FORMULATION OF A PARAMETRIC SYSTEMS DESIGN FRAMEWORK FOR DISASTER RESPONSE PLANNING

A Thesis
Presented to
The Academic Faculty

by

Stephanie Weiya Mma

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in the
School of Aerospace Engineering

Georgia Institute of Technology
December 2011

FORMULATION OF A PARAMETRIC SYSTEMS DESIGN FRAMEWORK FOR DISASTER RESPONSE PLANNING

Approved by:

Professor Dimitri N. Mavris,
Committee Chair
Dept. of Aerospace Engineering
Georgia Institute of Technology

Dr. Santiago Balestrini
Dept. of Aerospace Engineering
Georgia Institute of Technology

Mr. Charles Stancil
Georgia Tech Research Institute
Georgia Institute of Technology

Dr. Daniel Schrage
Dept. of Aerospace Engineering
Georgia Institute of Technology

Assistant Professor Brian German
Dept. of Aerospace Engineering
Georgia Institute of Technology

Date Approved: November 14, 2011

To Mom, Dad, and Phyllis,

and my dear friends,

whose support made this possible.

PREFACE

For this thesis, I spent a considerable amount of time reading and watching media coverage of Hurricane Katrina's damage in New Orleans, as well as several other disasters, some even as they were happening. It was always very difficult for me to see such destruction and suffering, particularly in situations where the response was inadequate. After all this reading, and with the experience of attending the Humanitarian Logistics Conference held at Georgia Tech for the first two years that it occurred, I began to see some areas where the knowledge I had gained in my time at the Aerospace Systems Design Laboratory was very applicable and could provide some of the capabilities which are not currently present in this field.

It was quite a step from boundary layers and takeoff gross weights. The seeming disconnect was always very apparent when any attempts were made to explain to anyone besides my advisor what I was doing and how it related to systems engineering. I often doubted that myself, and seeing little to no precedents in available literature and what I learned of the practice of planning for disaster response, it was uncertain in my mind whether this day would ever arrive.

There is no guarantee that anyone would ever adapt this method for their own purposes to aid in the planning of a community's restoration period after a disaster has occurred, but I wanted to take this step to see what would be possible. I have had the great blessing of living abundantly thus far, and I sincerely hope, without wishing any harm to anyone, if the future holds more tragedy, that there will be at least a time or two where I will have the chance to get my feet on the ground afterward and pass on the blessings that I have been given.

ACKNOWLEDGEMENTS

I would like to thank Dr. Dimitri Mavris for his wisdom throughout this unique program, and for the way he expects the best from his students. I am grateful to have had this opportunity to work on this research with his guidance and have learned immensely in my time at the ASDL over the past six and a half years.

I am also grateful for the professional experience and advising provided by Dr. Daniel Schrage, Mr. Chuck Stancil, Dr. Santiago Balestrini-Robinson, and Dr. Brian German, in their feedback and involvement in the Ph.D. process, and Ms. Leah Russell from GA-DOT for providing very insightful on-the-ground experience for me. I also thank the SMART Program staff, Edwin Bujan, the civil servants at Warner Robins Air Force Base, Mr. Jamie Cook, Ms. Maci Love, Mr. Russell Alford and others who have been so gracious to allow me to complete this degree. I am very grateful for their patience and the opportunity that I will have to complete the professional aspect of the program in the next few years.

In my time at Georgia Tech I have been blessed to know and room with Shannon Statham, Holly Longenecker, and Jenna Fu, who were all a big part of this time in my life. I am grateful for the helpful input I have received from my fellow students during my time at Georgia Tech, as well as the encouragement and life I received from dear friends in Atlanta and all over the world. Without your support and encouragement I would not have gotten this far.

My family, Mom, Dad, and Phyllis who gave unending support in the past several years - Thank you for walking with me through this time. I am also thankful for the grace of God and the journey that He has led me on over the past few years in Atlanta. It has been a crazy ride and I cannot wait to see what is next.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The occurrence of devastating natural disasters in the past several years have prompted communities, responding organizations, and governments to seek ways to improve disaster preparedness capabilities locally, regionally, nationally, and internationally. A holistic approach to design used in the aerospace and industrial engineering fields enables efficient allocation of resources through applied parametric changes within a particular design to improve performance metrics to selected standards. In this research, this methodology is applied to disaster preparedness, using a community's time to restoration after a disaster as the response metric.

A review of the responses from Hurricane Katrina and the 2010 Haiti earthquake, among other prominent disasters, provides observations leading to some current capability benchmarking. A need for holistic assessment and planning exists for communities but the current response planning infrastructure lacks a standardized framework and standardized assessment metrics .

Within the humanitarian logistics community, several different metrics exist, enabling quantification and measurement of a particular area's vulnerability. These metrics, combined with design and planning methodologies from related fields, such as engineering product design, military response planning, and business process redesign, provide insight and a framework from which to begin developing a methodology to enable holistic disaster response planning.

The developed methodology was applied to the communities of Shelby County, TN and pre-Hurricane-Katrina Orleans Parish, LA. Available literature and reliable media sources provide information about the different values of system parameters within the decomposition of the community aspects and also about relationships among the parameters.

The community was modeled as a system dynamics model and was tested in the implementation of two, five, and ten year improvement plans for Preparedness, Response, and

Development capabilities, and combinations of these capabilities. For Shelby County and for Orleans Parish, the Response improvement plan reduced restoration time the most. For the combined capabilities, Shelby County experienced the greatest reduction in restoration time with the implementation of Development and Response capability improvements, and for Orleans Parish it was the Preparedness and Response capability improvements.

Optimization of restoration time with community parameters was tested by using a Particle Swarm Optimization algorithm. Fifty different optimized restoration times were generated using the Particle Swarm Optimization algorithm and ranked using the Technique for Order Preference by Similarity to Ideal Solution. The optimization results indicate that the greatest reduction in restoration time for a community is achieved with a particular combination of different parameter values instead of the maximization of each parameter.

CHAPTER I

MOTIVATION

1.1 Disaster Occurrences in Recent Years

The statement that "the number of disasters in the world is increasing" may seem to be a subjective assumption, but in a world with a quickly increasing population and changing political, economic, and physical climates, the natural and man-made disasters have begun to affect more and more lives and livelihoods of people and environments due to the increasing overall population and population density of various areas in the world. [73](p75)

A compilation of the amount of natural disaster in the world from the Centre for Research on the Epidemiology of Disasters for the United Nations International Strategy for Disaster Reduction shows a significant increase in the number of disasters in the past thirty years compared to the past seventy years before that. As defined on the UN-IDSR website [159], a disaster is a " 'situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance [1]; an unforeseen and often sudden event that causes great damage, destruction and human suffering'." The disasters displayed in the compiled graph (Figure 1) fulfill the following criteria:

1. "10 or more people reported killed
2. 100 people reported affected
3. Declaration of a state of emergency
4. Call for international assistance"

"The number of people killed includes 'persons confirmed as dead and persons missing and presumed dead'; people affected are those 'requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation

[1]definition considered in the Emergency Events Database or EM-DAT

and immediate medical assistance (definition considered in EM-DAT)'. In the tables, people reported injured or homeless were aggregated with those reported affected to produce a 'total number of people affected'." [159]

1. Hydro-meteorological disasters: including floods and wave surges, storms, droughts and related disasters (extreme temperatures and forest/scrub fires), and landslides and avalanches;
2. Geophysical disasters: divided into earthquakes and tsunamis and volcanic eruptions;
3. Biological disasters: covering epidemics and insect infestations.

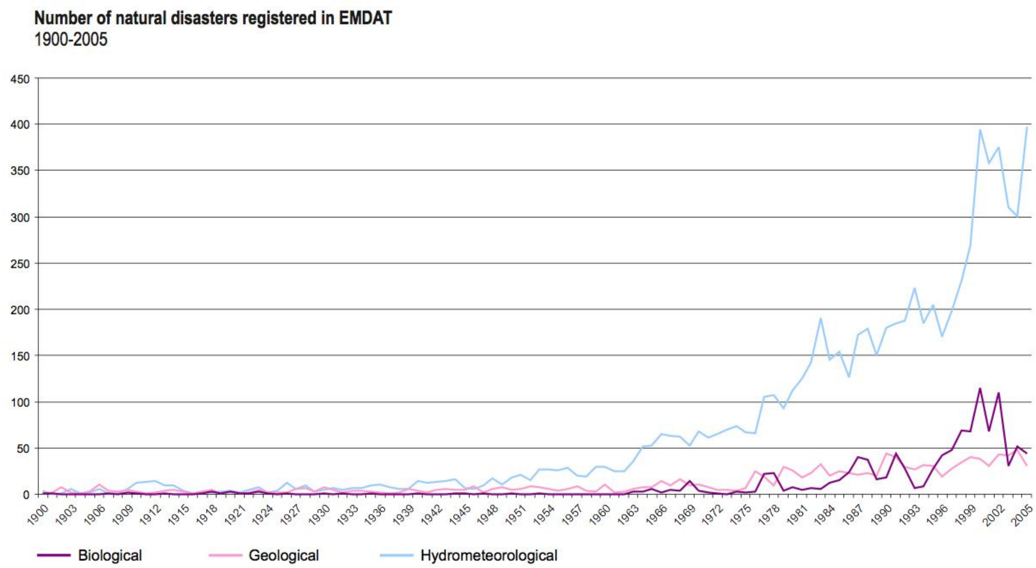


Figure 1: Registered Natural Disasters [159]

Crises such as famines were deemed as neither natural or technological, and therefore were not included in the data.

The number of severe natural disasters does not necessarily mean that occurrences of disastrous events themselves are more frequent. Some may argue that this is true and that global warming has something to do with it. However, since 1900, urban centers have been growing as well.

In urban centers, more people means a higher population density, many of whom are reliant on various infrastructural and socio-economical goods and services for survival needs (food, water, and shelter) as well as livelihood needs (transportation, utilities, communication, etc.).

When disasters occur and urban centers are affected, this means that as urban centers grow, more and more people will be affected whether it is the occurrence of natural or man made disasters. Because some urban centers benefit from well-thought-out urban growth plans, their citizen casualties and community resilience after disasters occur may differ compared to other urban centers, but the effects of disasters are never completely dissipated by the preparedness or sustainability of the urban center.

1.2 Observation of Specific Disaster Occurrences

Some specific events occurred which became the motivating factor for addressing disaster response planning. These events and the events of interest were suddenly occurring and overwhelmed the affected community's capability to respond and rebuild. The objective in observing some of the details of the event itself and the response is to develop an understanding of the disaster response planning process. As an understanding is developed, methods can be determined for assessing and addressing ways to improve response robustness as well as community restoration capabilities once a disaster has occurred.

1.2.1 Hurricane Katrina

The initial point of interest was the tragic occurrence of Hurricane Katrina and its consequent disaster response in 2005. The federal government was criticized for its poor handling of the response, and as a result conducted various studies assessing what went well and what went poorly in the response. The following section is a grouping of summaries from several chapters and appendices from "The Federal Response to Hurricane Katrina: Lessons Learned." [153] More detailed chronological descriptions of the pre-landfall, week of the hurricane, and post-landfall events as well as the federal recommendations for response improvements can be found in the referenced document. Hurricane Katrina and its response were some of the latest catalysts for the intense redesign of the United States disaster response structure, which is now called the National Response Framework.

The importance of efficient response structure redesign and any included planning is also emphasized in light of hurricanes occurring after Katrina, as following responses continued to reveal areas for response improvement. Various response system failures and inefficiencies were thrown into the spotlight because of the extensive media coverage. The areas needing change were addressed in various assessment documents by several different interest groups and non-profit organizations. After observing these recommended changes, particularly ones suggested by the federal committee assigned to deliver the Lessons Learned document, different levels of implementation were set into motion by federal authorities. This was because the document dealt mostly with changes at a federal level.

The steps of preparation before landfall up until implementation of the recommended changes are an example of the way disaster response planning was handled at the time of Hurricane Katrina. This response planning methodology included an initial general public opinion that the response system performance was inadequate. The tasked investigation committee drafted the Lessons Learned document, and other organizations also did their own assessments of the shortcomings of the response system. The document was the result of an extensive amount of data and information harvesting. The information came from news media, weather and meteorological services, local law enforcement reports, social services organizations and agencies, and other sources including personal interviews, etc.

Through the assessment done by the organizations, common shortcomings began to surface, and the main issues that needed addressing were consistently discussed in commissioned reports from different research groups. These shortfall listings and discussions were accompanied by recommendations for improving the response system to higher performance the next time that any similar events were to occur. How did this method play out exactly in the aftermath of Hurricane Katrina? This discussion will provide a good picture of the status-quo for disaster response planning before the hefty restructuring of the Federal Emergency Management Agency (FEMA) following Hurricane Katrina response.

Throughout the response periods the government struggled with the logistics aspect of aiding the victims and providing responders with adequate resources. "Lessons Learned" notes that the"highly bureaucratic supply processes of the Federal government were not sufficiently flexible and efficient, and failed to leverage the private sector and twenty-first century advances in supply chain management." [153](p56) The failed communications and logistics response also affected victim search and rescue, which left many victims in situations with insufficient resources for health and livelihood or means of communication for calling for help.

It was obvious throughout the period during and immediately after the storm that this level and quality of response was unacceptable. As the federal government reflected on the response, it was clear that a "transformation" of the Department of Homeland Security (DHS) response strategy needed to occur. While the details of the federal response transformation pertain specifically to federal agency changes, the same methodology of (re)designing disaster response has been used in other occurring disasters. These steps included:

- Recounting the occurrences of response after the disaster
- Identifying where deficiencies arose
- Taking steps to mitigate those problems before the next occurrence of a similar disaster.

To the defense of the federal government, however, it must be noted that authorities had done a lot to implement changes from the state of things from Hurricane Andrew response in 1992. For example, during the aftermath of Andrew, bureaucratic red tape delayed the deployment of aid resources to the responders and victims of the hurricane. [10] After that time there were changes made to improve the response for future similar disasters. The response plan has continuously been under revision and improvements and changes have been made yearly, and reviews of the effectiveness of the plans are conducted regularly by various appointed committees.

