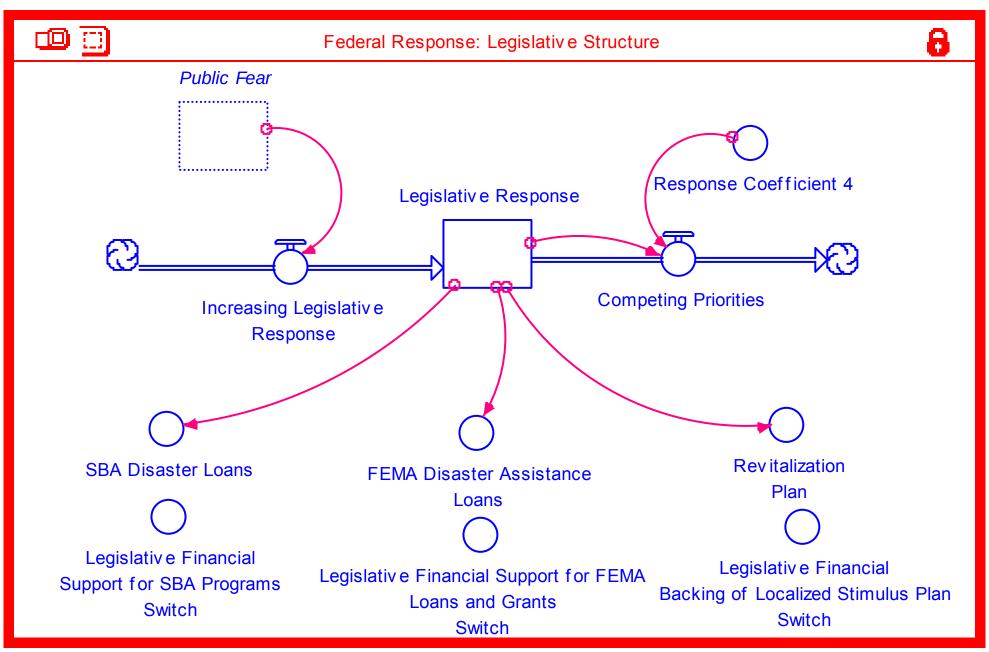



**Figure 29: Legislative Response Structure**

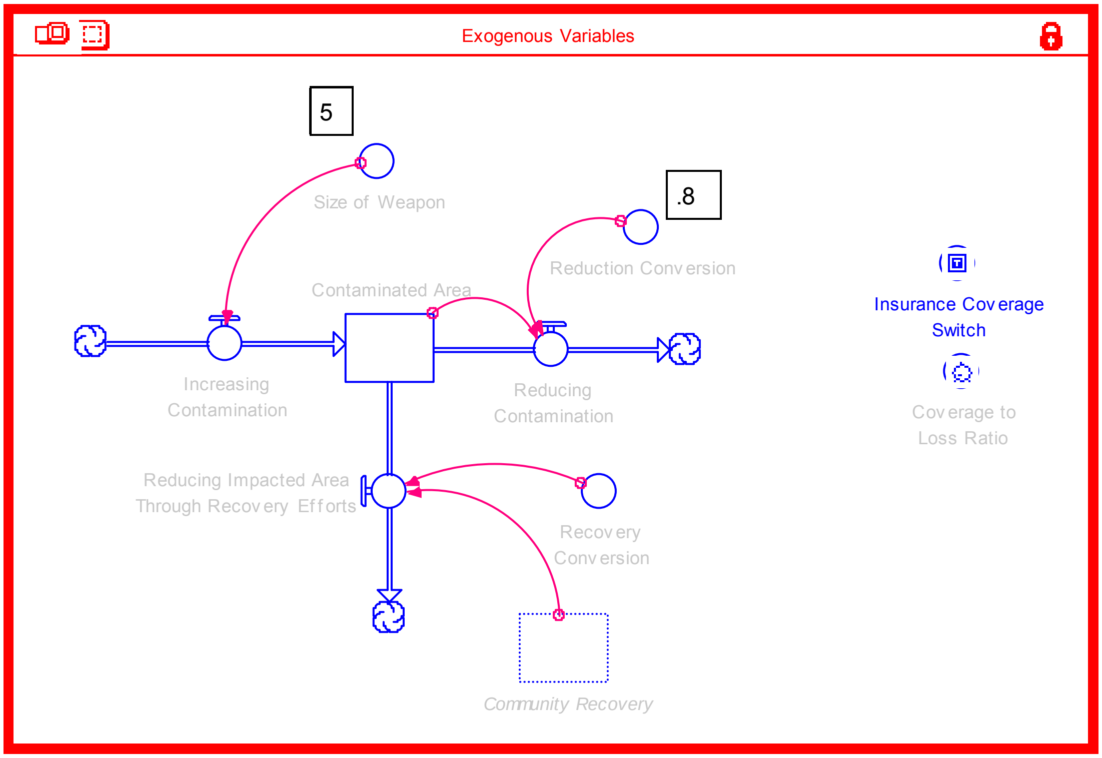


*Complete Model*

The onset of a terrorist attack involving an RDD triggers the creation of a contaminated area. Initially, the suspected contaminated area will be large in relation to the actual radioactive material deposition. During the early phase of response, the area of suspected contamination will decrease due to the identification of the actual deposition, this is a recovery event. As time passes, other recovery efforts will continue to decrease the area of contamination and its effects on the local economy. This expected recovery action provides a critical negative influence on the contaminated area variable (see Figure 30) and is the primary feedback mechanism between the exogenous variables and the psychological impact structure.

As the size of the contaminated area increases, the personal, business and tax revenue losses also increase in response to the lack of economic output within the suspected contaminated area. These losses continue to grow over time until full recovery, defined as a return to pre-attack economic output, is achieved. Similarly, the greater the contaminated area, the greater the costs associated with decontamination, response, reconstruction, and morbidity. These costs represent sunk costs that may or may not significantly change over time, yet each of these expenditures is a function of contamination and should therefore be included in the total economic impact.

**Figure 30: Control of Contaminated Area through Recovery Events**




Due to the physical size and numerous influences within the complete model, the following physical impact structures are presented individually with ghosted variables, such as community recovery, in Figure 30 above. Ghosted variables are merely a copy of model entities, represented with a dashed outline, that are used to decrease confusion and clutter. As noted in the causal diagram, the contaminated area is the only positive influence on each of the stock structures listed under physical impact. Therefore, the only inflow for individual loss, business loss, tax revenue loss, decontamination cost, response costs, reconstruction costs, and morbidity costs will be from the contaminated area variable. The various policy options used by the federal government can quickly offset some or all of the losses over time. Consequently, these policies represent outflows for each stock structure within the physical impact structure.

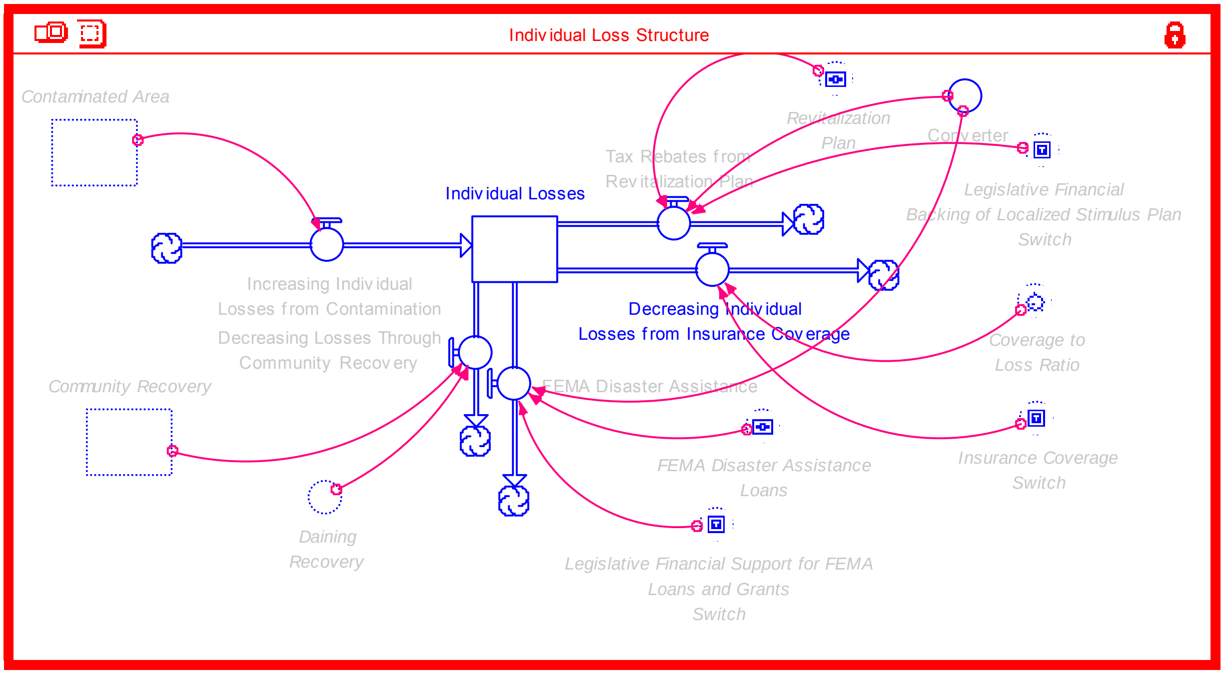
The accumulation of individual losses for those impacted by an RDD attack can be influenced by several policies (see Figure 31). As noted in the causal diagram, recovery efforts influence both the contaminated area as well as individual losses over time. An example of a recovery effort negatively influencing individual losses can be found the post-9/11 tax policies enacted by the New York City Office of Management and Budget (Government Accountability Office, 2005). In an effort to stimulate growth around the attack area, tax relief policies were enacted that placed more funding in the pockets of constituents and businesses, thereby offsetting some amount of losses over time. Another example of a community recovery effort that is non-monetary yet reduces individual losses over time would be local government employment relocation assistance for those who lost their jobs due to the attack. Both examples are units of recovery and negatively influence individual losses.

Following the September 11, 2001 attacks the insurance industry was faced with the unexpected decision of covering losses from terrorism or refusing related claims. The literature suggested that some companies have completely refused to cover losses from a terrorist act while others have decided to price a specific premium in the event policy holders presented claims due to an act of terrorism. Without knowing what the insurance industry will do concerning individual claims from an RDD attack, the model incorporates an insurance drain on the individual loss stock that can be turned on and off from the user interface panel.

In the immediate aftermath of the September 11, 2001 attacks as well as numerous natural disasters, FEMA offers individuals several tools that offset the immediate fiscal impact from an event. These fiscal offsets can be disaster assistance loans, relocation assistance grants, temporary housing, or even transportation out of the evacuated zone (Federal Emergency Management Agency, 2007). In each instance, these efforts offset the losses to the impacted individuals and therefore are a drain on the individual loss stock. Due to the expected small size of the RDD contamination, it is possible that FEMA may not respond with such assistance; consequently, the FEMA response drain is modeled with an on/off switch to replicate this possibility.

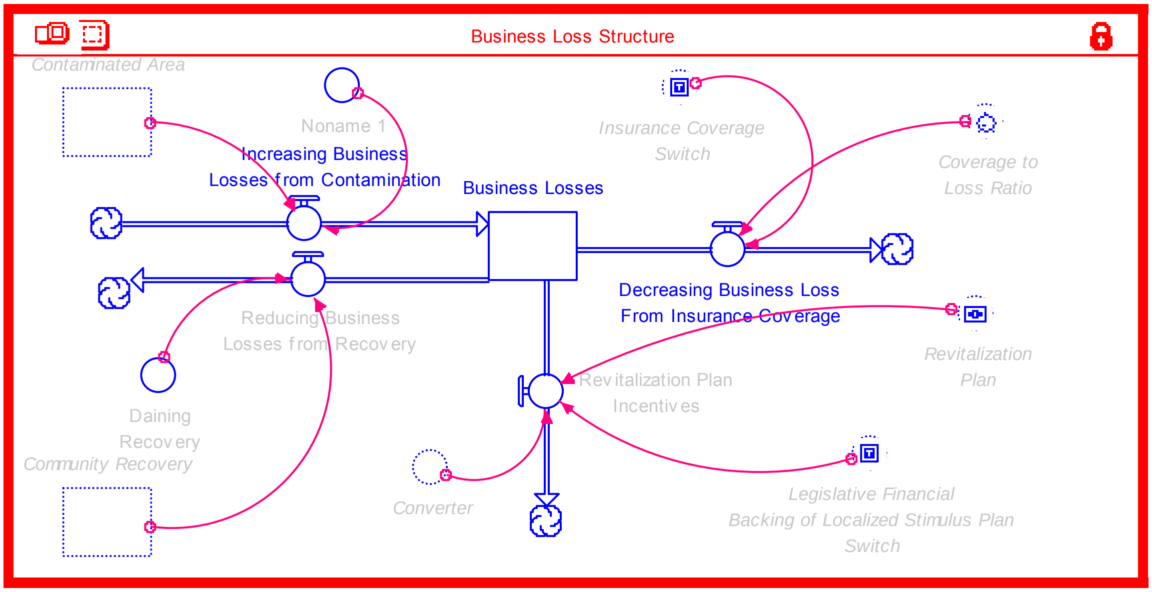
Similar to the FEMA response, in both disaster examples the legislative branch passed various appropriation bills to assist in the recovery efforts. However, it is important to note that both the effects of the September 11 attacks and major hurricanes are wide spread and directly impacted major financial sectors: Wall Street in New York City and the oil industry in the Gulf of Mexico specifically. The fear of widespread macro-economic impact from these attacks was a consideration in the level of legislative response (Congressional Research Service, 2002). Therefore, it is possible that if an RDD attack was carried out in an area lacking a significant economic sector node, the federal legislative response may be far less or non-existent and the state is allowed and expected to handle the economic recovery. Consequently, the ability for a revitalization plan from Congress to offset the individual losses is also modeled with an on/off switch so that users can explore the system behavior with and without a fiscal stimulus plan.

**Figure 31: Individual Loss Structure with Influences from Psychological Impact Structure and Federal Response Structure**



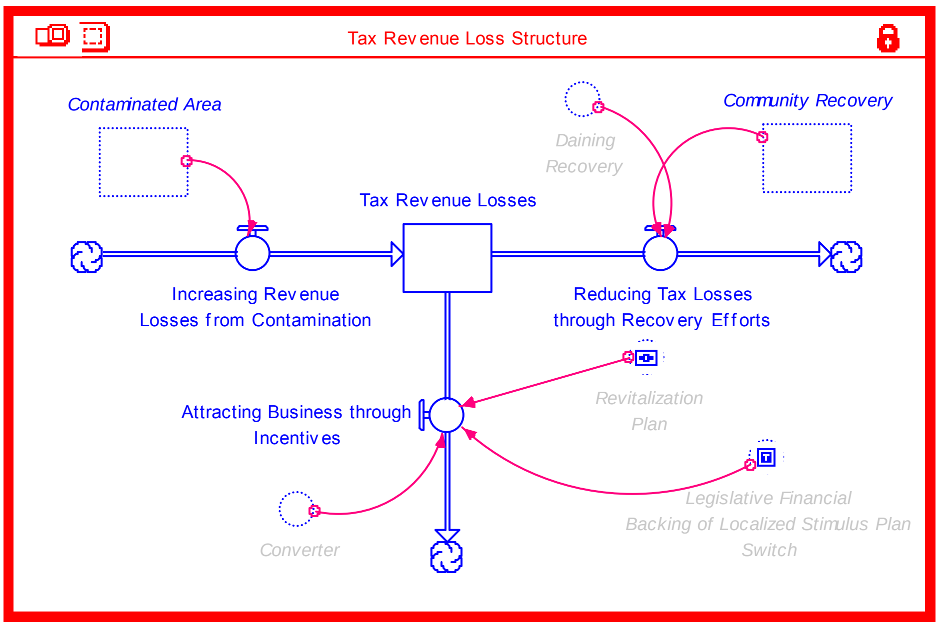

Similar to the individual loss structure, the business loss stock, Figure 32, is also negatively influenced by insurance coverage, community recovery efforts, and legislative revitalization plans.  However, an additional drain on business losses over time comes from the Small Business Administration.  This assistance is primarily in the form of low or no interest loans to impacted businesses (United States Small Business Administration, 2008).  While the expectation from the literature is that the SBA will provide some form of relief to businesses, significant federal spending must be authorized by the legislative branch.  Consequently, as a potential recovery effort that is dependent on legislative support, this drain is also modeled with an on/off switch found on the user navigation panel.

**Figure 32: Business Loss Structure with Influences from Psychological Impact Structure and Federal Response Structure**




The last variable expected to have increased losses over time is tax revenue.  Since the focus of this research is the localized losses surrounding the attack, the taxes of interest sales and property taxes.  This excludes federal income taxes for businesses and individuals since an RDD attack is not likely to create a macro-economic ripple due to the significantly smaller impact compared to the September 11 attacks (Congressional Research Service, 2002). With businesses closed, a direct positive influence is created by lost sales revenue.  This model captures this inflow of losses as a function of the contaminated area, see Figure 33.  Within the literature two primary outflows were found that would create a negative influence on tax revenue losses.  The attack is likely to make the local area less attractive for businesses as was the case for lower Manhattan following the September 11 attacks (Government Accountability Office, 2005).  The revitalization plans implemented by Congress following 9/11 sought to stimulate growth in the Manhattan economy through various means.  While the estimated tax losses for New York City were never directly refunded by federal legislative action, the effect of stimulating economic growth created a negative influence on the overall tax revenue loss. Similar to the drain created on business losses by the revitalization plan, this outflow is also modeled with an on/off switch to enable the exploration of system behavior with or without the presence of a stimulus package.

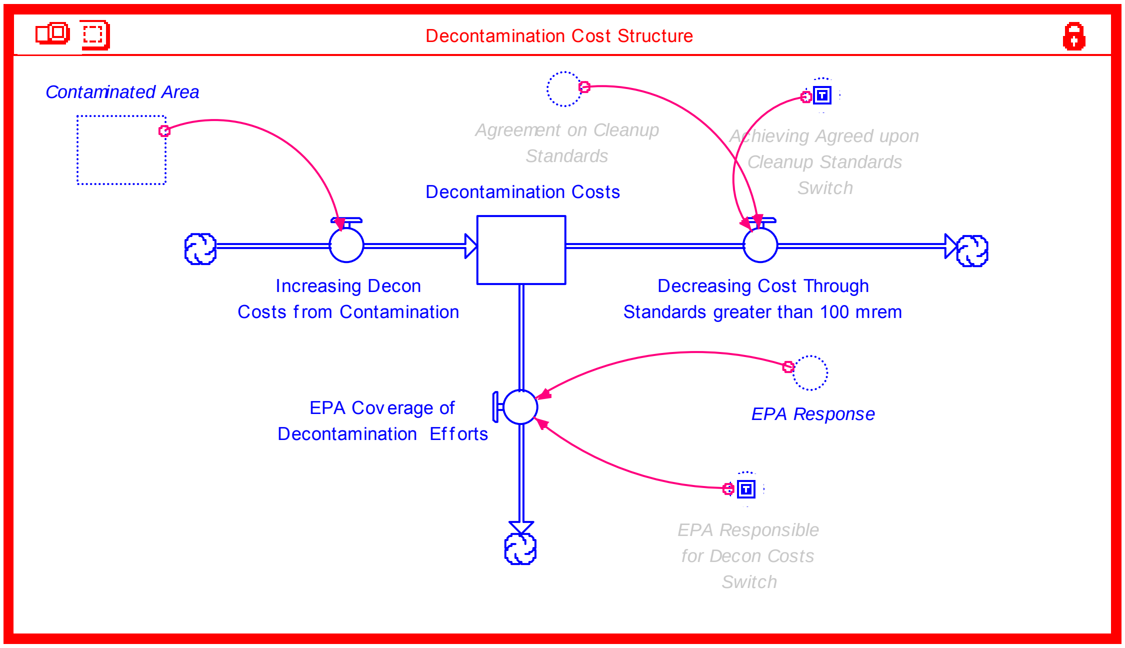
**Figure 33: Tax Revenue Loss Structure with Influences from Psychological Impact Structure and Federal Response Structure**