The effectiveness of the changes in response performance for the humanitarian logistics field is difficult to gauge. Qualitatively an observer might consider the response to be varying degrees of either adequate or inadequate based on the observed efficiency of the response. If the response was gauged to be severely inadequate, a response redesign would be given more urgency and priority. If response results become adequate after some changes are made (if another similar disastrous event were to occur), the response might be labeled successful but at first glance and from general federal employee opinion, it seems that no method exists to quantitatively document the improvement in response. [146]

The extensive lack of financial long term response accountability also raises the concern that the response effort, whether immediate or long term, may fall short of the needs of the victims and evacuees from the disaster event. After Hurricane Katrina, the US Government expended large amounts of resources to support evacuees left without homes and displaced from their city. After changes were made in the FEMA, DHS, and disaster response infrastructure, seeming improvements were evident.

The newly designed response structure was put to the test when other hurricanes hit the Gulf Coast. Hurricane Ike made landfall in Galveston, TX. Public outrage at the response was considerably less vocalized than after Hurricane Katrina. Although the damage amount was in the billions of dollars and some towns were still devastated, few deaths occurred after the storm, which was less severe than Hurricane Katrina when it made landfall. [109]

From observing the outcome from these events, some initial questions arose. Would having a system of metrics implemented into the response restructuring procedures improve the actual response during the next disaster and any subsequent or consequent planning? How would such a system be determined? What relevant metrics are established in similar or other industries that can be modified to incorporate disaster response? What kind of benefits might this offer to responders, affected civilians, and local, state, and federal authorities?

1.2.2 2010 Haiti Earthquake

1.2.2.1 Details

In January 2010, a magnitude 7.0 earthquake occurred near Port-au-Prince, Haiti. The country, already with a large percentage of its citizens living below the poverty line and a fragile infrastructure [52] suffered extensive damage to that infrastructure and over 200,000 citizens lost their lives in the quake.

Various countries, non-governmental organizations, and multi-national organizations came to Haiti's aid, sending food, water, and temporary shelters. Online donation sites and event awareness were utilized by the masses through social networking and various media venues, events, and mobile phone donation services.

1.2.2.2 Problems in Response

The government and MINUSTAH (United Nations Stabilization Mission in Haiti) buildings were destroyed in the quake, and many of the chief personnel, officers, and staff members were killed. [113] This devastating loss of leaders and organizers, combined with the significant damage to the infrastructure, left few resources available to initially coordinate the receipt and distribution of much of the aid. [29]

Additionally, the few available sea ports in the country through which aid could be received had sustained heavy damages as well, particularly in the Port-au-Prince area. Ships carrying aid for the country were unable to dock to begin supply delivery, and at the Port-au-Prince airport, whose runway was small to begin with, suffered delays in being able to receive aid as well. Aircraft bringing supplies were unable to land because the single runway airport was already crowded with aircraft being unloaded, which was taking much too long, and also because the airport had no fuel. Continued aftershocks also worsened conditions, toppling additional buildings and raising the already skyrocketing death toll. [29, 20, 47]

Days passed with few people receiving food or shelter resources. Injured people awaited care from a couple mobile hospitals or the single hospital left standing which was overcapacity and running out of resources. With bodies piling up that could not be disposed of except through mass graves, it seemed that not only was Haiti in capable of helping itself, the rest of the world was also unable to provide desperately needed aid. [113]

1.2.2.3 Aid Solutions

Although the initial aid delivery and distribution into Haiti was delayed, multi-national organizations and other non-governmental groups organized logistically online, and with an increased military presence from several countries, receiving aid and dispersing was regulated and implemented in the country of Haiti. The airport situation was improved and eventually alternate sites and routes for delivering aid were developed.

After time went on and aid resource distribution began, two concerns arose. The first was the question of how an infrastructure which was already delicate and not very well developed be rebuilt after suffering such extensive damage. The second was the concern that with the onset of a 2010 Hurricane season, the Haitians, millions of whom had no shelter over the heads, would be in another helpless situation if another hurricane were to make landfall during the summer.

1.3 Feedback Mechanism

An existing feedback mechanism within disaster response is naturally personal feedback on the situation and the response. For people who had resided in affected areas prior to the disaster, their opinion of how well or badly a response went may coincide more accurately with how well it actually did go. The more public venue in which people can voice their opinions and assessments of the response performance is though media outlets. News media groups report news which reflects these opinions if they seem to be strong in the negative direction. Additionally, reports which are easily sensationalized are more likely to be published or broadcast.

For more long-term feedback, there may be some available data which is available or can be made available that reflects some aspect of the response performance after a disaster. These may be rescue statistics, casualties, food, water or shelter need fulfillment, the rebuilding time, family relocations, reuniting lost individuals with families, and the time needed to disburse aid.

1.4 Observations

From reviewing available literature and media reports about the two specifically mentioned events as well as observing the current response planning overviews, some observations arise. Some of the more specific initial observations are listed from the first bit of research done. These observations gave rise to some more general observations which are also listed.

1.4.1 Specific Observations

- Communication and Collaboration is important in disaster response even within a single nation or governing body, particularly if external resources are being sent to and received by the affected community.

- Infrastructural development of the region is important in adding to the preparedness of a region or community.

- Economic status of a region is important in enabling the restoration process.

- There are few metrics which measure response performance.

- The differences in communities are significant and reduce ability to compare different disaster situations.

- Focus for performance improvements is on the immediate response period after the disaster occurs.

- Long term accountability for restoration and continued dispersion of aid is not consistent in all areas of restoration for a community.

1.4.2 Generalized Observations

These observations can be made at several detailed levels for several aspects of the response.

- The affected community may be seen as a system.

- The occurrence of the disaster and any prior preparedness activities as well as post-ante restoration process may also be included in this system.

- The system, and all of its included parts, may be broken down into components at different levels of detail.

Relationships exist among the different components and at different levels of detail. An understanding of these relationships may provide information on response performance.

These observations reveal a new perspective in observing a disaster situation. The disaster and its affected community may be defined at different hierarchical levels, the most general being the top level, or system level, and the most detailed being Level N, where N is the greatest number of levels. Not all of the hierarchical levels will be defined, depending on the parameters in each level. Numerical level annotation will enable the system developer to know where in the hierarchical levels a particular parameter resides. This also enables further decomposition to be done, or components to be added during the system development. The levels may be generally defined as follows:

1. Level 1 - the community at the system level
2. Level 2 - different components of the community
3. Level 3 - components of Level 2 components
4. Level 4 - components of Level 3 components...
5. ... Level N - components of Level N-1 components

The disaster and its affected community may also be defined throughout different phases. Some general definitions of these phases, based on observations to this point, are given.

Planning refers to the actions or activities which help to reduce the effect of a possible disaster or increase the speed and efficiency of the immediate response as well as the restoration, or rebuilding, phase. This includes changes made after a disaster occurs which help to increase the resilience of the community through reduction of effects or increase in efficiency and speed of response and restoration.

Response (prior) refers to the actions and activities which may take place once it is clear that a disaster is imminent. Not all disaster types or severities give enough warning for responders to begin response before the actual disaster occurrence. A hurricane is an example of a type of disaster which sometimes enables prior response actions and activities.

Disaster Event refers to the actual disaster occurrence itself. Different regions and communities may be more susceptible to one type of disaster than another. Communities following the all-hazards approaches may have an awareness of which hazards are more likely to occur in their community than others.

Response (post-ante) refers to the response activities and actions after the disaster has occurred. This may include both emergency medical services as well as food and shelter distribution.

Restoration refers to rebuilding and restoring the infrastructure and economy as well as the sociodemographic state of the community. This often takes the longest and may not even be complete when another disaster occurs.

Observations of disasters in different communities and even nations shows some of the different parameters that might change the ability of a community to respond and rebuild after a disaster has occurred. Differences in development, social demographics, economics, even physical characteristics between communities may make a difference in how much the disaster affects the community, and different parts of the community, and how long it takes a community to rebuild. The rebuild time, or restoration time, is important, since incomplete restoration subjected to another disaster will set a community farther back than it was before as far as restoration is concerned, and also affects resiliency after a disaster.

The particular aspects of the community and disaster pre- and post-actions will be defined more specifically in Chapter 8, but an attempt is made to remain as general as possible without making assessments and analyses difficult. Additionally, after the system model is developed, a sensitivity analysis is done to highlight the more influential parameters. Being able to look at a community from a parametric perspective will enable a relative and qualitative comparison of the different responses or aspects of the response.

1.5 Research Scope

A general agenda for the research conducted in this report includes:

- Observe current capabilities
- Identify opportunity for additional development

- Select proper method to enable communities to understand their response and restoration capabilities
- Apply method to community of interest

The focus of the research will be primarily on US communities since jurisdictional understanding is highest and policies are most available and most documented in these regions.

CHAPTER II

BACKGROUND

2.1 Benchmarking

2.1.1 Humanitarian Logistics Disaster Response Planning - Current Response Planning Capability

2.1.1.1 Current Approach

Development of response planning and related activities is a part of the field of humanitarian logistics. This type of response is different from similar military situations since there is a greater level of transparency within responding organizations. Procedural standards and exercises are readily shared instead of heavily guarded. Collaboration with external entities is more encouraged since this helps to improve the efficiency of the response, particularly in situations where local or national resources become overwhelmed. Because collaboration has been welcomed and encouraged the response planning activities have grown in the past several years into their own field.

A relatively new field, humanitarian logistics refers to logistical activities providing aid and relief in situations of crisis. [29] This includes training, collaboration, and design or redesign done in preparation for disasters or to help mitigate the effects of disasters on a community, as well as immediate response and recovery and rebuilding activities done after a disaster has occurred.

While the official field of study and application is relatively new, humanitarian logistics, particularly disaster response and its planning have been implemented for a much longer time, going through many changes as time has passed. Disaster preparedness has become a community initiative, something that communities from local neighborhoods to state-level planners have given greater priority to, particularly after Hurricane Katrina.

When disasters occur, immediate and longer term response both are crucial to mitigating the effects of the disaster in the lives of citizens. The definition of a disaster depicts a situation where response need exceeds the capability of the local response organizations.

[73](p27) With an increasing global population, significant natural events will have an increasing effect on nearby populations.

An event significant enough to overwhelm the response capacity of the affected area might be some type of natural disaster or terrorist event. As the severity of the disaster increases, relief and response effort becomes more and more complex. However, with the unpredictability of disasters, particularly natural disasters and/or events due to terrorism, it becomes clear that while the events themselves may not be predicted correctly by state-of-the-art technology or methods, the quickness of the response can be improved once the event happens.

This portion of the research will discuss building an understanding of some available perspectives that are used in Emergency Management Planning practices today, and covers several related frameworks/methodologies from other fields. The main difference between emergency management planning methodology and methodologies addressed from other fields is that most other fields view this type of problem proactively. Traditional emergency management methods are generally reactive. [73] It is important to also consider that catalysts are necessary to make the paradigm shift from reactive methods and approaches to proactive methods and approaches.

2.1.1.2 Federal Emergency Management Planning Methodology in the US

Emergency Management Planning has come under some heavy scrutiny in the past few years due to the occurrences of several natural disasters which had varying levels of response performance. This approach is somewhat generalized and while the various phases have been analyzed for areas of improvement following some of the disasters, the actual methodology for planning has been discussed to some extent.

Currently one of the main deficiencies is a lack of standardized metrics in the inter-organizational communications category. Essentially, these metrics enable some quantification of "customer requirements" that are available, but not necessarily used to define response planning methodology. The other main deficiency, as mentioned earlier, is the division between these types of reactive planning vs. the proposed proactive planning.

Communities and responders have begun to seek ways to actively prepare and pre-allocate resources to aid in the response and restoration of their communities after a disaster, expanding from a perspective focused solely on immediate response.

Figure 2: Disaster Response Cycle [73]

In the US, a specific Response Chain is followed when conducting disaster response. (See Figure 2) According to Haddow, Bullock, and Cappola [73], the different stages for disaster response are: mitigation, response, recovery, and preparedness.

Figure 3: Disaster Response Planning Methodology [73]

Preparedness Preparedness activities include training and exercises to build the response capability of responders, planners, and response coordinators, in their response, mitigation, and recovery activities before, during, and after a disaster. See Figure 3.

These activities focus more on preparing communities for both the initial and longer term response after the disaster occurs. In addition to communities, responding disciplines should also conduct their own preparedness activities in the time before the disaster. While the preparedness phase is discussed as a phase in disaster response, it must be a constant assessment and reassessment of the response capability of a group or community, and consistent implementation of improvements to remain prepared. Planners should understand that the preparedness of any community may change at any time.

Some methods for community assessment are provided by FEMA for US communities. One example of community assessment is through the National Emergency Management Baseline Capacity Assessment Program (NEMB-CAP). The NEMB-CAP gives a federal financial incentive and provides a baseline standard for readiness, which were developed by the National Fire Protection Association.

Accreditation of readiness is done by the Emergency Management Accreditation Program (EMAP) which enables recognition for emergency management organizations or communities in readiness levels, as well as help to bring up areas which need improvement.

Citizen preparedness is also a part of this phase, and various family and individual preparedness tips are available from local governments or state and national emergency management websites. Some types of disasters may require different preparedness activities but specific areas and communities aware of the potential disasters can disseminate information and preparedness tips accordingly. [73]

Mitigation Mitigation is different than preparedness. Some mentions of these two different parts of the response chain interchange mitigation and preparedness, but this document will use the definitions laid out by Haddow, Bullock, and Cappola. As the approaching event grows imminent, it becomes more important to have already conducted preparedness activities. Unless otherwise specified, mentions of preparedness in this research include the mitigation activities.

During mitigation, actions are taken which will reduce the impact of disastrous events on the people and land or property affected. This refers to long term changes that must be made to reduce risk and not the short term immediate response or rebuilding and recover phases. During this phase hazard and risk identification is done, and steps should be taken to reduce the risk of property damage or to ensure human safety. Specific activities might include beefing up building codes and inspections (and possibly making construction changes if necessary) in areas where collapses may be imminent in the case of an occurring disaster.