With the creation of a contaminated area come associated sunk costs from decontamination, emergency response, reconstruction, and morbidity. Currently, the Environmental Protection Agency is responsible for the cleanup efforts involving radiological material (Department of Homeland Security, 2008). Since a radiological terrorist attack has never occurred within the United States, it is unknown if the EPA would cover these costs or if decontamination costs would be paid for through other means. Consequently, this drain on decontamination costs is modeled with a switch to test the possibility of not paying for the decontamination costs. An important consideration addressed in the most recent EPA Protective Action Guide for RDD incidents is the amount of acceptable radiation to the community. This threshold establishes the cleanup standard that the decontamination costs will be dependent upon. To establish this decontamination standard, the involvement of stakeholders in the community is required (Department of Homeland Security, 2008). Through information exchange between stakeholders and government agencies, such as proposed by Craig Conklin in Figure 34, the cleanup standards can be established (Conklin, 2005). Due to the desired expediency of recovery, it is likely that decontamination standards will be agreed upon that is higher than the 14 mrem/yr standard (Smith, 2008). Consequently, as the cleanup standard relaxes, the decontamination costs will decrease. The drain on decontamination costs from a more lax cleanup standard is at risk since the local community stakeholders may not agree to lower the standards. This possibility is modeled as an on/off switch within the decontamination cost structure.

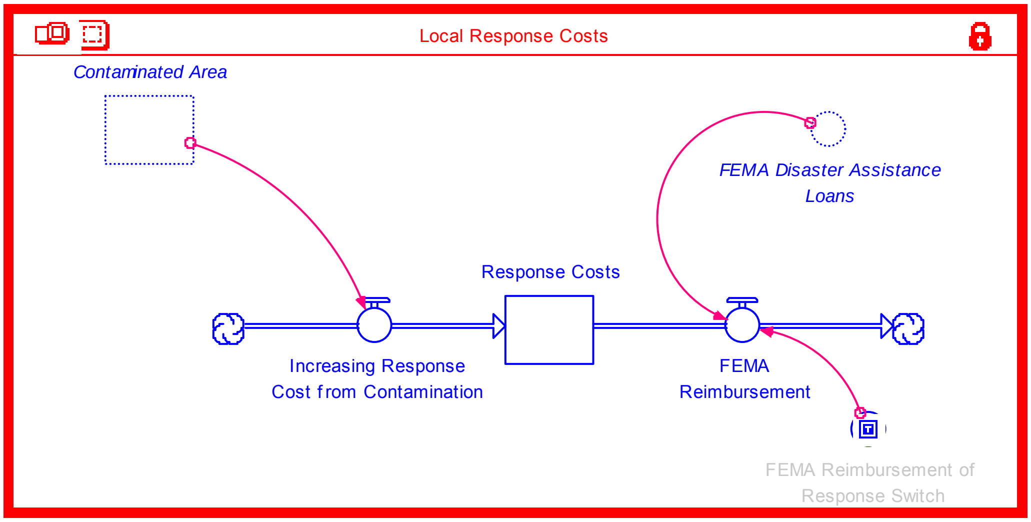
**Figure 34: Proposed RDD/IND Cleanup Process (after Conklin, 2005)**

**Figure 35: Decontamination Cost Structure with Influences from Federal Response Structure**



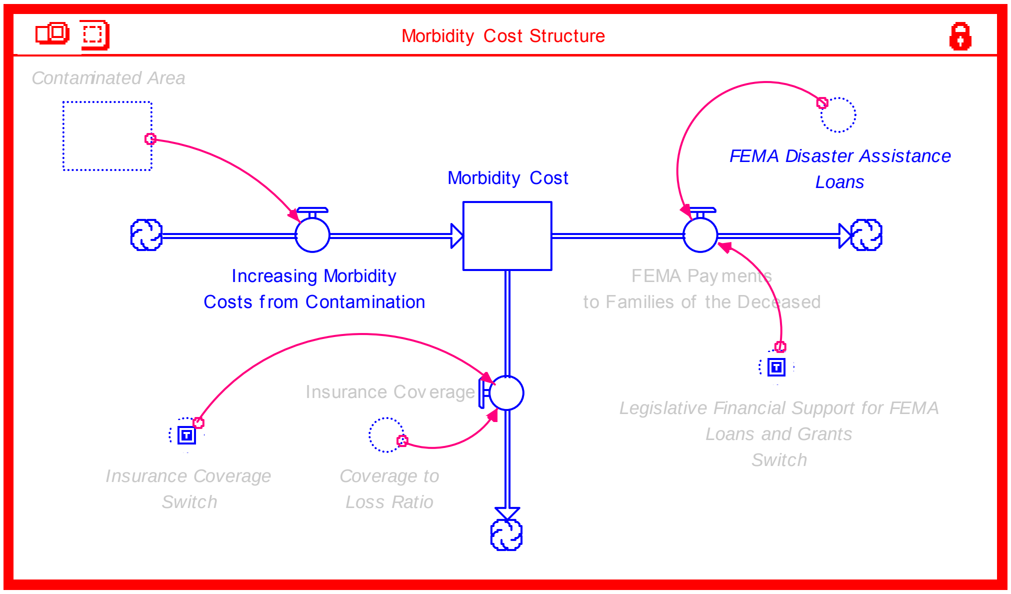

Following the September 11 attacks, New York suffered significant response costs. Many, if not all, of the associated costs were aggregated by the New York City Management and Budget Office and submitted to the Federal Government for reimbursement (Government Accountability Office, 2005). Similarly, following Hurricane Katrina, FEMA reimbursed municipalities for many types of response costs. In both instances, legislative fiscal support offset local response costs which create the only drain on the response cost variable.

**Figure 36: Response Cost Structure with Influences from Federal Response Structure**




The final cost associated with an RDD attack is the cost of morbidity. Should life insurance companies cover claims from impacted policy holders, this cost is expected to be eliminated. However, following the September 11 attacks, some insurance companies denied coverage and the federal legislature stepped in to offset these costs through FEMA disaster assistance (Congressional Research Service, 2002).

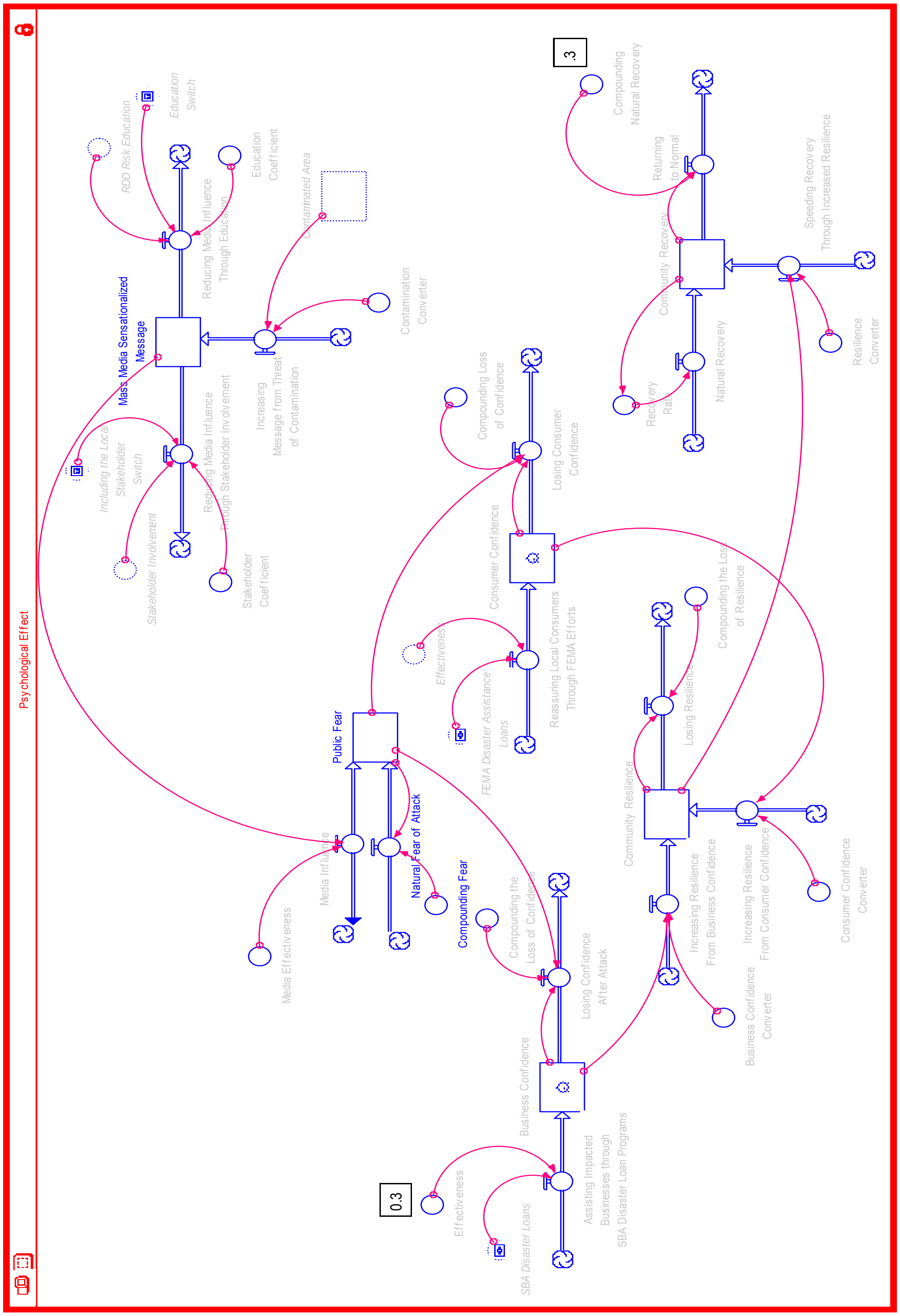
**Figure 37: Morbidity Cost Structure with Influences from Federal Response Structure**




The final influences within the complete model are the effects of the federal response variables on the psychological impact variables, see Figure 38. One of the most important influences within the model is the negative influence the radiological risk education can have on the sensationalized coverage of the attack. In the literature, references to this influence were mentioned as a lesson learned from both the Three Mile Island incident and the Goiania, Brazil incident where misinformation and uneducated analysis by the media fed public fear. Additionally, within the Three Mile Island example, stakeholders such as Pennsylvania Lieutenant Governor William Scranton III was cited as also having a negative influence on the sensationalized coverage by both the local and national news media (Congressional Research Service, 1999). Due to this influence, the policy variable, stakeholder involvement, within the federal response structure is also modeled as a drain on the mass media sensationalized message. This would be a logical expectation of the behavior created stakeholder involvement and can be seen in more common incidents where news conferences and press releases reset the facts presented by the news media.