When a disaster becomes imminent, the ideas from the preparedness phase should be put in action. Some disaster provide more warning time than others. As authorities gauge the impact and severity of the event, they are able to pre-position aid resources (food, water, medical supplies, personnel, etc.) enough for all the victims, as well as carry out evacuation orders. Emergency Management also suggests that a ”systems approach” be taken when considering preparedness activities, so that all of the functional areas can be prepared and the community and responders are all functioning on the same level. [73](p185)

There are many tools available, and case studies to prove the activities to bring locales to a place less susceptible to different types of disasters. Some of the tools listed in Haddow, et. al, include: hazard identification, design and construction applications, land use planning, financial incentives, insurance, and structural controls.

Hazard identification makes use of different hazards and their mappings to the areas of concern. Various federal agencies have access to this pertinent information, and some employ complex geographic information systems (GIS), such as FEMA-developed HAZUS, to estimate earthquake losses for communities. These programs tend to focus more on “one-disaster-at-a-time” approaches, rather than the all-hazards approach that FEMA is beginning to implement.

Construction applications take hazard risks into account when in designing stages for buildings and structures. Examples of this would be using fire-retardant roofing materials in areas where fire risk is high in certain seasons, or constructing houses on pilings in areas where flooding occurs. If disaster response planning takes place in a fully developed community, this part of mitigation would be more easily implemented after the destruction of some of the existing infrastructure. If a community is planning and implementing changes before a disaster occurs, planners would need to replace the current materials with selected "better" ones depending on what hazards the community is trying to mitigate itself against.

Land-use planning methods employ these hazards approaches in development of different areas in the community. This may mean restricting development in areas more prone to certain hazards, or encouraging development in other areas. Various local ordinances can encourage implementation of this tool.

Financial Incentives may be offered to community citizens to become more active in mitigation activities. This often means that costs to citizens in relocating or making changes in their community are federally covered to encourage the community to participate in mitigation activities. Various financial planning tools exist to help communities with these incentives as well.

Insurance from the perspective of Haddow, et al., is seen as a way to help transfer some of the financial risk from individuals to the insurance companies. If properly wielded, insurance can be a useful mitigation tool.

Structural controls are also used but are constructed specifically to protect communities against some form of natural force (a levee is an example of a structural control). To a point they can be used to physically mitigate a disaster, but this is also an area of controversy because of their limits. People may feel a false sense of security if a structural control is in place in their community.

Mitigation activities can help reduce the impact of a particular natural hazard but rarely ever fully eradicate such impacts. The activities typically also require federal funding to be implemented but if local authorities are required to bring funding proposals to the federal government, it reduces time available for their other daily duties which they may put at higher priority than mitigation activities for a hazard which is not imminent. Some mitigation tools request citizens to act on their own land or affect other privately owned plots, and the over-involvement of federal authority in private arenas may become an issue.

Various programs exist within the federal structure that enable funding for various mitigation activities. These programs also contain specific information about details which should be included in the plans, that take into account various issues associated with the mitigation activities that should be assessed and/or resolved and implemented.

Once the disaster has occurred, communities and responders must begin to deal with the aftermath of the event, whether it is a natural disaster or terrorist event. The initial response takes place in the hours immediately following the event. For natural disasters, local responders are first on the scene to begin dispersing medical aid and restoring order to the area. These responders include medical personnel, firefighters, and law enforcement personnel. As the scale and severity of the disaster increases, the initial response needs may be too great for local first responders to handle. As a part of the preparedness activities, authorities may have anticipated this need and had other responders waiting at ready to aid the local responders.

Response During this phase, which occurs directly following the actual disaster event, various units of first responders begin to arrive on the scene of the disaster; to provide first aid to injured persons, and begin restoring order to what may be a chaotic scene. The main objectives in this phase are to maintain proper communication and collaboration between the various groups, agencies, and responders which are volunteering or providing their aid, to operate within the incident command system, which encourages this collaboration and communication. Planning and management systems as well as resource management can be done through the ICS, but must be utilized at multiple levels for increased effectiveness. [73] (p111)

The chain of command follows from the mayor or similar authority at a local level, who then appeals to the state government authorities at the state level. If the event is such that state level responders cannot respond to restore order and disperse aid as needed, the governor may seek assistance from the community and state. If these response capabilities are not adequate to properly respond to the event, assistance may be sought from the president to declare a major disaster for that area and receive federal dispersement of aid.

Before such a thing may happen, FEMA officials must make a recommendation to the President that a disaster declaration is made, which would occur after analysis of the situation. This part may be done with haste depending on the nearness and severity of the impending disaster or severe deficiencies in response after the disaster has already occurred.

The National Response Plan simplified the federal assistance request process. Supplemental to the NRP was the NRF which was released in 2008. Under the procedures outlined in the NRF, the Governor of the state requesting assistance interacts with the FEMA regional administrator to submit the request to the President. The regional administrator evaluates the request and recommends to the (national) FEMA Administrator, who submits the request to the President. When the president has made the declaration, all of the respective and relevant parties are then notified of the decision, and the assistance is deployed. [58](p42)

Various assets may contribute to the effectiveness of the response effort. Aviation support proved a critical asset group in the response to Hurricane Katrina, being utilized for search and rescue operations as well as providing the only working form of communication by passing messages between two locations. [153] In other circumstances aviation support assets were also used to bring food, water, and shelter to areas which had become inaccessible to ground logistics assets. In non-disaster situations aviation support assets are also used to distribute aid to communities in need. The implementation of Unmanned Aerial Vehicles (UAVs) will reduce the risk to asset operators in search and rescue operations. Without these assets many more lives would have been lost. These critical assets need to be allocated for community use prior to the disaster occurrence to prevent added delays in securing permission for the allocation of those assets during the midst of the post-disaster chaos.

Recovery After a one to two week time during which the majority of the immediate response is done, the immediate response moves into the recovery phase. During this phase, the emergency part of the response is over, and the job of first responders is primarily finished. During the recovery phase, the focus of aid givers has broadened greatly compared to the initial responders. Haas, et. al. decomposes the Recovery period into three different phases. The Restoration phase involves repairing and restoring repairable and restorable structures, and the restoration of functionality of the socioeconomic aspects of the community. The Replacement reconstruction phase involves restoring social and economic levels to pre-disaster (or better) levels. The commemorative, betterment and developmental reconstruction phase include projects which remember the disaster but also mark a restored and improved community. These phases overlap each other and follow the emergency response phase. In this research the Recovery or Restoration phase refers to the collective group of these post-response phases. [72] Figure 4 shows a notional timeline of these phases as well as the collective phases which will be referred to in this research. This period involves restoration of the community, physically, socially, and economically. An underlying consideration as citizens rebuild their community is the importance of reducing the impact of future disasters which may come their way. In this situation the government may provide aid to the community, as rebuilding is often the costliest part of the disaster response.

The National Response Framework [58] defines the role of the government as well as the local community, NGOs and private sector businesses. ESF no.14 is the basis for support from the federal government and outlines various plans for aid that the government can provide. FEMA provides individual assistance recovery programs, which include disaster housing, unemployment assistance, legal services, counseling, other related needs, tax considerations, public assistance grants. Various other agencies also provide long term aid programs.

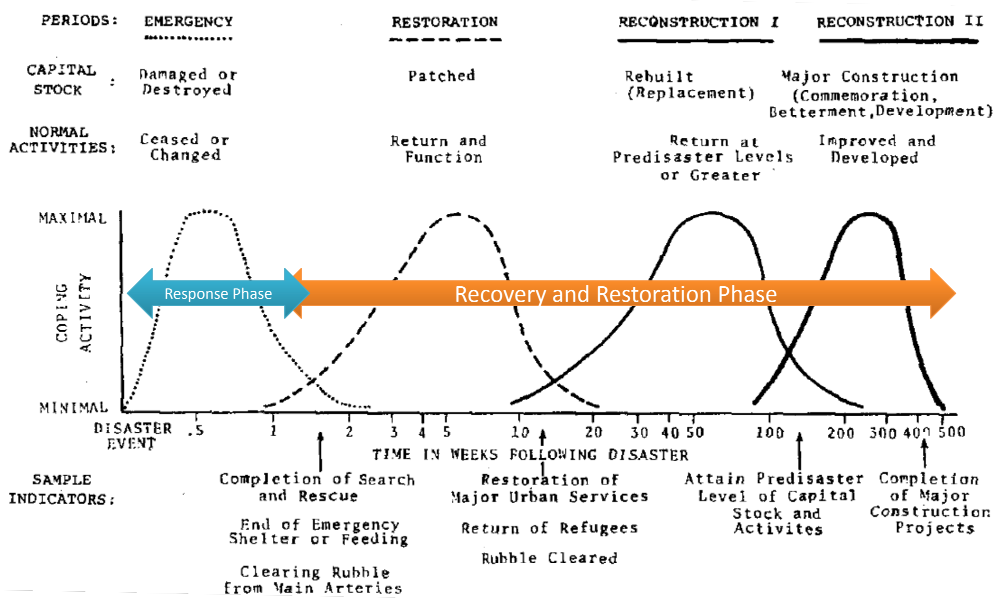


Figure 4: Response and Reconstruction phases [72]

2.1.1.3 Disaster Response Planning

In discussing disaster response planning, it is important to make assessments from a methodological point of view. In designing the response methodology, designers must take into consideration the circumstances of a rapidly changing world, both climatologically, politically, socially, and economically. Any response to a disaster, natural or man-made, should be as robust as possible, and if being redesigned, care must be taken to ensure the robustness of the new methodology to the dynamic circumstances surrounding disaster events. For disaster response planning, planners and decision makers must consider the most effective changes that can be made to improve the response as much as possible. Figure 5 shows the response and assessment phases alongside each other.

In the first part of redesign, some event or cause has occurred, prompting an assessment of the event itself and any short or long term response that has occurred. Smaller disasters may have less detailed assessment records available, or assessment may have been a jointly

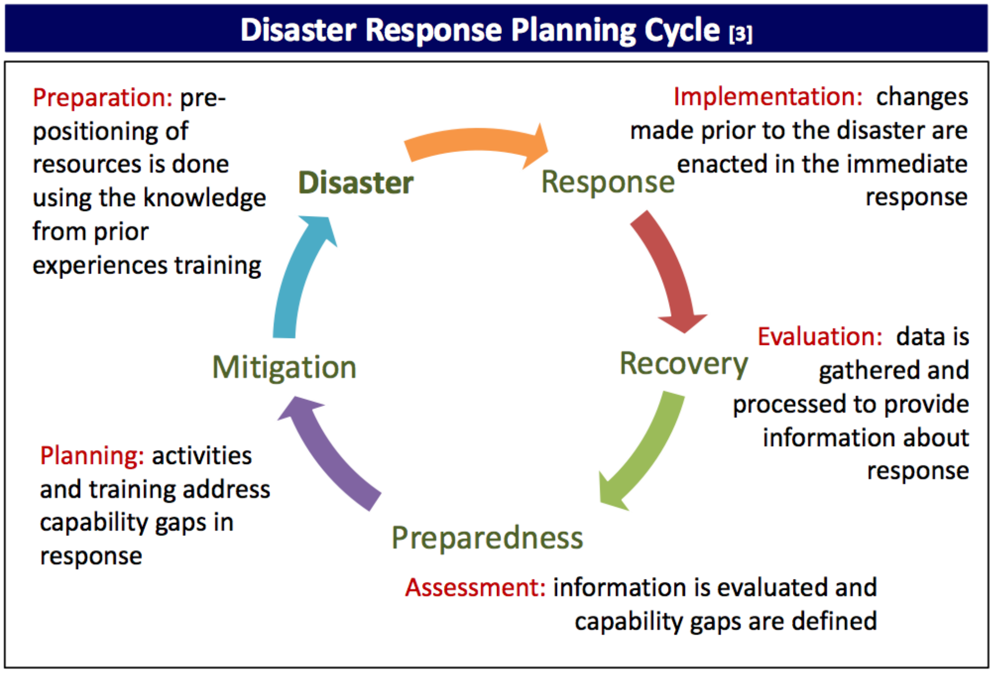


Figure 5: Disaster Response Planning Cycle [73]

conducted meeting among a few people in authoritative positions over a specific area experiencing the need for redesign. Larger, more severe disasters typically receive more national press than smaller ones, consequently the response also is thrust under the public eye and people will react to it.

Analysts conducting the assessment gather data from various sources to provide the best perspective on what happened between the event occurrence and the beginning of the assessment. This data can take a large variety of forms. Analysts may tend to use data with the least opinion bias (such as news sources or TV talk show / news talk reports) and utilize information available to them from weather and meteorological organizations, census and demographic data from the government, and various types of topographical information. This may be done through a computer simulation program that may be available to analysts.

The purpose of the assessment is to list out the elements of the disaster response that were unsatisfactory to decision makers. This part of the assessment phase is qualitative in its nature because of the lack of standardized metrics available to the humanitarian logistics. Not everybody is on the same page, but if the severity of deficiencies in the response is high, it is agreed that in general something needs to change to improve this aspect of the response.

2.1.1.4 State and Local US Disaster Response Planning

Within the US, State and Local disaster response planning are done compartmentedly, with no standard method in place. With varying tools, as well as different disasters faced and different population demographics, geographical variety, and infrastructure, communities should plan somewhat individually.

2.1.1.5 Multi-national Non-Governmental Disaster Response Planning

Most multi-national non-governmental disaster response organizations act as resource aids for governments or organizations, seeking to further the life and livelihood of citizens staying in the community of concern. The projects of concern address both impending or recently occurring natural or technical disasters, as well as non-natural and non-technical disasters, such as famines, for example, which may be termed developing disasters. [29]

2.1.1.6 Current Field Focus and Issues [29]

In the initial approach to this problem, an observatory assessment was done of the disaster response part of the humanitarian logistics field. Stemming from an initial interest in system-of-systems operations disruption, responses to various types of disasters were examined. The disasters ranged from small-scale and local to large-scale international responses at various points of time in history. There was somewhat of a focus on US response to disasters but responses which took place internationally were also examined as well.

Current key issues were also discussed at the Health and Humanitarian Logistics Conference, another source for current industry standards and practices as well as opinions for shedding light on what some organizations and leaders see as a “hopeful ideal” to strive toward.

Humanitarian workers at the organizational level are aware of issues that arise with each disastrous event and consequent response, and are working to enable communities and organizations to address these issues in their response planning and training.