The last two influences from the federal response variables are the positive influences of FEMA disaster assistance and SBA loans on consumer and business confidence respectively. This relationship infers that the financial assistance from the Federal Government will have a positive influence on the confidence of impacted consumers and businesses that the local economy will recover.

**Figure 38: Psychological Impact Structure Influenced by Federal Response Variables**



**Testing**

The dynamic modeling process is incremental and iterative (Shelley, 2008). As each stage of the model is created, testing occurs to identify flaws or sensitivities within the model. At the completion of the original complete model, the researcher performed thirty two iterations of refinement to create the final model presented above. The three most useful analysis tools for this research effort were the sensitivity analysis, behavior anomaly, and extreme conditions tests.

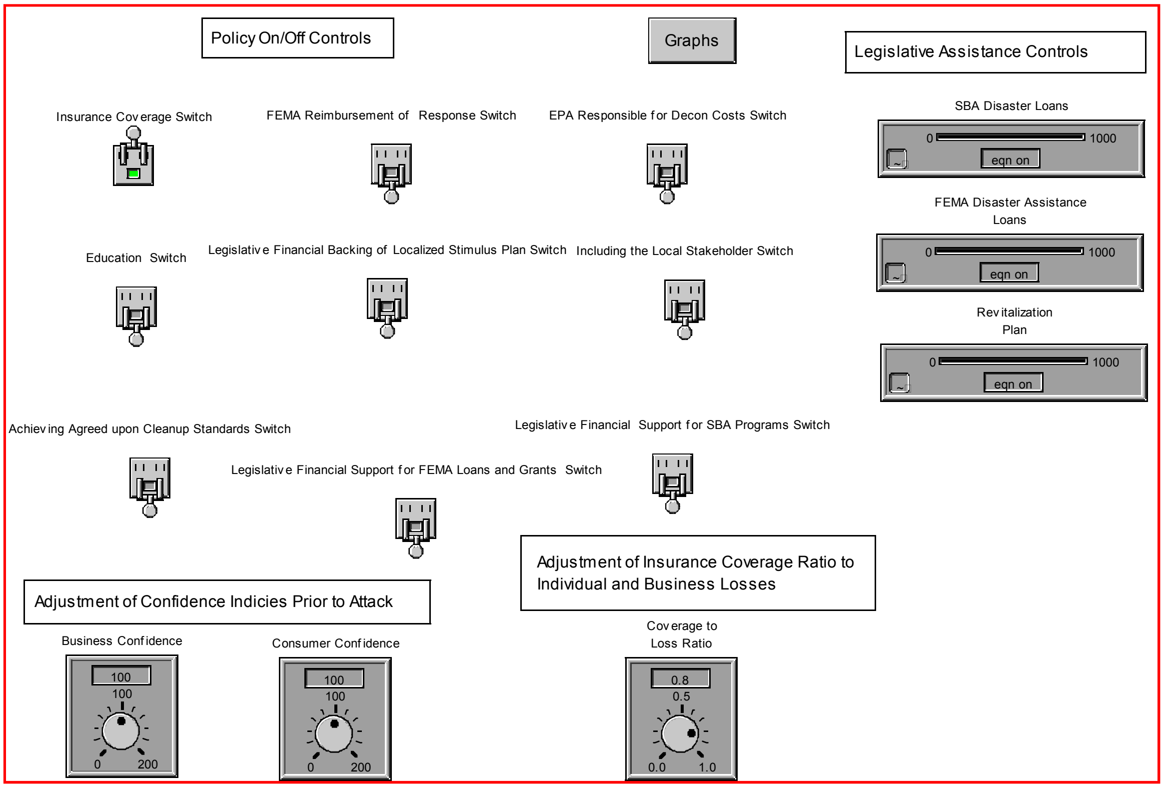
Incremental sensitivity analysis tests were conducted for each sub-structure of the system. While the federal response and physical impact structures presented no significant sensitivities to changes in policy or numeric inputs, the psychological impact structure required the majority of refinements to the compounding nature of stocks feeding stocks. This problem persisted within the final model when all influences between structures were created and a few behavior anomalies were unexpectedly produced. Through trial and error, the anomalies were corrected through modifications of the conversion coefficients or embedded logic within the stock structures. An example of modification within the stock structures is the change of the media sensationalized message from a stock than cannot present a negative value to one that is allowed to drop below zero. In the initial model, this stock was not allowed to go below zero, and while the graphical outputs appeared acceptable for the psychological structure alone, once the influences from the other structures were added, there were illogical behavior patterns emerging within the psychological structure. After some assessment, the stock was allowed to go below zero meaning that the influences from RDD risk education and stakeholder involvement could eliminate the media's sensationalized coverage of the attack creating informative reporting in the associated media outlets.

## Policy Result Analysis

### *User Interface*

As noted in the literature review, there are several policy tools available to the federal government to counter act the negative local economic impacts of a radiological terrorist attack. Due to the expected small deposition and blast area from an RDD explosion in relation to the only recent example of a terrorist attack, September 11, 2001 the federal government may not respond in the same manner. Therefore, the model presented in this research allows the user to test the effects of each potential policy independently. To assist in policy testing, the user interface, Figure 39, was created allowing the researcher to turn various policy implementations on and off as well as adjusting the model for existing economic conditions prior to the attack, such as the status of business and consumer confidence indices.

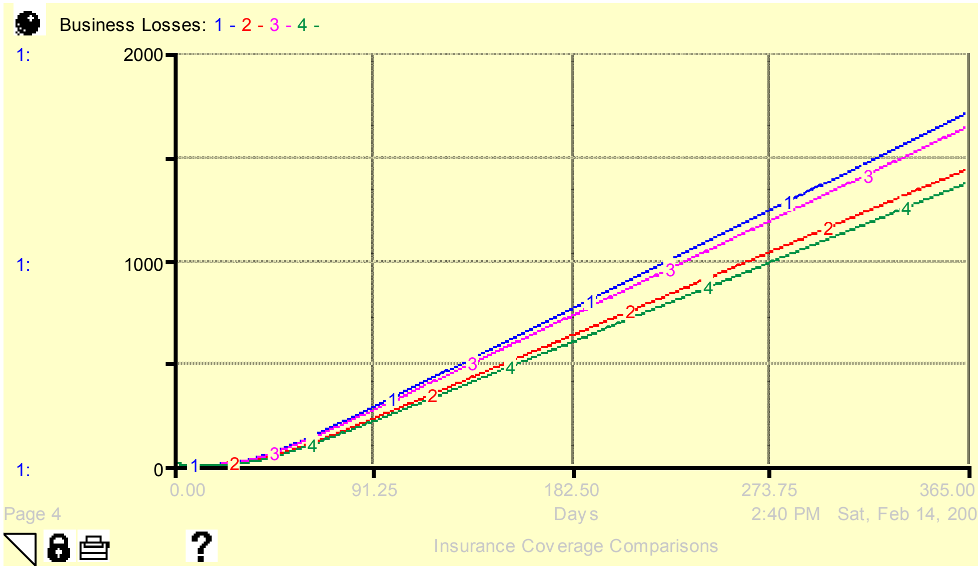
**Figure 39: User Interface**




*Insurance Coverage*

Following an attack, significant individual and business losses will occur if the insurance industry refuses coverage. Without insurance coverage the expected behavior would yield final fiscal figures much higher (curve 1) than if coverage is applied (curve 2) in Figure 40. An assumption of the model is that even with insurance coverage, the settlement would only cover 80% of the total losses due to uninsured items, expenses, or lost income for either individual or business losses. Consequently, the user interface is provided with an adjustment tool to change the expected ratio of coverage to total loss for each variable. Adjusting the coverage ratio produces different losses over time as in Figure 40 where curve 3 represents only 20% coverage of all business losses and graph 4 represents 100% of all losses.

**Figure 40: Comparison Results of Insurance Coverage**




It is important to note that the results in Figure 40 represent only the implementation of insurance coverage with no federal response policies enacted to influence the system. It is expected that insurance coverage would not be able to offset all fiscal impacts from the attacks, primarily lost revenue, if there is no recovery of the system allowing the impacted businesses to reopen.