Forecasting Within the past few years the capability for disaster forecasting has made significant strides in enabling communities to make use of a warning time period prior to a disaster occurrence. For some disasters this warning period may be shorter than others. During this time, response resources may be pre-positioned so that immediate post-disaster response areas of need are in close proximity. Additionally, community residents may take action to secure their homes or find more secure locations, stock up the needed supplies, and even preemptively relocate if necessary.

Because warning times provided by forecasting techniques may be very short, preparedness planning addresses development of the necessary action. Different communities within the US have been implementing planning at this level so that forecasting capabilities may be maximized.

Data Collaboration Several issues in particular come from the oft-encountered difficulty of data-sharing between various sectors in the health and humanitarian logistics. Not only is the health care industry subject to data compartmentalized by specialties and hospitals, but also with patient data being the object of interest, data privacy issues come into play and may make obtaining data for research or solution development difficult. During disaster response, if a tool requires the use of patient data in real-time immediate response, the complexity of the health care data system may compound the difficulty that may arise in acquiring patient data.

Metrics The topic of metrics and performance evaluation seems to draw reluctance from planners and leaders. This may be due to the business- and performance- based nature that evaluation tends to push planners toward. The importance of metrics is emerging with the rise of social media networking as a tool for enabling individuals to easily financially be a part of the response process, and as private companies and for-profit corporations partner with more and more non-profit organizations to be involved in disaster response.

As profiting companies partner with non-governmental and non-profit organizations, accounting for specific uses of provided donations and other resources will be required. Utilizing helpful parameter metrics and relevant performance metrics will enable responding organizations to account for where all of their donations where spent, and assess how much of an improvement the donations enabled in the response.

Resilience Capability of Communities While there is little infrastructure in place within the humanitarian logistics field for implementing a system-of-systems perspective on disaster response, an awareness exists that each of the components of disaster response must not be neglected. As immediate response issues are addressed, the focus shifts toward enabling communities to return as quickly as possible to a restored infrastructure and "life as it was" before the disaster. Some issues that arise with this are the timing of inserted forces coming and going in the disaster area, particularly if the military becomes involved, and how to return stability to places such as Haiti, which were not initially very resilient.

Transfer of Authority While military use of force and command during disaster response is often the quickest and most efficient way to restore order, the issue arises, particularly for responders working in foreign countries, as to the timing of the military responders' departure. While it is essential to ensure that the disaster area remains as orderly as possible and that rescue and recovery operations continue as smoothly and efficiently as possible, at some point military power must leave and allow local military power or responding authorities to regain control of the critical area.

The issue was not so much whether or not the military should leave, but dealt more with when the appropriate time was. The military representatives stated that, specifically for any US military special groups, a lengthy stay was not desirable, but most of the time, ensuring the stability of the situation was the thing that would delay military departure from critical disaster areas.

Increased Financial Involvement from Private Sector through NGO With the rise of social media networking as a source of information about disasters and their consequent responses and responders, not only have more general population civilians been enabled to participate in financial donations, but greater awareness is raised about disaster and response. Many private organizations are beginning to partner with non-profit response organizations financially and in other ways.

It is an important issue for private companies and individual donors who need to know that their money is being used to further the response cause, which is to save and improve the lives of the victims. It is this issue which precludes and validates the importance of being able to assess the effectiveness of a response or the effectiveness of changes being made with the donations from companies and individuals.

Perhaps the most can be learned about response from observations on actual events themselves. Some observed disasters are discussed below, during which response issues prompted the initial interest in this topic. Some more recent disasters were also observed, to identify where some of the response efforts have developed since previous disastrous events. Various organizations, both non-governmental and multi-national, are working to address the issues discussed in this section. Some of the main focuses of the improvement efforts are discussed in the next section.

Collaborative Planning Post-disaster collaborations via social media networking have grown in popularity, with the biggest example of its use in the days following the Haiti earthquake when mobile texting was used to raise millions for Haiti, and social networking sites such as Facebook and Twitter were used to provide information about the situation to those outside of Haiti. These social networks also provided other avenues for evacuees and the rescued Haitians to informed their friends and loved ones that they were okay.

Collaboration between the private sector and non-governmental organizations (NGOs) in response enabled businesses to become more involved with disaster response before time-critical needs arise from an actual disaster event. Even if those businesses do not operate any sort of supply or logistical aspect of their respective industries, financial and material contributions can help response efforts.

Multi-national aid organizations such as USAFRICOM and MEDCAP have developed strategic support frameworks which support communities internationally and focus on building resiliency as well as aiding immediate and ongoing needs. [29]

Training Training has also become more collaborative as inter-organizational simulations and training sessions have been developed and utilized to train response coordinators. An example of this is the training programs available through the United Nations World Food Programme(UNWFP), and collaborative intense training sessions which response coordinators have access to. [29]

Through the Department of Homeland Security, FEMA offers emergency management courses which are available online. Regarding training availability, many state emergency management sites also have information on organizations through which people can volunteer or receive training. The process requires citizens and community residents to be proactive in seeking out training, or practicing personal or family emergency plans.

Logistics Tracking This area of disaster response seeks to enable logistical organizations and relevant governmental agencies to better track their relief supplies and other response inventory. Continued focused development in this area will enable the responding authoritative personnel to assess the amount of supplies and resources which are being sent through each origin-destination combination. Taking into account the transit distances and conditions, resources can be routed or re-routed to meet existing needs or "surplus" needs that cannot be met by supplies already in transit. If something happens to the supplies in transit, logistics tracking enables a quick tool to show what other resources are on the way and if those resources will get to their destination in time or not.

Some challenges in this area continue as the level of collaboration increases because at times it may be difficult to obtain proprietary data or share it quickly during times of disaster. In addition, as different companies and organizations have different ways to track and label resources, the non-standardization issue arises, and may also complicate response logistics.

Academic Resources Again, as humanitarian logistics is becoming more established as an official field, various universities and research entities are also establishing that subject as a field of study. Typically the humanitarian logistics research groups are found within the supply chain or logistics or management departments at universities because of the strong ties that disaster response, logistics, and management have with each other.

Within the academic research areas, research groups assess the humanitarian logistics field as a whole and focus on aspects of it for which there exist capability gaps between current capabilities and the level of capabilities which are needed. Academic research advances and testing are able to bring in new and sometimes more radical applications from various other fields of study, something which humanitarian logisticians may not have the time or expertise to do.

The best utilization of this valuable intellectual resource is for companies and organizations working directly in the field to continue working with academic and research institutions to convey what the current needs are, and work to understand and implement viable solutions or ideas which come back from academia. This should be done through publishing papers in humanitarian logistics journals, or attending conferences [29] and presenting current field issues and needs as well as some of the academic and field-developed innovations which address those needs.

With the onset of some disasters that have occurred within the past couple years and the implementation of the NRF, this area is one where the various aspects are being developed and improved the most, as some of the disasters revealed the various weaknesses that the system contained. The four most obvious improvement areas include:

1. Inter-organizational collaboration
2. Situational awareness during immediate response
3. Resource management and logistics (including personnel)
4. Communications

The Need for All-Hazards Holistic System-of-Systems Approach It is clear that continued improvement in humanitarian logistics response must be sustained. However, many people and organizations are working to improve on various aspects of both the response and the response planning. Is there a need for the implementation of a robust, all-hazards, holistic system-of-systems approach to response planning?

The importance of the all-hazards approach being currently implemented by the federal government in their disaster response planning is also passed down to planners at the state, regional, and local levels. If a community has planned or would like to plan response to address the widest variety of hazards which face the community, it would be important to know which response aspects to focus on so that the available financial, planning, and physical resources are utilized to provide the best response for the community. Some of these items include mitigation activities, stockpiling, training, and other preparedness activities, inter-agency and multi-national organization coordination.

If a more robust understanding of the response system-of-systems is to be achieved, it is better to enable this understanding so that the implementation of the response planning consists of the steps and activities which will provide the most effective possible response if current resources are used. There is an urgency to this and any response planning, because of the uncertainty of when a disaster may strike. The sooner that holistic system-of-systems understanding is achieved, and the sooner the planning steps are implemented, the sooner a community will be more prepared to face disasters to which their communities are at risk. Because some steps or tasks may take longer to complete, efficient planning and prompt implementation are both necessary to increase the time between disasters during which a community is not recovering from the previous occurrence.

2.1.2 Technological and Infrastructural Barriers

There are several technological and infrastructural barriers to enabling a community to approach all-hazards holistic system of systems disaster response planning.

Technological barriers prevent effective system of systems disaster response planning to be conducted. The term "technological barriers" refers to components of response development which are chosen by planners which provide planning capabilities through their implementation. These types of barriers include different methods, which can outline frameworks as well as steps for planning disaster response or enhance compartmented planning and ineffective assessments of current response and restoration performance. The methods serve to help fill in action steps at the planning level.

When the planning becomes more detailed, tools may be used to supplement different parts of the planning, execution, and assessment of the response and restoration. Also, different tests must be conducted to ensure that the planning methodology and actions will be effective and efficient in their roles. This type of barrier also includes different benchmarks which can serve to guide the planning directions.

Infrastructural Barriers come from within the way the community is set up and also prevent different aspects of planning to be fully effective. The term "infrastructural barriers" refers to components of the community where disaster response planning will be conducted, which restrict capabilities to complete the different steps in the planning methodology framework implementation. In most cases, it may be political or organizational restrictions and policies which hinder collaboration or the implementation of frameworks that planners have developed or social development which is restrictive toward response planning implementation.

Some examples of infrastructural barriers include the following:

- Lack of awareness
- Lack of priority
- Lack of understanding of the behaviors of the different systems involved

Technological Barriers An example of a technological barrier to communications for a community may be the susceptibility of the cellular communication towers to storms in the area, and the consequent inundation of the remaining network by displaced persons attempting to get in contact with family or loved ones. The network may be improved with some planning through improved protocols during disasters, or the tower strengthened structurally before the next disaster occurs. The structural strengthening might be considered an infrastructural modification, which also helps to show an example where both types of barriers may be wrapped up in one issue.

Although two different types of barriers have just been described, often a barrier to enabling the type of disaster response planning that is needed comes from both a limitation in technology or in some form of technology not being implemented yet, as well as different areas within the community infrastructure which also inhibit the implementation of this methodology.

Natural risks : The disaster forecasting field has grown but there is still no way to completely know if or when a disaster will strike. If there are risks to several different types of disasters, it is possible that any one of those different types will occur.

Lack of technical standardization: "...Emergency managers need to establish a baseline for preparedness at both the state and federal level in order to meet increasing standards of preparedness." [110] Since most planning is done within different groups or agencies, decisions and assessments are made based on the needs and roles of the groups. While collaboration among different planning groups or agencies does occur, there remains a lack of technical standardization across these groups and agencies. This is not necessarily a deficiency, since most of the expertise is contained within those groups and agencies, but a solution would need to be developed which enables some way of standardized assessment.

Lack of standardized metrics : Because of the lack of standardization and because of all the differences among the communities in characteristics, there is little to no ability for self-assessment of inter-community comparison. Metrics would enable a common gauge of how well a response and restoration period will go after a disaster. In the longer run, metrics would also enable standards to be defined as far as levels of preparedness. In light of the different aspects being included in this research, this issue is critical to the development of a solution and is discussed and addressed at length in Appendix B.

Insufficient specific response testing areas : Current test environments are not conducive to full response system-of-systems exploration, which would encompass being able to test many different response planning schema for a region and determine one or a group of response planning scheme(s) which has a high likelihood of improving the response.

Lack of comprehensive framework : Developed solutions implementing more than one or two planning aspects of the holistic system-of-systems approach are done locally by planning authorities and focused on custom responses for specific regions. Currently there is no comprehensive framework which enables system-of-systems to do holistic response planning.

While the framework does not need to be so general that participating communities need to fully customize the design and set up of the testing and analysis environments, parts of it must be flexible to allow for a community to address the response needs of many different communities and regions to many different hazards both natural and man-made, of varying occurrence likelihoods and severity likelihoods.

To use a GIS modeling program to simulate an earthquake in a northern California county, for example, analysts must input 3 or more layers of data which help to identify the topographical characteristics of the selected region and the predicted damages which may be inflicted on the region. Because of the complexities of the actual system, which is the region being investigated, and its represented GIS data, it is difficult to do tradeoffs to detect how different mitigation plans or response plans might improve or worsen the response performance.

Although cost assessments in response planning are still rising in usage during response planning, this is another enabler to entering into optimization of the capability for the available funding, personnel, and resources. Additionally, because partnering businesses donate money to non-governmental organizations for use during disaster response, cost assessments would show where the money will be used and how it will improve the response with particular activities.

2.2 Research Objectives

2.2.1 Enable Parametric Response Planning

One research objective is to determine whether the need for parametric response planning exists and whether it is currently implemented. This will be done with available literature and media reports to assess what the current capabilities and standard practices are.

Within this, some overarching research areas have been identified, and different research questions specified which help to outline the scope of how much needs to be done in each area and what issues to address. Based on these observations of current practices as well as capability gaps, hypotheses regarding the enabling of parametric response planning will be developed.

2.2.2 Answer Research Questions and Address Hypotheses

Through the course of the literature search and development of the background information, various research questions emerged. They are discussed in Chapter 3 and again with the results in Chapter 10. It is an objective of the research to address these questions through the course of the method development. Previously unquantifiable values will be quantified with the best known data and methods available for this researching order to test the hypotheses.

2.2.3 Develop Employable but Flexible Methodology for Implementation

One main objective is to provide an implementable methodology for response planners to customize to their own communities. While this may still be in the early stages, it is important for the methodology to be developed with flexibility built into the framework so that the framework and method are not sent into obsolescence because of the specific tools that were implemented in the method.

2.2.4 Explore Available Tools

For this research available tools include both software and methodologies. Since the development of a methodology to enable capability planning is one of the objectives of the research, it will need to include steps which enable the implementation of a response planning method which will enable holistic planning for a parametric disaster response and restoration system.

Available software tools may provide some data about a particular community, or enable the manipulation of data to produce some information useful to planners. Available methodologies may be some process development or planning methods used in other fields but applicable to the same type of situation that disaster response and restoration planners will face.

In order to conduct parametric disaster response planning certain tools or software should be used in order to fulfill a specific function for the description of the community or for the estimation of how much the response might change if certain actions are taken.

Some of these tools may be more desirable than others depending on the situation surrounding different communities in that different tools provide different levels of detail. Higher levels of detail and more detailed simulations may give some detailed estimates of the response but it may be more difficult to set up tests or gather data for the tests. As stated before, in some cases tools from different but still related fields may be usable and could be incorporated into the planning methodology.

2.2.5 Assessment and Comparison Metrics

The current lack of metrics and capability for benchmarking will need to be addressed. Part of the development will require some infrastructural changes in a community and in the disaster response and restoration field in general. However, some enabling ideas will be presented and implemented in the example. The capability of using metrics for benchmarking will enable inter-community comparison as well as enable intra-community assessments with regards to disaster responses and longer term restoration time.

Once this capability has been developed, it will enable economic justification for actions made during non-disaster times. Together with the capability to know how the system works and the requirements for improvement, proper planning may be done effectively and efficiently so that changes will be implemented with an idea of how they will affect outcomes.

As with the methodology development, a level of flexibility will be retained. This will enable experts and analysts to develop their own metrics based on their expertise, but will allow the metrics to be updated easily if needed.

CHAPTER III

RESEARCH AREAS AND QUESTIONS

3.1 Area 1: Current Practices and Capability

3.1.1 Hypothesis One

Application of parametric design principles will improve current disaster response and restoration planning practices by adding capability which is currently not present in the field.

3.1.2 Related Questions

1. What capabilities are currently present in the field?
2. What capabilities are currently needed?
3. How will parametric design principles be applied?
4. Which capabilities will be added by the application of the principles?

3.2 Area 2: Parameterization of the System

3.2.1 Hypothesis Two

Representation of the community as a system through model development will enable quantified community assessment and comparison.

3.2.2 Related Questions

1. What type of model will best represent the community as a system?
2. How will model development be done?
3. How will the model enable community assessment?
4. How will the model enable community comparison?

3.3 Area 3: Application of Response Planning Methodology

3.3.1 Hypothesis Three

The development of a methodology for Exploration of System-level Capability Through Aggregation and Analysis of Parametric Elements will improve disaster response and restoration planning objective(s) by enabling implementation plan comparison and selection.

3.3.2 Related Questions

1. What steps will be included in the methodology?

2. What are the response and restoration planning objectives?

3. How will the objectives be quantified and improved?

4. What is an implementation plan?

5. How will the implementation plan be compared and selected?

3.4 Refined Research Scope

3.4.1 Assessments

1. The research will assess how parametric design would be able to provide some capabilities to specified research objectives through the development of those objectives as well as application of parametric design to a specific situation.

2. Relevant and applicable methods and tools will be sought out to aid in the application of parametric design for the purposes specified. Some tools may be more relevant or useful than others but may not be adequately available.

3. One outcome from the research will be to develop a framework for metric development. Applying the metric development can be used by experts to give a more accurate view of how a disaster will affect the restoration time of a community. During the restoration time, experts and planners may be interested in how the preparedness and development of the community change and may want to assess what levels of change would be most efficient for restoration purposes.

4. The research maintains focus on one community or region and one type of disaster unless within the time designated for the research, more is able to be done. The assessment will focus on how this community is able to rebuild after a specific type of disaster and what improvements may be done to improve the restoration time.

5. The research will use a sample community and hypothetical disaster to assess the difference that pre-planning and focusing on preparedness and development can make over time.

6. The research will include conducting a sensitivity analysis once a system model is developed to identify which components are the most influential and under which circumstances. The research will also include tests to verify the believability of the model behavior.

7. Another outcome of the research will be to set up transfer of knowledge to experts and planners so future planning may be well-informed. This will include use of the input data combined with sensitivity analysis results to assess what some priority areas may be in terms of preparedness and community development growth but also taking into account shortening the restoration time after a disaster.

3.4.2 Assumptions

There are several assumptions accompanying the data selection and those are discussed in Chapter 7. The selected specific type of disaster was an earthquake with no aftershock. The capability for an aftershock inclusion is available but was not used in the developing of the model. It may be activated or deactivated as needed if further tests need to be done. The selected earthquake magnitude is not specified but is a mid-level quake that would do some damage and require a significant level of response and restoration.

The system model was developed for a mid-sized metropolitan community in the US and specifically for the Shelby County metropolis area of Memphis, TN. The model was developed at the county level but information is found even at the census tract level as well. However, including that much detail about a community may be too computationally cumbersome for a system-level assessment.

The financial assessment of the restoration plan is crucial to the development of a community's resiliency, and the issue should be addressed thoroughly and implications implemented into the developed solution. However, during this research it would have been a significant added task which would not only affect every parameter and relationship developed in the model, but additionally each parameter and relationship affected would require an amount of research in order to understand how each of those components in the community financially relates.

A robust implementation of this financial aspect of the community development was beyond the scope of the research, but budgetary issues could not be completely ignored in a developed system model. As a way to include finances within the system model at the simplest level, the budget was given possible values based on its sufficiency. The values for X (representing the budget for any particular component or parameter) were as follows:

$$X = \begin{cases} \text{shortage} & \text{if } 0 < X < 1 \\ \text{adequate} & \text{if } X = 1 \\ \text{surplus} & \text{if } X > 1 \end{cases}$$

The capability for developing some of the relationships with other components through the financial perspective is easily added in this way at a simple level but the budget or available funding for the component, parameter, or aspect of the system model is set at "adequate"' by default. The focus will then remain on finding out which parameters are most influential without the pressure of budgetary concerns. Because this is a significant aspect of community development, however, future work must include budget and funding considerations. Section 11.3 contains more detailed potential implementation ideas and rough development ideas.

Initially, aid setup was done with the intention of scaling the incoming aid based on stability of the originating location. In other words, for nations dealing with their own internal crises the assumption was that less aid would come from that nation. However depending on the depth of the disaster and the ability of the affected nation to deal with it internally, aid would arrive even from countries with internal crises and from countries with low purchasing powers and higher levels of poverty. The amount and quality of the aid differed depending on the financial situation of the nation but not the decision to offer or not offer aid. [36]

For example, federal standards and procedural issues with receiving the offered aid played a part in whether or not the aid was received and implemented in the United States after Hurricane Katrina. Many nations, regardless of financial standing or political standing with the US offered aid but most was not receivable by the US.

3.4.3 General Proposed Solution

Based on the initial literature review, background research, and academic resources available for addressing the proposed three areas of concern, a general conceptual solution was developed to address the issue of enabling parametric system-of-system planning for disaster resiliency for a community.

This solution includes the following items:

- Assess planning from the perspective that a disaster, its associated preparedness, response, and restoration are a long term cycle, through which the response and restoration slowly improve as each disaster continues to reveal new weaknesses or shortages in the response phase and during the restoration phase.

- Enable baseline development by setting up a framework for decomposing community characteristics to measurable metrics, and enabling metric development and implementation if previously non-existent.

- Further utilize the developed framework to enable not only community assessment but also community exploration to understand where current resources and methods can be implemented for purposes of reducing amount of time spent rebuilding and restoring a community after a disaster has occurred. Utilize the framework for these purposes through development of a parametric system model which contains the behaviors of a community in its response and rebuilding activities and resource flow both before and after a disaster occurs. Utilize the framework by developing relationships between parameters in the system model.

- Conduct exploration of the community (system) through the system model to develop an understanding of alternative actions which will improve the rebuilding and restoration time.
- Retain flexibility in the system model for further development or implementation by specific communities to implement the framework for communities not used in the development example.

CHAPTER IV

DEVELOPMENT OF METHODOLOGY

4.1 Definition of Requirements for Methodological Solution

Chapter 2 addressed some of the planning needs that the HUMLOG field is currently experiencing, particularly in regards to planning by US entities. In the Research Objectives, an enabling methodology is one of the productive output goals of this research. Any methodological solution must also consider the following requirements which represent some of the system characteristics.

* Response to sudden network disturbance
* Multi-disciplinary system or system-of-systems
* Complex interdependencies
* Possibly disabled communications
* Community resilience capability
* Local response capability
* Long-term restoration phase
* Geographic constraints by region
* Development state of region
* Receipt and distribution of resources from other organizations and places
* Requirement for interoperability in response and resource distribution
* Activated response groups dependent on need
* Need uncertainty due to obstacles in communication or transport

"System of systems" refers to a collection of smaller entities and functions which also function together as a whole. In the case of disaster response the function is a collective objective of minimizing the effects of damage and the time needed to restore the community to its previous state (or better) and maximizing the amount of lives saved and persons aided who were in need of aid.

In reviewing some of the tools and practices from the non-humanitarian logistic fields, being able to efficiently determine whether a tool or practice would be suitable for the needs of this particular research project at various steps in the process would enable a rapid down-selection from a wide variety of non-humanitarian logistics fields, tools, and practices to a useful set of potential tools and practices applicable to the disaster response system-of-systems and its needs for robust capability.

The objective use of the tools, as discussed in the previous section, is to develop a model which accurately represents the variables, entities, situations, and outcomes of a disaster response system-of-systems. Through a means of system exploration, capability gaps between the needs and requirements of the system will be revealed. Some of the emergent behaviors of the system will become apparent. This system exploration may include sensitivity analyses or subjecting the system or a representative system to a hypothetical disaster situation.

After some of these gaps are revealed, an assessment will be conducted of what may be done to close these gaps. The implementation of those changes will need to be included in the system-of-systems model - to test and be sure that such changes will actually improve the system-of-systems response. The tools themselves must be:

1. accessible / affordable - able to be acquired for use or easily deployed if integrated into a decision support visualization tool
2. usable - operable by the time the testing and simulation must be done
3. integrable - if more than one tool is used it is important that they are all able to be integrated in a single environment if necessary
4. fast in simulation runtime - to fully explore the system-of-systems it is important for complete runs to take as little time as possible, so that more exploration can be done

The modeling capability of the tools must be able to represent the actual system-of-system characteristics. To begin looking for these tools, searches were done within the humanitarian logistics field to determine which tools are currently being used to address some of the capability gaps and what capabilities they provide. Certainly there are tools outside of the humanitarian logistics field which can be used in the proposed approach, to provide the same needed capability. Some fields face very similar problems as the disaster response community faces, and have developed approaches to these problems with specific tools or methods.

The following section is a discussion of currently used approaches outside of the humanitarian logistics field to address the design methodology of system-of-systems with similar characteristics to a disaster response system-of-systems.

4.2 Methodologies Used in Non-Humanitarian Logistics Fields

In various non-humanitarian logistics fields, a similar problem exists, where an entity must react to a disruptive event. Some methodologies have been developed to address the application of that situation in those fields. These solutions may offer some insight into addressing event response planning for the disaster response community in humanitarian logistics field. If some of the lessons learned from other fields can be helpfully implemented in disaster response planning, planners can keep from having to "reinvent the wheel," so to speak.

4.2.1 Top-Down Complex Systems Design

In the Engineering Product Design field, a new methodology for decision support in complex system design is being implemented. This methodology is the realization of a paradigm shift in design objectives. It takes the focus from designing for maximum performance despite the cost, in a single point-design, and places objective priority on designing for capability quality and affordability. [96]

For complex system design, the past several years have seen a shift in design methods. As a departure from traditional performance focused design methods, particularly in strategic design of advanced concepts in the aerospace industry, a shift has been occurring toward physics-based conceptual design. This design method addresses issues for advanced aircraft or system concepts that cannot be based on historical data and need to meet time-critical deadlines and financial constraints, as well as satisfy a certain capability standard. This may be at the system level, or for a conglomeration of multiple systems into a higher system-of-systems level.

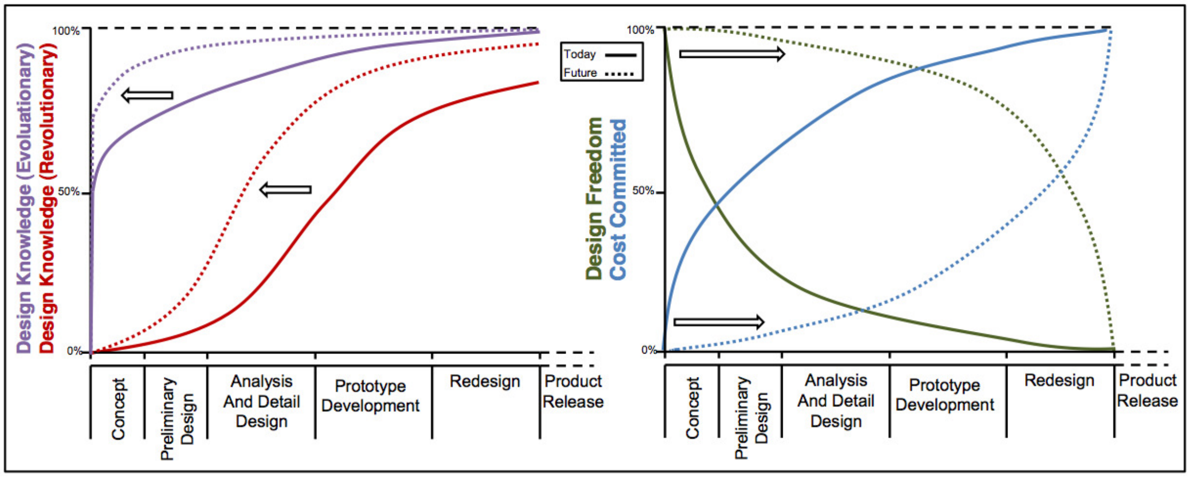


Figure 6: Bringing Cost, Knowledge, and Freedom Forward in Design Process [45] [96]

In the cost-knowledge-freedom diagram [45][96] (Figure 6) for an engineering system design, designing for affordability through a multi-disciplinary parametric approach has enabled the shift of the knowledge curve forward in time, and with an increase in knowledge of the design during the conceptual design phase, greater design freedom can be kept longer into the design process, and the cost committed to the design can be pushed back in time.

Having greater knowledge of the design at an earlier stage in the design phase enables engineers and analysts to explore more options for a certain concept. With information about the behavior of the design based on either historical or physics-based data, designers and engineers can conduct studies within the limits of each design variable or discipline to evaluate various concept alternatives in a dynamic environment.