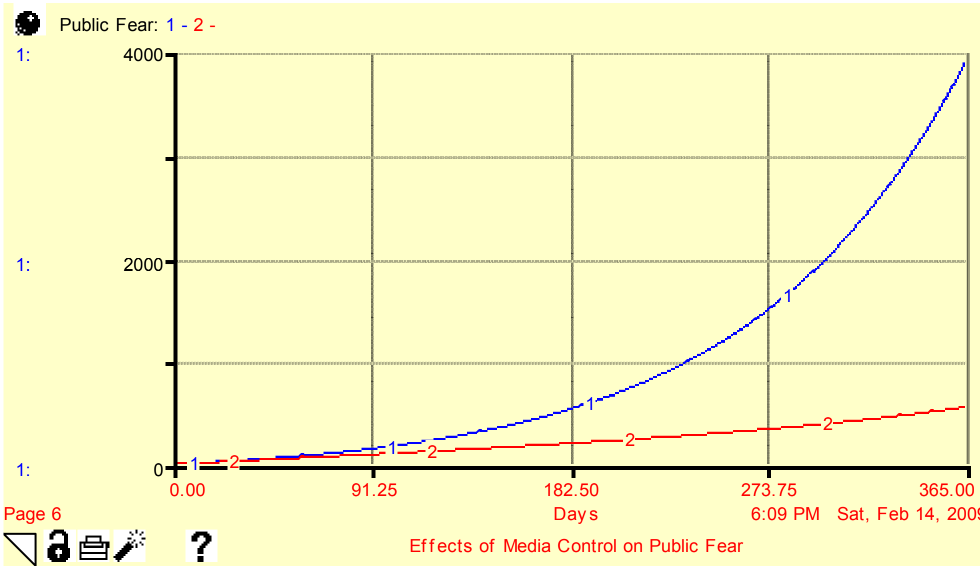
*Executive Response Policy Analysis*

In the event of a terrorist attack it is unlikely that the executive branch agencies would not respond. What are of interest to the model are the recommendations from the EPA guidance for response to RDD incidents and lessons learned from the Three Mile Island incident that might impact the economic recovery of the local area. In the absence of fiscal offsets provided by legislative action, the implementation of stakeholder involvement and controlling the mass media's sensationalized coverage of the attack will assist in the control of the psychological system.

Guidance from the new EPA Protective Action Guide for response to RDD and IND incidents notes that, "the Federal Government is a primary funding agent for site cleanup… [and] assumes an incident of relatively large size." However, for smaller incidents this guidance may not be warranted as the recovery efforts may be left to the State for action (Department of Homeland Security, 2008). In the analysis that follows, it is assumed that the EPA will cover the cost of decontamination through Superfund or other means. However, the model interface includes the ability to turn off that assumption implying that the decontamination costs would be expensed through other means.

The first recommendation of interest is the inclusion of local and state stakeholders such as Mayors, Governors, and the State EPA. By including such influential people or agencies, some control over the expected misinformed and sensationalized media coverage can be created. The negative influence of this control measure does reduce the total economic impact; however, the reduction is miniscule within the first year of study. This is due to the built-in delays in the model structure as expected by the researcher. Until the sensationalized message can be overcome for a long enough period of time to eliminate public fear, the existence of fear will only continue to negatively influence recovery. As in Figure 41, the inclusion of stakeholder involvement assists in bringing public fear under control, curve 2, and creates significant reductions from the uninfluenced behavior in curve 1.

**Figure 41: Effects of Stakeholder Inclusion on Public Fear**




The second recommendation taken from lessons learned after the Three Mile Island and Goiania, Brazil incidents is the effects of radiological risk education on the public's fear. In both examples there was a lack of public knowledge concerning general radiation risks compounded by ineffective communication of the actual risks involved in the responses. If radiation risk education was immediately implemented in the mass media by responding federal agencies along with stakeholder involvement, the public fear can be brought under control relatively quickly and the desired outcome can be seen as a significant reduction of the total economic impact within the first year. Curve three of public fear under both influences becomes zero, or no fear, at 130 days in Figure 42. The difference in total economic impact can be seen in Figure 43 where curves one and two represent no media control and stakeholder involvement, respectively, and curve three represents the inclusion of radiological risk education.

Figure 42: Influence of Education and Stakeholder Involvement on Public Fear

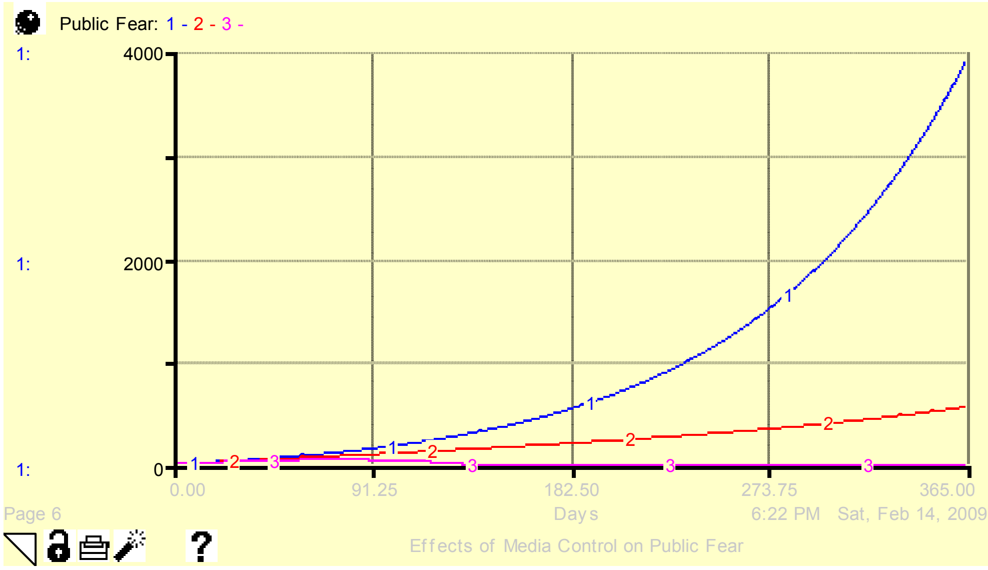
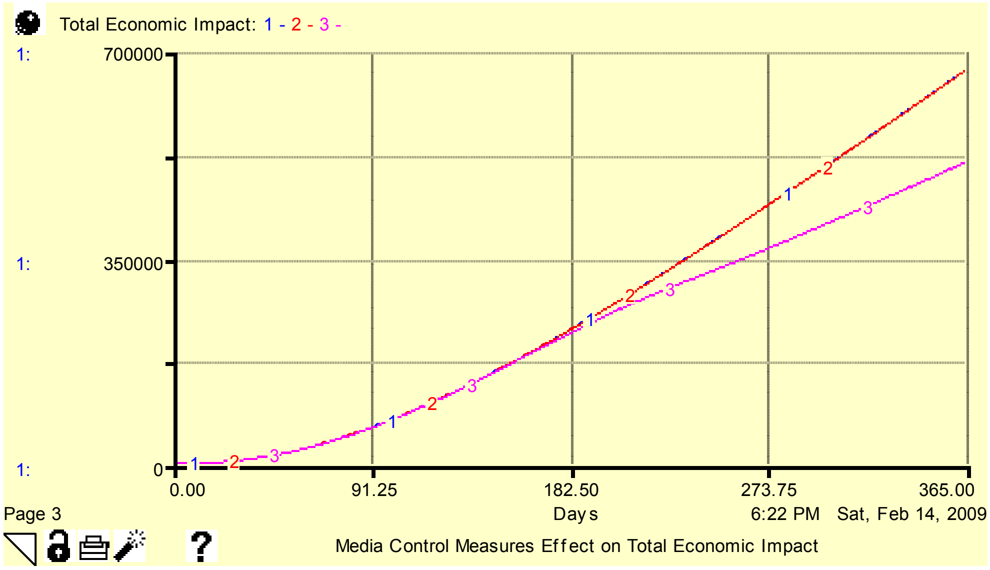



Figure 43: Influence of Education and Stakeholder Involvement on Total Economic Impact



*Legislative Response Policy Analysis*

As identified in the literature, the three primary tools used by the federal government that may be used to assist a community recover from an RDD attack are FEMA disaster assistance funds, SBA disaster assistance loans, and a specific stimulus package passed for revitalization of the local economy. It is important to note that while FEMA and the SBA reside in the executive branch, the emergency funding was provided by the legislative branch in the examples highlighted in chapter two. It is for this reason that these three policies are listed under the legislative response.

The following analysis is strictly of the legislative response influences on the system and do not include the executive response influences. These two will be combined in the final section of analysis. Of the three policy options, the first to be implemented will likely be the FEMA disaster assistance funding. In Figure 44, curve one represents the uninfluenced system response of the total economic impact. Curve two represents the expected impact of FEMA disaster assistance funds on the total economic impact. While the FEMA efforts do diminish the total economic impact, alone these efforts are not enough to push the community's economic recovery out of uninfluenced system behavior pattern (see Figure 45). This is primarily due to FEMA's assistance focus on individuals and their families without much response to the primary economic driver, business or the psychological impacts of the public fear of radiation. In order to influence the psychological impact structure, more assistance will be required.

The addition of the SBA disaster assistance loans is the next policy likely to be implemented by the federal government. Unlike the FEMA response, the SBA is focused on assisting businesses with their financial needs required to recover from the attack.

**Figure 44: FEMA Disaster Assistance Influence on Total Economic Impact**

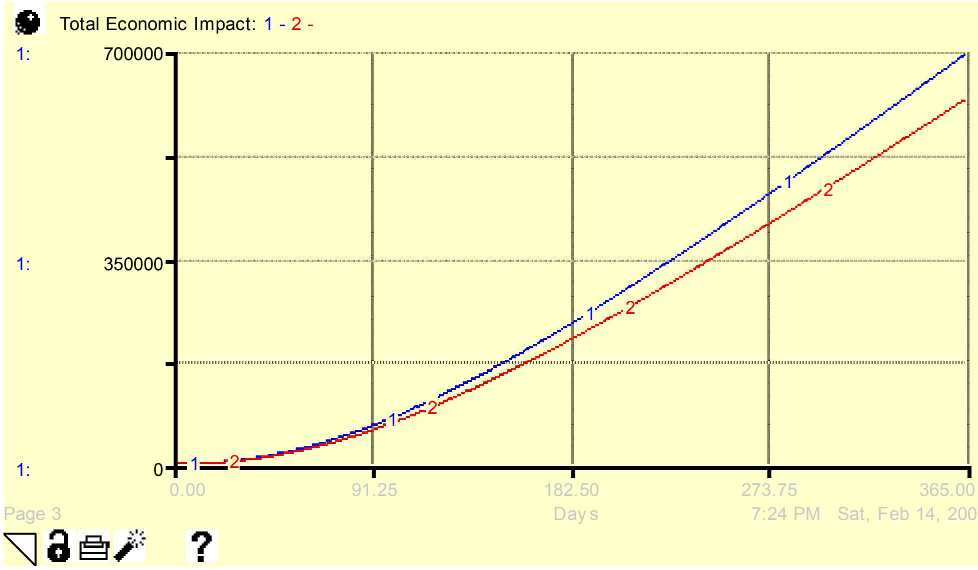
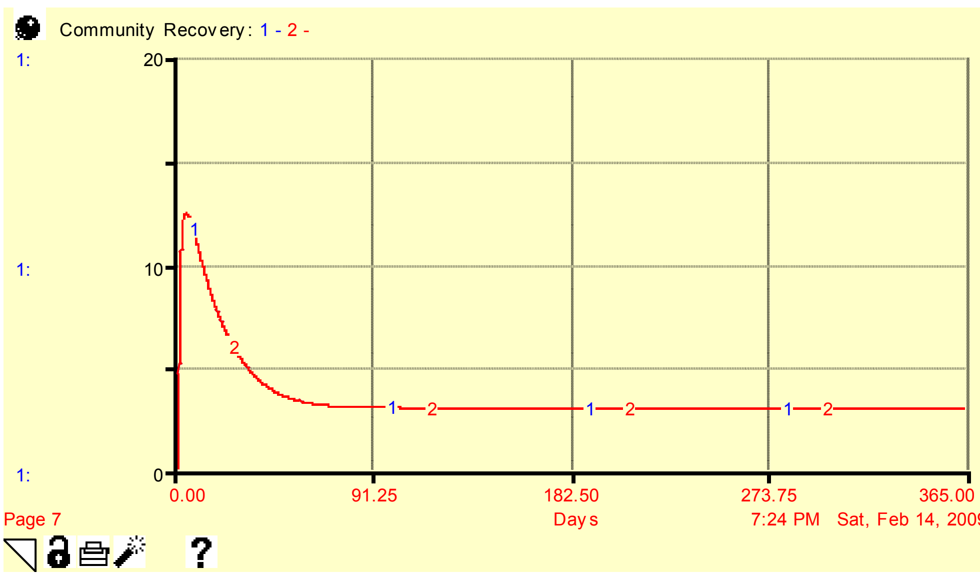



**Figure 45: FEMA Disaster Assistance Influence on Community Recovery**




While the SBA assistance and FEMA assistance do positively influence business and consumer confidence, neither addresses the public fear of radiation. Without controlling this fear, it is unlikely that the economy would recover within the first year due to the unwillingness of consumers to return to the area fearing radiation exposure. In Figure 46, the behavior of the system from both policy implementations remains the same.  Even with the addition of a federal stimulus package, the community recovery will remain unchanged until the public fear of radiation is addressed.  This illustrates that while the total economic impact to the local community may be decreased significantly by the legislative branch throwing money at the problem (curve 3 in Figure 47) the eventual collapse of the local economy remains a significant possibility.

**Figure 46: FEMA and SBA Disaster Assistance Influence on Community Recovery**

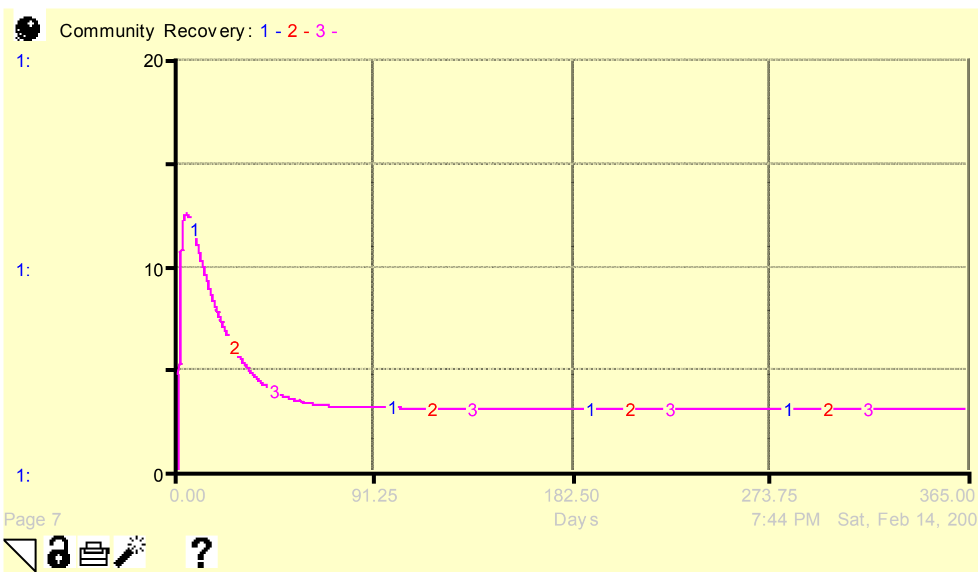
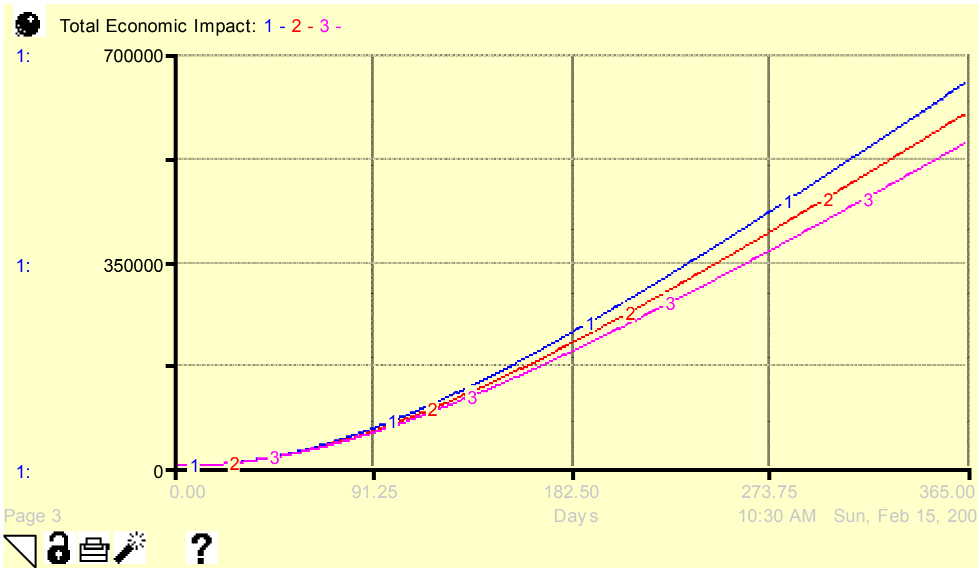


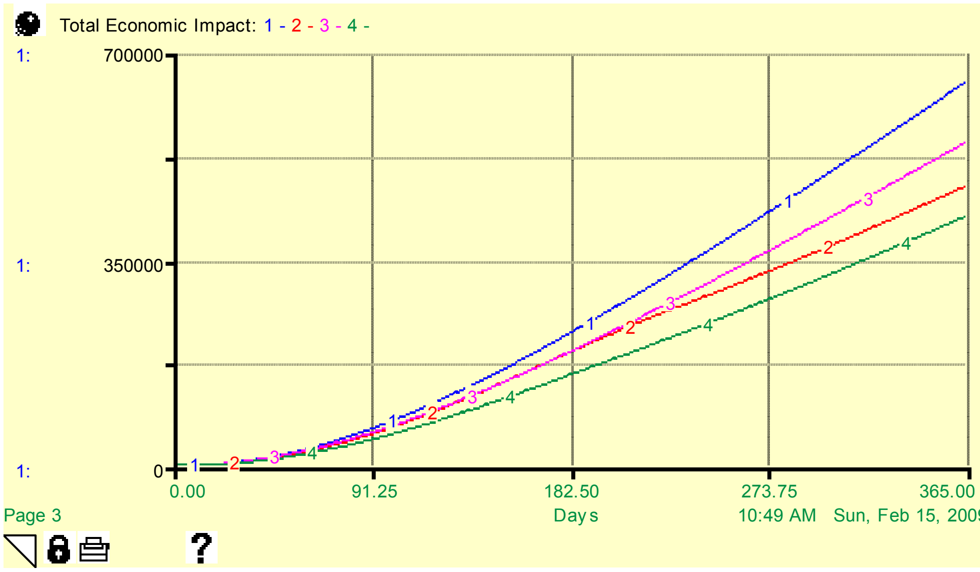
**Figure 47: The Influence of all Legislative Responses on Community Recovery**




*Analysis of combining all Federal Response Tools*

If all the federal response policies were enacted, there will be a significant negative influence in the total economic impact to the community that was attacked. In Figure 49, several significant insights into the system are gained. Curve one represents the baseline of total fiscal costs from the attack without any influences from the federal government. Curve two represents the independent impact of the executive branch policy implementation on total fiscal cost, and curve three represents the independent impact of the legislative actions. It is important to note that the control of the public fear by the stakeholders and radiological risk education from the onset of the response generates more reductions in total economic impact than combined effects of the legislative response within the year following the attack. Combined, in curve four, all policy actions significantly reduce the economic impact to the local community.

**Figure 49: The Influence of all Federal Responses on Total Economic Impact**




Once the early phase of the response concludes and the local stakeholders begin to organize recovery efforts, a likely concern will be for the restoration of tax revenue from the area impacted by the attacks. Tax revenue losses have also been a common focus found in the literature concerning the September 11, 2001 attacks. Figure 49 demonstrates the effects of the federal response policies on tax revenue losses. Curves one and three, doing nothing and legislative support only respectively, represent a continuation of tax losses over time. The system does not return to full recovery, 235 days after the attack, until the executive policies have all been implemented. The cumulative effect of both the executive and legislative policy options accelerates recovery of the tax revenue system from 235 days to 195 days, as seen in curve four, by simultaneously addressing public fear, business recovery needs, consumer recovery needs, and economic stimulation.

**Figure 49: The Influence of all Legislative Responses on Tax Revenue Losses**

## V. Conclusion

The results of chapter IV present several interesting insights into the problematic behavior of the system. The most notable result of the research is the importance of controlling public fear of radiation. Public perception of the radiological risk following the Three Mile Island incident was so negative that it arguably threatened the future of the nuclear power industry. In the event of a radiological terrorist attack, it is likely that such behaviors will resurface unless all responding entities collectively address these concerns across all forms of media from the onset of the attack through the final cleanup stages. Community recovery will hinge on the public perceptions of risk and the influence of those perceptions on community attractiveness to businesses as well as the willingness of consumers to enter the area. No matter what level of fiscal response the Federal Government applies to the recovery efforts, unless public perceptions and business incentives are addressed, the full economic recovery of the community will likely be difficult to achieve.