Then, as the requirements and constraints become more defined by decision makers, or change with time and budgeting constraints or external circumstances, parameters can be changed and the various concepts can be down-selected until a reduced number of alternatives are left. As this design process is being implemented, various techniques and multi-disciplinary optimization methods must be created and implemented to enable the concept design. To address and risk and uncertainty associated with conceptual design, stochastic methods should also be included.

Various enablers are needed for this shift to occur, including computationally capable

Table 1: Paradigm Shift in Design

Shift from:	Shift to:
Deterministic design	dynamic parametric trade environments
Single-objective optimization	multi-objective optimization
Historical data based formulations	physics-based formulations
Serial design and analysis sequence	multi-disciplinary design and analysis
Deterministic methods	probabilistic or stochastic methods
Design for performance	Design for capability and affordability

modeling and simulation environments, as well as an integration into the infrastructure of design implementation. After all, changes will not affect improvement if they are not implemented by the groups or organizations who actually needed the changes in the first place. Table 1 shows how the paradigm shift is changing one perspective or methodology to the new approach being taken.

However, there must also be enablers for such changes, particularly in areas where such tasks have not previously been widely implemented in the field, such as the inclusion of physics-based formulations in aircraft design. Traditionally, aircraft systems were designed based on historical data, but in a much more dynamic market and environment that puts greater demands on design requirements, there is no available data. This gives rise to a need for an effective design methodology which reduces the time needed to gain knowledge about the requirements for and characteristics of system being designed in a holistic and robust manner.

The development of the methodology by Mavris [96] includes critical elements which the approach needs. These elements address enabling concepts for increasing the knowledge of conceptual designers, so that subsequent designs may address requirements holistically and be utilizing available resources for the best design.

Of these various enabling elements, the humanitarian logistics disaster response field will benefit the most from elements which enable holistic exploration of the behavior of a compartmented response system, address risk, provide reasonable data, and enable decision support both in analysis and real-time if possible. Some of these important elements include:

* Holistic Exploration: Multi-disciplinary analysis and optimization methods focus on

holistic perspectives for problems and address uncertainty in early design phases.

* Organizational Dispersion: With computation architecture frameworks, tools from compartmented areas may be integrated and automated for exploration and testing.

* System Exploration: Physics-based approximation models will replace higher fidelity tools which may be much slower, more difficult to learn to use, and difficult to glean information from. These models may be surrogate or meta-models.

* Risk Assessment: Probabilistic use of system parameters in meta-models enables quantification and assessment of risk and more rapid exploration of system and emerging behaviors, as well as provide potential for a visual interface for decision support.

* Decision Support: Multi-attribute decision making tools, and specific tools such as genetic algorithms give the ability to deal with multi-objective or discrete parts in an analysis or a developed solution tool.

While the process to develop new complex systems is applicable to a number of different fields with similar design objectives, this field has integrated quality engineering methods and systems engineering methods which increased opportunity for system robustness. The general steps in the methodology are shown in Figure 7. A framework developed in the Georgia Institute of Technology Aerospace Systems Design Laboratory enables complex system to "be designed with high quality and low cost to meet future aggressive customer requirements." [95]

The framework structure includes three elementary areas which each have some defining parameters. These areas offer some useful tools for conducting this type of design. They have been extended to include system-of-systems design, something which is of critical interest for the topic of disaster response system-of-system planning.

Mavris and Kirby [95] list the three areas and their sub-areas as:

* Life Cycle Considerations
  - Non-traditional Disciplines: including economics, reliability, and process design
  - Increased Knowledge: utilizing higher fidelity, preliminary analysis tools

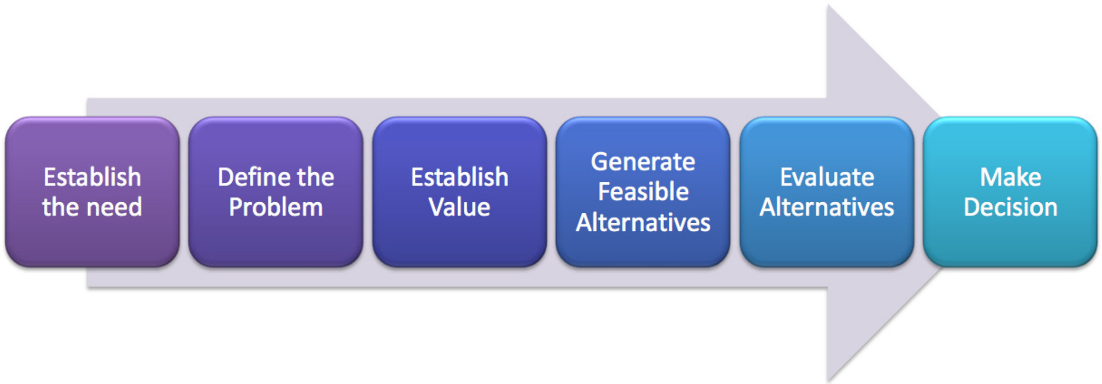


Figure 7: Top-Down Design Decision Support Process [138]

- Design Freedom Leverage: enabling exploration of families of alternatives

* New Design Methods
  - Inherent Uncertainty: utilizing probabilistic and statistical methods
  - Multiple Customers: handling multiple, subjective, and conflicting requirements
  - Shorter Design Cycles: developing modeling and simulation environments

* Breakthrough Technologies
  - Concurrent Conceptual Design: building robustness against obsolescence
  - Aggressive requirements: using high payoff, low risk technologies
  - Immature Technologies: modeling and forecasting for risk mitigation
  - Limited R&D Budget: providing quantitative investment justification

The majority of the tools and methods for addressing some of the capability gaps in disaster response will be taken from these methods developed through the Systems Design Lab. While methods and tools from other fields may be applicable, many are inaccessible for this research and there is a degree of unfamiliarity with these external-field tools in operation and integration. The tools discussed and implemented in this research were the most accessible and their implementation was built upon a level of understanding already present.

Through the literature review it has also become apparent that some of the fields exhibit a fragmented documentation of or tutorial for various available tools, which are not only difficult to find or obtain a copy of, but also it is difficult to gauge how widely each tool or method has been implemented. This is understandable, particularly for business proprietary or military operation procedures, which often are restricted in distribution and discussion. The application of the methodology in similar fields is briefly discussed below.

4.2.2 Military Response

4.2.2.1 Needs

Within a military context, a specific set of needs requires fulfillment in order to enable the success of a specific mission or the accomplishment of a large scale objective. There are often various groups working together in different roles, which makes collaborative planning within the branch primarily assigned to the mission or objective and with other military branches important.

Commanders must also manage complex systems which fulfill various roles (single and multi-roles) in dynamic environments that often have high risk. For full mission effectiveness, each component of the responding systems must be coordinated, and supplied with the needed resources. Because often missions may be conducted in high risk environments, all personnel must be continually flexible and adaptable to different situations, maintaining consistency with commands but also thinking on their feet.

4.2.2.2 Approach to System-of-Systems Planning

The military response process is shown in Figure 8. In wartime or in a battlespace environment, prompt and efficient response to unexpected events is critical to preserving the capabilities of the critical areas where the event occurs. Various frameworks have addressed the ideas of effectiveness and interoperability, as well as other system-level aspects. The problems rising from the current systems are addressed through the implementation of actions based on the framework perspectives or views. Often the approach is very proactive, due to the nature of military operations.

While the military planning process follows similar steps to the complex systems design process, [50] which are similar to the complex systems analysis. The steps are shown in Figure 9. COA refers to Course of Action.

Another type of problem solving algorithm is depend not on logical thinking but on

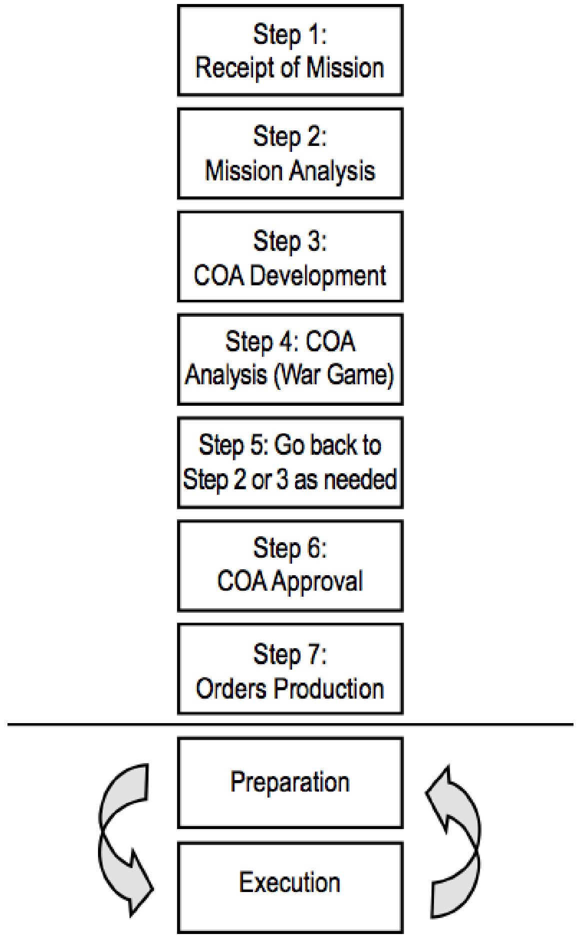


Figure 8: Military Response Process

intuition, which also has fewer steps and was developed by Klein et al. In order for this problem solving methodology to legitimately aid in decision support, the planning model shown in Figure 10.

4.2.2.3 Military Strategy

The need for military response as it pertains to disaster response planning lies in the concept of interoperability, and the ability to be connected with other parts in the "system-of-systems" to carry out a concurrently executed order without losing coordinated effort capability. Military strategy is planned and executed in an operating environment which is very different from disaster response planning and implementation. Asset allocation is dictated by an established framework, and available assets are accounted for and their specific

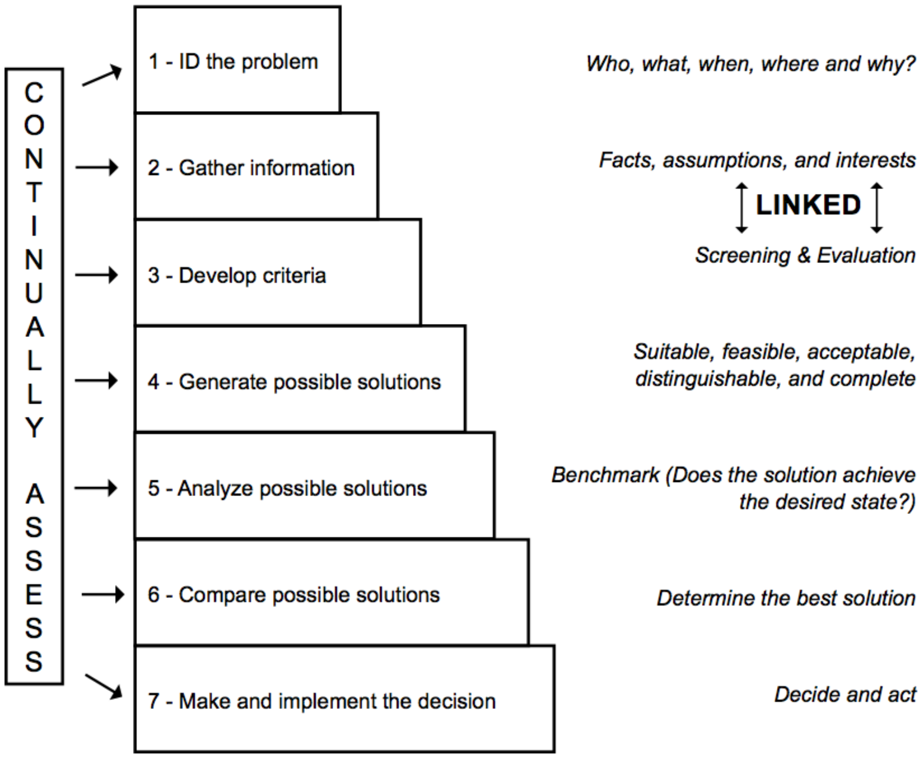


Figure 9: Military Problem Solving Process

usage is highly regulated. [112] Disaster response and restoration planning is not standardized in this manner, and because planning and response is done in a very ad-hoc manner, asset allocation must be included in the planning phases prior to the disaster occurrence to minimize delays in acquiring assets in the post-disaster response phase when the need will be the most urgent. Military mission objectives are developed through rigorous testing and assessment using war-game simulations, and this process is also standardized. A selected objective, for example, disaster response, would be given carefully developed funding structures over a specified time period after exploring the objective through modeling and simulation, and carefully assessing the needed assets and funding in order to achieve a particular state in the selected objective.

While it may seem unlikely that military strategy would have transferable objectives or principles to those seeking to change the way disaster response planning is done, there is merit in examining some of the military theory that goes into emergency or event response.

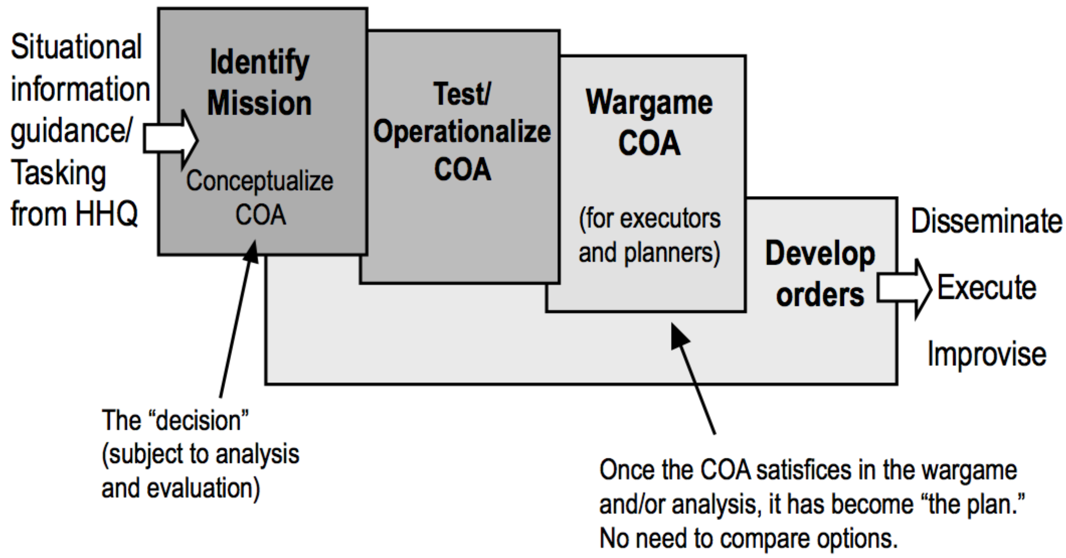


Figure 10: Military Course of Action Development and Implementation

Military theory by nature is more proactive than current disaster response. Emergency Response implementation is currently focused more on reacting to a disaster that has just occurred or building and rebuilding communities so they are more protected from possible event scenarios. The all-hazards response planning approach follows this line of thought.