The model also illustrates the importance of accelerated reduction in the suspected contaminated area. Based on the results, if there is a rapid decline in the size of the suspected contaminated area, the system will more rapidly recover. While this may appear logical, responding agencies may not be concerned with the rapid reduction in the size of the cordon area for fear of public harm. However, the model illustrates the important positive influence this action will create on the community's recovery as well as the final summation of fiscal impact. An additional consideration for accelerating the reduction of the contaminated area is the established cleanup standard. Using the NRC standard for radiological site restoration of 14 mrem per year will significantly slow the recovery of the community. Such standards have established regulated site decommissioning timelines that are measured in years. If applied to radiological terrorism, this standard will likely lead to economic collapse of the local economy. Taking this possibility into consideration, it is recommended that responding agencies and local stakeholders quickly establish acceptable levels of decontamination.

This research project has proved valuable in several manners. It has served to highlight the need for dynamic modeling of complex systems that include such immeasurable, yet critical variables such as public fear. It has also illustrated the importance of communication with the community and stakeholders to the overall recovery of the economic system. Lastly, it presents an opportunity for further study in a relatively void niche of disaster response to radiological terrorism.

## VI. Recommendations for Further Research

The research model presented is does not address actual fiscal losses calculated from economic analysis programs such as IMPLAN©. It is the researcher's position that estimation of the final dollar figure with such programs is irrelevant and the more important question to be answered is how the final dollar figure can be reduced. While the model does not produce an output that is representative of actual fiscal losses, it has the ability to incorporate data from economic input-output analysis tools. For researchers that are interested in tying the two together, data from the U.S. Census Bureau and Federal, State, and Local Departments of Revenue show potential for creating this capability. Ideally, geospatial information systems could be created that incorporate financial data for each property in the United States. Elementary examples of such a system can be found on county tax assessor web sites where users are allowed to explore data on property taxes through a map interface. Such a system would allow stakeholders involved in any type of natural or man-made incident rapid assessment of economic impacts and therefore speed recovery decisions.

## Appendix A: Model Equations

Business Loss Structure
Business_Losses(t) = Business_Losses(t - dt) + (Increasing_Business__Losses_from_Contamination - Reducing_Business__Losses_from_Recovery - Revitalization_Plan__Incentives - Decreasing_Business_Loss_From_Insurance_Coverage) * dtINIT Business_Losses = 1
INFLOWS:
Increasing_Business__Losses_from_Contamination = Contaminated_Area
OUTFLOWS:
Reducing_Business__Losses_from_Recovery = Community_Recovery
Revitalization_Plan__Incentives = Revitalization__Plan * Legislative_Financial_Backing_of_Localized_Stimulus_Plan_Switch
Decreasing_Business_Loss_From_Insurance_Coverage = Coverage_to_Loss_Ratio * Insurance_Coverage_Switch

Decontamination_Costs(t) = Decontamination_Costs(t - dt) + (Increasing_Decon_Costs_from_Contamination - Decreasing_Cost_Through__Standards_greater_than_100_mrem - EPA_Coverage_of_Decontamination__Efforts) * dtINIT Decontamination_Costs = 1
INFLOWS:
Increasing_Decon_Costs_from_Contamination = Contaminated_Area
OUTFLOWS:
Decreasing_Cost_Through__Standards_greater_than_100_mrem = Agreement_on_Cleanup__Standards * Achieving_Agreed_upon_Cleanup_Standards_Switch
EPA_Coverage_of_Decontamination__Efforts = EPA_Responsible_for_Decon_Costs_Switch * EPA_Response

Contaminated_Area(t) = Contaminated_Area(t - dt) + (Increasing_Contamination - Reducing_Contamination - Reducing_Impacted_Area__Through_Recovery_Efforts) * dtINIT Contaminated_Area = 1
INFLOWS:
Increasing_Contamination = Size_of_Weapon
OUTFLOWS:
Reducing_Contamination = Contaminated_Area * Reduction_Conversion
Reducing_Impacted_Area__Through_Recovery_Efforts = Community_Recovery * Recovery__Conversion
Coverage_to_Loss_Ratio = .8
Insurance_Coverage_Switch = 1

Recovery__Conversion = .1
Reduction_Conversion = .9
Size_of_Weapon = 5

Executive_Response(t) = Executive_Response(t - dt) + (Increasing_Executive__Response - Other_Priorities) * dtINIT Executive_Response = 1
INFLOWS:
Increasing_Executive__Response = Public_Fear
OUTFLOWS:
Other_Priorities = Executive_Response * Response_Coefficient_3
Legislative_Response(t) = Legislative_Response(t - dt) + (Increasing_Legislative_Response - Competing_Priorities) * dtINIT Legislative_Response = 1
INFLOWS:
Increasing_Legislative_Response = Public_Fear
OUTFLOWS:
Competing_Priorities = Legislative_Response * Response_Coefficient
Achieving_Agreed_upon_Cleanup_Standards_Switch = 0
Agreement_on_Cleanup__Standards = Stakeholder_Involvement
Education__Switch = 0
EPA_Response = IF Executive_Response > 1 then 1 else 0
EPA_Responsible_for_Decon_Costs_Switch = 0
FEMA_Disaster_Assistance__Loans = IF Legislative_Response > 1 then 1 else 0
Including_the_Local_Stakeholder_Switch = 0
Legislative_Financial_Backing_of_Localized_Stimulus_Plan_Switch = 0
Legislative_Financial_Support_for_FEMA_Loans_and_Grants__Switch = 0
Legislative_Financial__Support_for_SBA_Programs_Switch = 0
RDD_Risk_Education = IF Executive_Response > 1 then 1 else 0
Response_Coefficient = .05
Response_Coefficient_3 = .3
Revitalization__Plan = IF Legislative_Response > 1 then 1 else 0
SBA_Disaster_Loans = IF Legislative_Response > 1 then 1 else 0
Stakeholder_Involvement = IF Executive_Response > 1 then 1 else 0

Individual_Losses(t) = Individual_Losses(t - dt) + (Increasing_Individual_Losses_from_Contamination - Decreasing_Individual_Losses_from_Insurance_Coverage - Decreasing_Losses_Through__Community_Recovery - FEMA_Disaster_Assistance - Tax_Rebates_from_Revitalization_Plan) * dtINIT Individual_Losses = 1
INFLOWS:

Increasing_Individual_Losses_from_Contamination = Contaminated_Area
OUTFLOWS:
Decreasing_Individual_Losses_from_Insurance_Coverage = Coverage_to_Loss_Ratio * Insurance_Coverage_Switch
Decreasing_Losses_Through__Community_Recovery = Community_Recovery
FEMA_Disaster_Assistance = FEMA_Disaster_Assistance__Loans * Legislative_Financial_Support_for_FEMA_Loans_and_Grants__Switch
Tax_Rebates_from_Revitalization_Plan = Revitalization__Plan *Legislative_Financial_Backing_of_Localized_Stimulus_Plan_Switch

Response_Costs(t) = Response_Costs(t - dt) + (Increasing_Response_Cost_from_Contamination - FEMA__Reimbursement) * dtINIT Response_Costs = 1
INFLOWS:
Increasing_Response_Cost_from_Contamination = Contaminated_Area
OUTFLOWS:
FEMA__Reimbursement = FEMA_Disaster_Assistance__Loans *FEMA_Reimbursement_of__Response_Switch
FEMA_Reimbursement_of__Response_Switch = 1

Morbidity_Cost(t) = Morbidity_Cost(t - dt) + (Increasing_Morbidity_Costs_from_Contamination - FEMA_Payments_to_Families_of_the_Deceased - Insurance_Coverage) * dtINIT Morbidity_Cost = 1
INFLOWS:
Increasing_Morbidity_Costs_from_Contamination = Contaminated_Area
OUTFLOWS:
FEMA_Payments_to_Families_of_the_Deceased = FEMA_Disaster_Assistance__Loans * Legislative_Financial_Support_for_FEMA_Loans_and_Grants__Switch
Insurance_Coverage = Coverage_to_Loss_Ratio * Insurance_Coverage_Switch

Business_Confidence(t) = Business_Confidence(t - dt) + (Assisting_Impacted_Businesses_through_SBA_Disaster_Loan_Programs - Losing_Confidence_After_Attack) * dtINIT Business_Confidence = 100
INFLOWS:
Assisting_Impacted_Businesses_through_SBA_Disaster_Loan_Programs = SBA_Disaster_Loans *Effectiveness
OUTFLOWS:
Losing_Confidence_After_Attack = Business_Confidence * Compounding_the_Loss_of_Confidence *Public_Fear

Community_Recovery(t) = Community_Recovery(t - dt) + (Natural_Recovery + Speeding_Recovery_Through_Increased_Resilience - Returning_to_Normal) * dtINIT Community_Recovery = 0
INFLOWS:
Natural_Recovery = Community_Recovery * Compounding_Natural_Recovery
Speeding_Recovery_Through_Increased_Resilience = Community_Resilience* Resilience__Converter
OUTFLOWS:
Returning_to_Normal = Recovery_Rate * Community_Recovery
Community_Resilience(t) = Community_Resilience(t - dt) + (Increasing_Resilience__From_Business_Confidence + Increasing_Resilience_From_Consumer_Confidence - Losing_Resilience) * dtINIT Community_Resilience = 100
INFLOWS:
Increasing_Resilience__From_Business_Confidence = Business_Confidence_Converter * Business_Confidence
Increasing_Resilience_From_Consumer_Confidence = Consumer_Confidence * Consumer_Confidence__Converter
OUTFLOWS:
Losing_Resilience = Community_Resilience * Compounding_the_Loss__of_Resilience
Consumer_Confidence(t) = Consumer_Confidence(t - dt) + (Reassuring_Local_Consumers_Through_FEMA_Efforts - Losing_Consumer_Confidence) * dtINIT Consumer_Confidence = 100
INFLOWS:
Reassuring_Local_Consumers_Through_FEMA_Efforts = Effectiveness * FEMA_Disaster_Assistance__Loans
OUTFLOWS:
Losing_Consumer_Confidence = Consumer_Confidence * Compounding_Loss__of_Confidence * Public_Fear
Mass_Media_Sensationalized_Message(t) = Mass_Media_Sensationalized_Message(t - dt) + (Increasing_Message_from_Threat_of_Contamination - Reducing_Media_Influence_Through_Education - Reducing_Media_Influence_Through_Stakeholder_Involvement) * dtINIT Mass_Media_Sensationalized_Message = 10
INFLOWS:
Increasing_Message_from_Threat_of_Contamination = Contaminated_Area * Contamination_Converter

OUTFLOWS:
Reducing_Media_Influence_Through_Education = RDD_Risk_Education * Education__Switch * Education_Coefficient
Reducing_Media_Influence_Through_Stakeholder_Involvement = Stakeholder_Involvement * Stakeholder_Coefficient *Including_the_Local_Stakeholder_Switch
Public_Fear(t) = Public_Fear(t - dt) + (Natural_Fear_of_Attack + Media_Influence) * dtINIT Public_Fear = .1
INFLOWS:
Natural_Fear_of_Attack = Compounding_Fear * Public_Fear
Media_Influence = Mass_Media_Sensationalized_Message * Media_Effectiveness
Business_Confidence_Converter = .1
Compounding_Fear = .01
Compounding_Loss__of_Confidence = .1
Compounding_Natural_Recovery = .3
Compounding_the_Loss_of_Confidence = .1
Compounding_the_Loss__of_Resilience = .1
Consumer_Confidence__Converter = .1
Contamination_Converter = .001
Education_Coefficient = .1
Effectiveness = .3
Media_Effectiveness = .1
Recovery_Rate = Community_Recovery * .1
Resilience__Converter = .1
Stakeholder_Coefficient = .1

Reconstruction_Costs(t) = Reconstruction_Costs(t - dt) + (Increasing_Reconstruction_Costs_from_Contamination - SBA_Assistance_Reducing_the_Recon_Costs) * dtINIT Reconstruction_Costs = 1
INFLOWS:
Increasing_Reconstruction_Costs_from_Contamination = Contaminated_Area

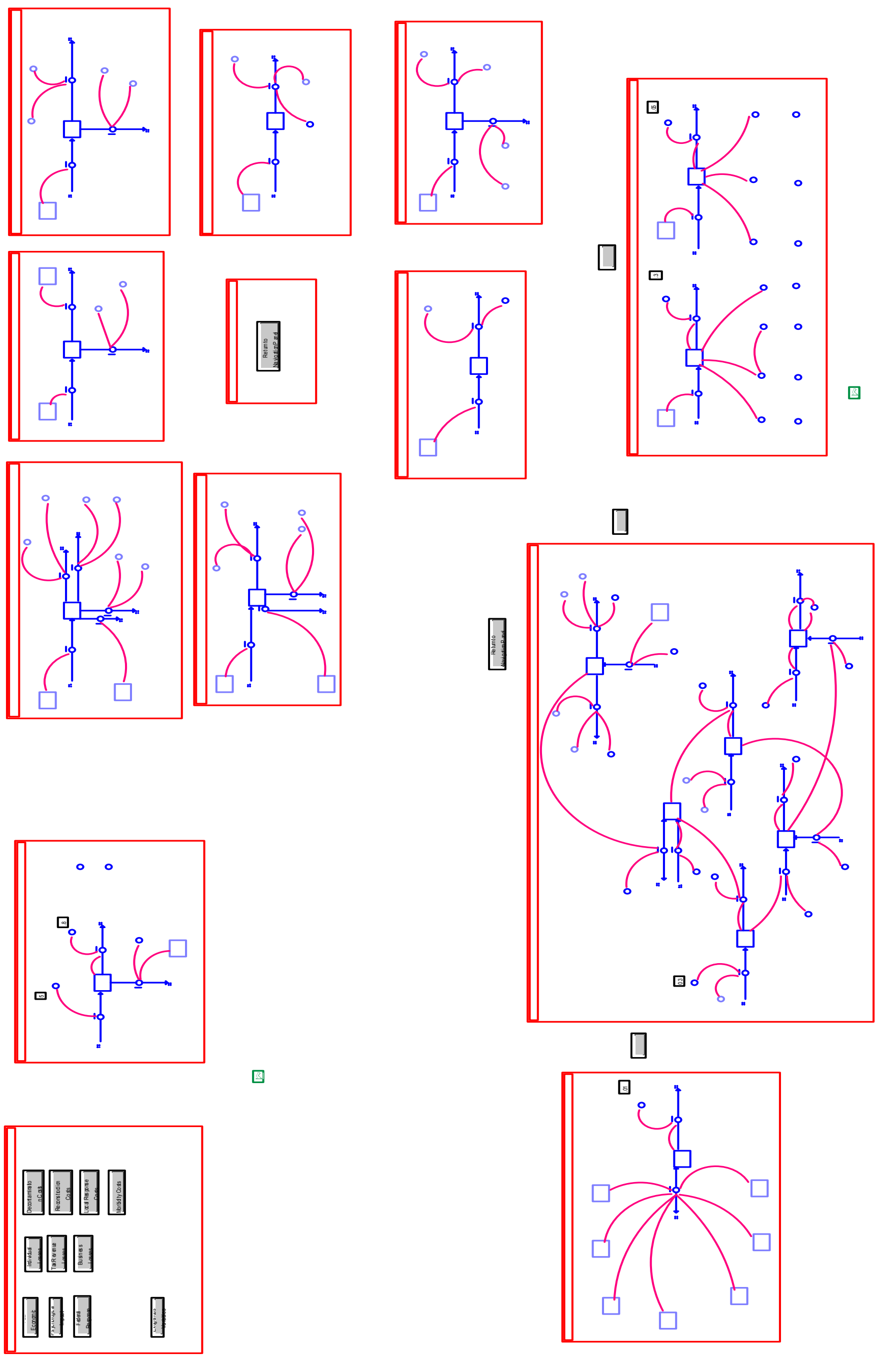
OUTFLOWS:
SBA_Assistance_Reducing_the_Recon_Costs = SBA_Disaster_Loans *Legislative_Financial__Support_for_SBA_Programs_Switch * Cost_Savings__Coefficient
Cost_Savings__Coefficient = .1

Tax_Revenue_Losses(t) = Tax_Revenue_Losses(t - dt) + (Increasing_Revenue_Losses_from_Contamination -

Reducing_Tax_Losses__through_Recovery_Efforts - Attracting_Business_through__Incentives) * dtINIT Tax_Revenue_Losses = 1
INFLOWS:
Increasing_Revenue_Losses_from_Contamination = Contaminated_Area
OUTFLOWS:
Reducing_Tax_Losses__through_Recovery_Efforts = Community_Recovery
Attracting_Business_through__Incentives = Revitalization__Plan * Legislative_Financial_Backing_of_Localized_Stimulus_Plan_Switch

Total_Economic_Impact(t) = Total_Economic_Impact(t - dt) + (Increasing__Cost - Eventual_Realization__of_All_Costs) * dtINIT Total_Economic_Impact = 1
INFLOWS:
Increasing__Cost = Business_Losses + Decontamination_Costs + Individual_Losses + Morbidity_Cost + Reconstruction_Costs + Response_Costs+ Tax_Revenue_Losses
OUTFLOWS:
Eventual_Realization__of_All_Costs = Coefficient_of__Realization * Total_Economic_Impact
Coefficient_of__Realization = .01

# Appendix II: Complete Model



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## Vita

Captain Christopher Ledford graduated from Louisiana Tech University in 2000 with a Bachelors of Science in Construction Engineering Technology. Following commissioning as a Second Lieutenant in the U.S. Air Force; Lt. Ledford commanded the 2nd Bomb Wing Disaster Response Force at Barksdale AFB, Louisiana. During this time, he led numerous responses to man-made and natural disasters, including the Space Shuttle Columbia disaster, as well as deploying in support of joint special operations forces to undisclosed locations in September 2001. In August of 2002, First Lieutenant Ledford temporarily left Barksdale to command the Joint Service Lightweight Nuclear, Biological, and Chemical Reconnaissance System (JSLNBCRS) testing team at Dugway Proving Grounds, Utah. In 2003, he departed Barksdale and reported to U.S. Naval Mobile Construction Battalion 74 at Construction Battalion Center Gulfport, Gulfport, MS. While there, he commanded Alpha Company and was promoted to the rank of Captain while on deployment. In 2005, Captain Ledford reported to Keesler AFB, Biloxi, Mississippi where he commanded the Housing Flight, Maintenance Engineering, and Engineering Elements. During this time, Captain Ledford also commanded the Disaster Control Center during Hurricanes Rita, Cindy, and Katrina. Following Hurricane Katrina, he orchestrated the $1.2B recovery effort of the base. In 2007, Captain Ledford transferred to the Graduate of Engineering Management Program at the Air Force Institute of Technology located on Wright Patterson AFB, Ohio.

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**14. ABSTRACT**

**The purpose of this research is to model the dynamic economic influences associated with an attack using a radiological dispersion device (RDD). Specifically, this thesis seeks to identify the variables associated with the total economic impact to the local community where the attack occurs and gain better insights into how local, state and federal entities can employ various policy decisions to bring the system under control within the first year of recovery. Of primary interest to the research is the problematic behavior of exponential economic impact and how the final accumulation of fiscal cost can be reduced. Using a system dynamics research method and the dynamic modeling software STELLA©, considerations such as controlling the media's influence on public fear, consumer confidence, community resilience, and community recovery are incorporated with fiscal impact stocks such as business losses, tax revenue losses, and response costs. Once combined, the model uses historical examples of responses and recommendations from the latest EPA guidance to examine the effect on the impacted community's recovery and total fiscal impact**

**15. SUBJECT TERMS**
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