Military Theory addresses the "enemy" as a system which is actively attempting to destroy the self-system. The enemy system can be broken down into components which have varying degrees of vitality to the life of the enemy system, and varying degrees of targetability. The military theory put forth by Col. John Warden gives a prioritization for various types of targets, such as political leadership, which may have a significant effect on a country or enemy's ability to respond militarily. (p297) [18]

Warden developed a Five-Ring Model (see Figure 11) of systems or entities believed to be the key areas that would need to be successfully attacked in order to bring down or severely damage an enemy system's capability to attack or retaliate. The central and therefore most critical of these five, was the leadership, or the brain of the enemy system. His theory was that both attacking this critical entity and attacking any of the other four also-critical entities would harm the overall performance of the enemy system. (p299) [18] The end goal in this type of attack would be the freezing of the enemy's capabilities. By strategically choosing and attacking certain critical targets, maximum damage would be sustained efficiently.

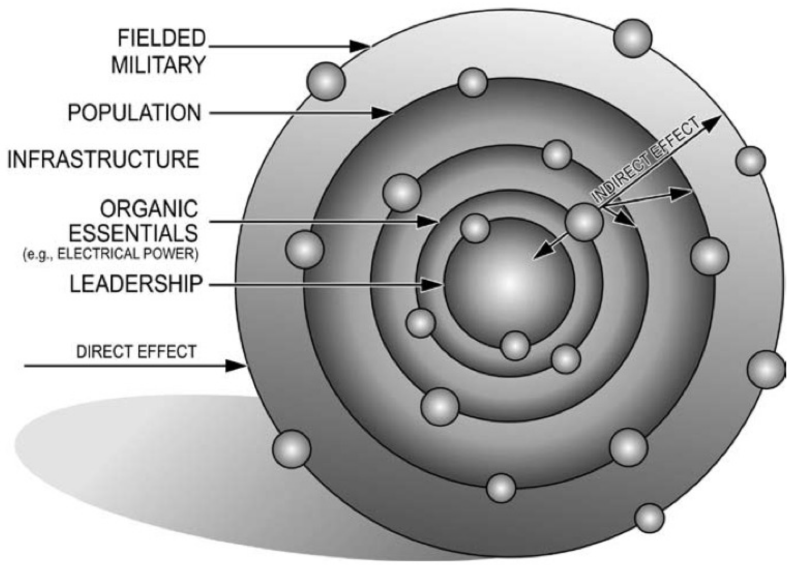


Figure 11: Warden's Five-Ring Model

Another main focus on 21st century national security strategy is the definition of main goals, or "core interests" that define the way national security policies are defined and implemented. (p121) [19] As the international theater changes, different approaches to military strategy implementation, or warfare, surface necessarily. [22] To respond to changes in the warfare environment, often times policy and technology end up being at different stages and need extra time for the policy and decision-making to compensate for the lag between those disciplines and the quantifiable disciplines which mainly focus on adapting technologically to the changing military environments. [126]

By infusing some of the advanced design concepts done by Georgia Tech's Aerospace Systems Design Laboratory [66], some decision support tools have been implemented in military weapons portfolio selection, military project morphological analysis, and various innovative methods for decision support.

Disaster response planning also has to take into account changing environments, something which military strategy also must deal with. Strategic planning and decision making tools used in military planning developed through academic research entities at Georgia Institute of Technology may also be helpful for setting up disaster response resource allocation or decision support.

4.2.3 Business Process and Manufacturing Process Redesign

With the emergence of a more dynamic market many businesses and manufacturers have been striving for product designs that are flexible enough to remain viable in the market or whose processes are changeable enough to retain high product turnover efficiency and a better way to respond more quickly to the customer and client demands. [104]

In the business world, companies seeking to significantly increase their profits may consider conducting business process re-engineering. This process, abbreviated BPR, is not intended to provide a modest percentage in increase, but rather a significant factor increase (such as tenfold, twentyfold, etc). Such a revolutionary change in response or results involves significant changes within the organization or company. Various methods seem to be available or used in the engineering industry, some of which are explored by Kettinger, et al. [82] who also put forth a general framework for BPR. Within this framework, researchers or engineers seeking to incorporate BPR into their business practices or apply BPR to a particular aspect of their company can find specific models, techniques and tools (referred to as MTT) applicable to specific situations.

Some types of products may need long setup times but only rarely would the machines be making those products for clients. Many business and manufacturing processes address the need to have several design methods which provide the ability for companies to spend less money on machine and process idle time as well as increase the throughput.

Various methods exist that BPR consultants employ, and numerous tools are available for implementation as well. These methods and tools enable companies to re-engineer their production process. [83] Kettinger et al. studied these various methods and tools, and compiled them into a standard framework which enables "organizational change" and is defined as "characterized by strategic transformation of interrelated organizational subsystems producing varying levels of impact", something which also characterizes the type of

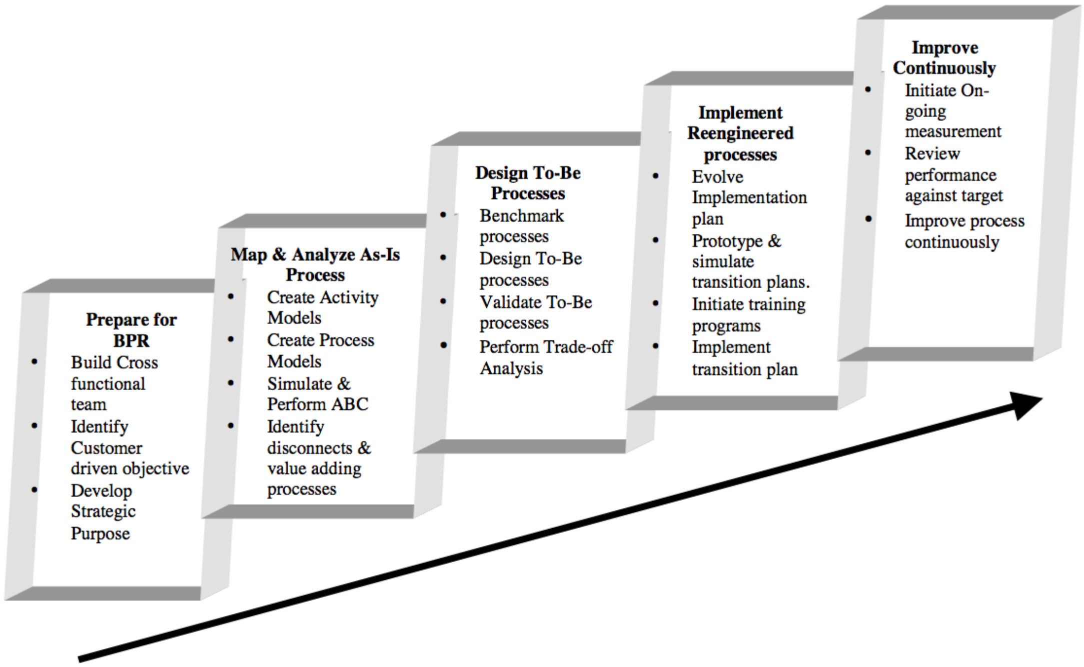


Figure 12: A General Business Process Re-engineering Methodology [104]

organization that disaster response planning often takes. Disaster response planning is also currently being transformed officially by FEMA and other federal committees.

Through various applications of management and planning tools and methods, BPR consultants are able to provide a select group of techniques which can be used by their clients. The appendix to the work of Kettinger et al. reviews several methods and tools that can be used in BPR and lists when those tools and methods would be helpful, dependent on the characteristics of the process of interest. [83] Because of the similarities in process characteristics, perhaps some of the methods detailed in the paper by Kettinger et al. may be applicable to disaster response planning.

Various technological and methodological advances and innovations have occurred in the field of supply chain and logistics planning. With the onset of fast-paced global businesses, [87] companies in the commercial industry sector need to provide demanded products without requiring large storage spaces for surplus or large lead times for provision. [141] At the same time, to keep prices competitive, this supply must be provided efficiently as well.

Addressing areas of risk and being more prepared for supply disruptions are issues that must be addressed to some degree by global businesses. [78] Globalizing demand forecasting within the organization, also known as collaborative forecasting, coordinates several local supply-and-demand clusters to improve overall efficiency. [15] Sadeh, et al. use this concept with a tool capable of handling multi-objective problems. [132]

Goldratt's Theory of Constraints introduced both a new method for approaching process improvement, as well as a new perspective altogether with the ongoing improvement concept. [70] In a process, from start to finish, various elements may require more time than others, and may be the throughput constraint depending on the production approach used. Finding these constraints is a challenge in itself, but taking steps to eliminate them is an even bigger challenge. Not only is it difficult to make changes to a process, especially for larger or more complex processes, but mitigating the resistance to changes in the workers and supervisors working with the process is just as difficult, if not even more so.

Goldratt also notes that merely making one improvement and changing peoples' minds once will only work for a time. It is important to also maintain an attitude that seeks ongoing improvement, and to culture and foster similar attitudes in workers. [70]

In the process of building an understanding of the development methods for these various fields, some aspects of each method emerged as being both relevant and implementable in this research. The three main criteria for including a particular step or aspect in the methodology were:

1. Need: Was the step needed in order to conduct disaster response and restoration planning at a quantitative level?

2. Scope: Is the step within the scope of this research?

3. Implementable? Will communities be able to implement this step?

Each methodology is shown below in Tables 2 and 3 with steps and sub-steps if applicable. The columns titled N, S, and I refer to how well each step (and/or sub-step) fulfill each of those three criteria, Need, Scope, and Implementable, respectively. Some of the steps are very similar, so any repeated steps were consolidated in the final methodology steps. The different steps are rated from 1 to 5, with a score of 1 being very inadequate and 5 being a very adequate fulfillment of the criteria.

Table 2: Methodology Development

Method	Step	Sub-step	Criteria N	S	I
Top Down Complex Systems Design	1. Establish the need		5	5	5
	2. Define the problem		5	5	5
	3. Develop criteria		5	5	5
	4. Generate Feasible Alternatives		5	5	5
	5. Evaluate alternatives		5	5	5
	6. Make decision		5	5	5
Military Response Planning	1. ID the problem		5	5	5
	2. Gather information		5	5	5
	3. Develop criteria		5	5	5
	4. Generate possible solutions		5	5	5
	5. Analyze possible solutions		5	5	5
	6. Compare possible solutions		5	5	5
	7. Make and implement the decision		5	2	5

Table 3: Methodology Development (continued)

Method	Step	Sub-step	Criteria N	Criteria S	Criteria I
Business Process and MFRg Process Redesign	1. Prepare for BPR	a. Build cross-functional team	4	2	3
		b. Identify customer driven objective	4	3	4
		c. Develop strategic purpose	2	1	5
	2. Map & analyze as-is process	a. Create activity models	3	3	4
		b. Create process models	5	5	5
		c. Simulate and perform activity-based construction	5	5	5
		d. Identify disconnects and value-adding processes	5	5	5
	3. Design to-be processes	a. Benchmark processes	5	5	5
		b. Design to-be processes	5	5	5
		c. Validate to-be processes	5	5	5
		d. Perform trade-off analysis	5	5	5
	4. Implement Re-engineered Processes	a. Evolve implementation plan	5	2	5
		b. Prototype & simulate transition plans	5	2	5
		c. Initiate training programs	5	2	5
		d. Implement transition plan	5	2	5
	5. Improve Continuously	a. Initiate on-going measurement	5	2	2
		b. Review performance against target	5	1	3
		c. Improve process continuously	4	1	3

The steps for Top-down Complex System Design and Military Response Planning are similar, and for both methods each step is within the scope of the research, except for the implementation of developed plans. This research leaves that up to the planner, since it is assumed that a re-work of the method will be needed to develop a solution plan which captures information and expertise that planners and experts can provide. The BPR Method is similar in that a few of the steps detail part of the process for benchmarking and trade-off analysis, which is needed for steps 4 and 5 of both the Top-down Complex System Design and Military Response Planning methods where possible solutions are generated and evaluated.

These methods and steps are used in parametric systems design, and the following section explains the concept of parametric design and some applications in relevant fields. The selected steps in the developed methodology enable an application of this concept to the field of disaster response and restoration planning.

4.3 Current Applications

4.3.1 Parametric Design: General Concept and Methodology

How would a planner or system designer benefit from applying parametric design methods to their system? If planners seek to quantify an objective measure, such as response planning performance or another measure that enables comparison of the a community's preparedness, development, response, and restoration in the event of a disaster, the system perspective chosen must allow such a comparison and quantification of whichever objective measure or measures is selected.

Planners will also be able to assess the community from a system perspective as a group of objects or entities interacting with each other. If each of these entities is broken down to representative aspects, those aspects can be given values and quantified. The relationships between them can also be defined quantitatively, and additionally, some response level or performance level metrics may be developed among the entities and relationships in this system. As the system is perturbed naturally or purposefully, these quantified representative aspects will change, and if the correct relationships have been developed to explain the behavior or performance of the system, the quantified performance metrics can also be monitored to see how the system performs under perturbation.

Parametric systems design will also enable true inclusion of requirements on different aspects of the system, which are complex, non-deterministic, inter-related entities. And as planners go from using the parametric design capability for assessment to using the capability for planning future development, parametric systems design will enable an exploration of the effects of possible changes for more than one different setting. For certain aspects of the system which come with limitations or constraints, other aspects of the system may be tested to see if a single or multi-factor effect will be as efficient at improving the objective measure or measures. [96]

Mavris [96] defines parametric design as enabling a user to assess many configurations of the system. Assessing designs without a developed parametric design significantly limits the amount of exploration of system configurations which may be done. Instead, by implementing parametric design in the representation of the community as a system, planners will be able to

- *test hundreds or thousands of designs* - enabling a wider range for system exploration
- *parametrically scale each design* - adding flexibility to the system
- *assess a distribution of inputs* - enabling assessment of uncertainty and variability in the system
- *aid in generation of meta-models of system* - enabling rapid system assessment and tradeoff testing capabilities

In the presence of constraints, properly implemented parametric design in a system will enable the development of the system if particular parameters or aspects are specifically defined to be capable of change or development. In the event that changes are made, or selected within the system model, effects on selected metrics and the objective measure(s) should be observable. Regarding measures and selecting metrics, if there are standard metrics available, those should be used to retain relevancy within the field.

	Alternatives	1	2	3	4
	Characteristics				
Configuration	Vehicle	Wing & Tail	Wing & Canard	Wing, Tail & Canard	Wing
	Fuselage	Cylindrical	Area Ruled	Oval	
	Pilot Visibility	Synthetic Vision	Conventional	Conventional & Nose Droop	
Mission	Range (nmi)	5000	6000	6500	
	Passengers	250	300	320	
	Mach Number	2	2.2	2.4	2.7
Propulsion	Type	MFTF	Turbine Bypass	Mid Tandem Fan	Flade
	Materials	Conventional	High T Comp		
	Combustor	Conventional	RQL	LPP	
	Nozzle	Conventional	Internal Flow Alteration	Mixed Ejector	Mixer Ejector & Acoustic iner
Aero	Low Speed	Conventional Flaps	Conventional Flaps & Slots	CC	
	High Speed	Conventional	NLFC	Active Control	HLFC
Structures	Materials	Aluminum	Titanium	High Temp Composite	
	Process	Integrally Stiffened	Spanwise Stiffened	Monocoque	Hybrid

Figure 13: An example of a morphological matrix for an aircraft system [96] (Orange parameters are the chosen configurations for one theoretical aircraft)

A basic methodology for developing and implementing a parametric system [96]:

1. *Problem definition* - identify problem or need and any potential or currently developed solutions
2. *Concept space definition* - define a concept space which may provide a solution, and establish a standard point for feasibility investigation (an available tool is the morphological matrix, example in Figure 13)
3. *Design space exploration* - generate different potential solutions based on concept space
4. *Modeling and simulation* - evaluate different potential solutions to generate system response for those configurations
5. *System feasibility assessment* - assess solutions and respective responses for feasible solutions
6. *Technology Identification* - identify potential improvements via technologies which may help to meet different constraints for the system
7. *Technology Evaluation* - evaluate technologies for effectiveness in meeting constraints or improving response(s)

8. *Technology Selection* - select technologies to implement into system to improve response(s)

4.3.2 Engineering Systems Design

The engineering design process is shown in several steps in Figure 14

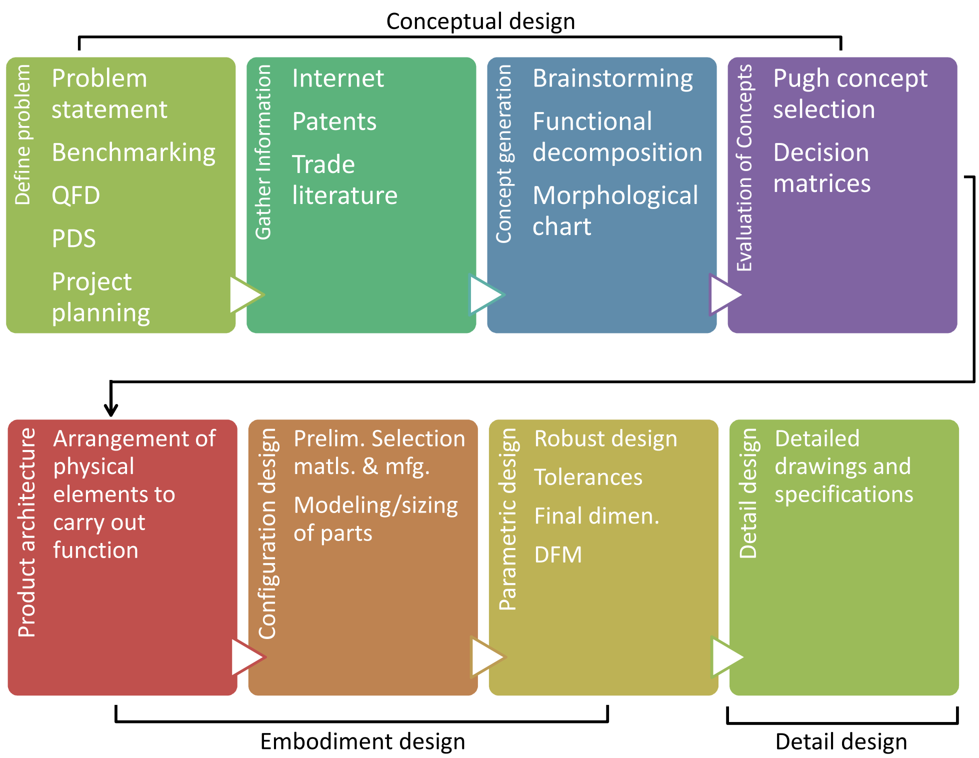


Figure 14: Conceptual, Embodiment, and Detailed Design Phases

During embodiment design [1], the concepts and objectives are incorporated into the detailed design through product architecture design, configuration design, and parametric design.

During the product architecture design, the parts of the engineering product are given a layout so that the product purpose is fulfilled. Specifically, each aspect of the product and its connection with the other aspects must contribute toward the overall goal of the product

[1] also referred to as preliminary design

at a system level. [45] Each product is composed of a group of aspects, or parts. Dieter also refers to these parts as subsystems, clusters, or modules. Depending on the type of architecture, the subsystems can be set up differently, but each subsystem has a defined set of functions that it performs, and the subsystems can be linked together through defined interactions.

In a more general sense, this process is also applied to developing systems which may not specifically be physical products to be manufactured. Mavris [96] discusses the paradigm shift occurring in both systems and physical products. Traditionally, design has been done deterministically - that is, there are a handful of considered solutions around which the design is fixed. This design typically is a point design or point solution which may not be the optimal solution for the given needs, but was the concluding design after design iterations were made within the time and cost limitations. Because engineering design (and specifically aircraft design) experienced a change in design limitations and requirements, such as a reduction in available time in which to make design decisions coupled with more developed and more complex products, a need rose for more required analysis toward the beginning stages of design, as well as a need for multi-functional capabilities.

The second part of the embodiment or preliminary design is the configuration design, during which the relationships between the subsystems as well as the subsystem definitions are defined. During this step, the design is assessed for redundancy and interdependency, and changes can be made to reduce or increase it within the design. Material constraints and production limitations are also applied during this step. [45]

The parametric design is done next. During this phase of the preliminary design, the different parts of the system or product are used as design variables. The designer has the option of changing these variables, ideally to the optimal configuration which will produce the best design to fulfill the design objectives. In the parametric design, there is also a focus on developing the robustness of the system, which can be defined as "achieving excellent performance under the wide range of conditions that will be found in service." [45]

4.3.3 Strategic Decision-Making Methodology

There is much information which may be offered by the results of parametric system design, particularly after an exploration of the system has been done. However, merely having the information is not sufficient for decision makers, who may be searching for areas with less developed capability which will benefit from more focused funding or development programs with the objective to improve preparedness for a disaster event or response, or optimizing another specified objective.

These decisions for funding or other implemented actions may be based on some goal for the community. That goal may be an ideal setting of the different community parameters, which may be based on the results of a particular scenario in the parametric design environment.

As discussed in the previous section, part of enabling parametric capability includes developing a way to quantify some of the important measures that will demonstrate if an objective or goal is being met based on the parameter settings which define the rest of the system. There may be more than one measured objective value, or they can always be consolidated into the overall objective value.

Different combinations of parameter values represent different possible systems which may or may not meet objective criteria. Within a range of parameters there may be hundreds or thousands (or even millions) of particular combinations of different parameter values, which satisfy an objective criteria. Each of these combinations represent an individual solution and while the solution is a possible one, if behaviors of different parameters are known, it would be possible to improve the objective measure value by changing some of these parameters in the proper direction.

Depending on the approach used to develop objective criteria, there may be more than one possible combination of parameter values, known as the solution, which satisfy the criteria or optimize the objective(s). This group of solutions cannot all exist at the same time in real life, so one must be chosen by a selection method.

Once the solutions are ranked in some fashion, there will be one that ranks at the top. If the criteria for ranking the solutions are based on some weighting means, those may also be subject to change. This means that depending on different situations, different solutions may be ranked the highest.

4.4 Application of Tools to Parametric Disaster Response

In selection of appropriate tools and methods to implement in the solution for Disaster Response Planning, several capabilities are included in the requirements.

Value - The solution components must contribute to the understanding of the system or community through enabling decision-makers to perceive this information. Knowledge added has value in the system planning and components should contribute to the value of the solution through added knowledge. If there is no method currently used to determine value, this method also needs to be selected from another field or application within the same field. If no other fields have an applicable method it will need to be developed.

Efficiency - The solution components must contribute toward channeling the available time for assessment to focus on priority areas for development, preparedness, response, and restoration.

Effectiveness - The solution components must contribute to enabling planners and decision-makers to know which improvements and actions will make the most difference in the objectives for the response and restoration of the community.

Flexibility - The solution components must be capable of updates so that the solution does not become obsolete after a few years. Different parameters or metrics may become linked to certain components or behaviors through research or other disasters, and in order to improve any developed system models, this flexibility must be available.

4.5 Integration with Disaster Response Planning

In order to integrate the concept of Parametric Systems Design with an application to Disaster Response Planning, three different phases and each of the steps within those phases in the design process must be implemented. During the design process, architecture design occurs, where a top level view of the system is set up, during preliminary design more specific details are added to the model, and during parametric design those values are quantified and an evaluation method is set up.

4.5.1 Architecture Design

- Breakdown system into different subsystems
- Show their placement symbolically
- Show how resources flow through the system
- Show relationship between subsystems

4.5.2 Preliminary Design

- Specify components of subsystems
- Specify more detailed relationships among subsystems and components
- Check system architecture for redundancy
- Check system architecture for limitations

4.5.3 Parametric Design

- Determine possible values (or ranges) for variables
- Set up a way to evaluate system configuration
- Evaluate system for design objectives

4.5.4 Design for Disaster Response Planning

While the engineering design cycle easily benefits from parametric capabilities, disaster response planning comes from a different field and enabling parametric system design in this field will need to be carefully implemented.

Top Level: Develop Response Process - Cycle, not Linear Through observations of different types of disasters, the response and rebuild/restoration phases, as well as disaster recurrences in different communities, the more reasonable understanding of the disaster and it's surrounding phases began to be more of a cyclic phenomenon, similar to what Rohit [79] saw in his research. One of Rohit's diagrams from [79] is shown in Figure 15.

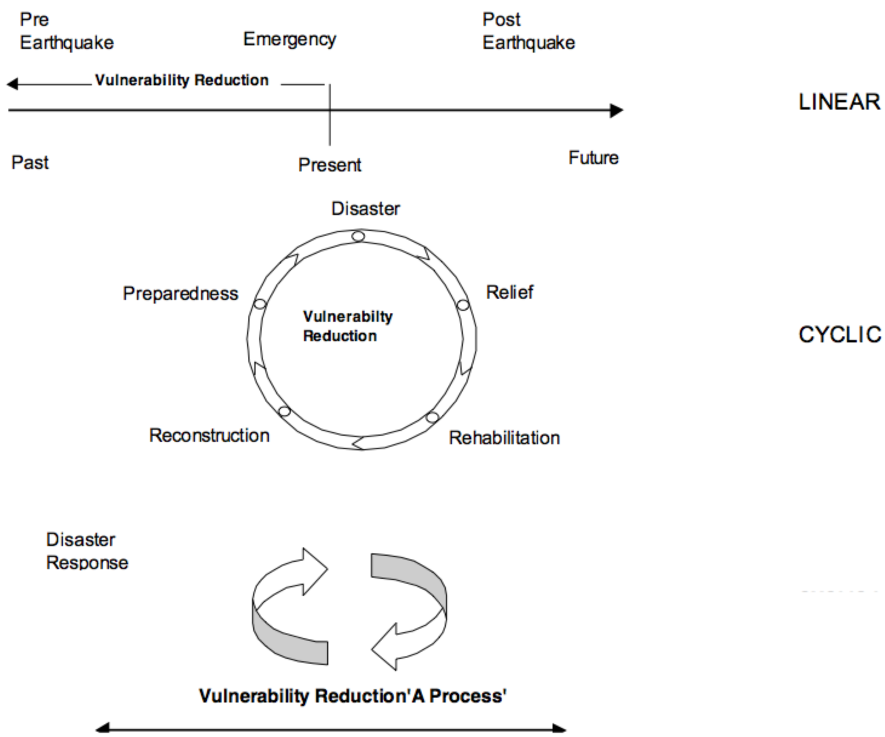


Figure 15: A comparison of a linear approach to looking at disasters versus cyclic approach [79]

The main tasks in enabling the parametric capabilities for a community-specific disaster cycle center mainly around ensuring that representations of the community are as accurate as the desired level of detail but also that they do represent the community characteristics, and also on enabling a quantifiable evaluation of the community in some way.

Tasks include the following:

- Specify common inter-community parameters
- Specify parameter relationships

- Enable measurement of outcome
- Enable system evaluation
- Evaluate system

4.5.5 Enabling Parametric Systems Design Capability

It is important that the system be properly defined. Does it include external resources or regions outside of the jurisdiction of the current location? Will the system be addressed at a local, state, national, or even global level? FEMA's disaster simulation software is capable of scaled levels of detail. Users may select whether they want to address the disaster from a census tract level, county level, or state level.

Next an understanding of the system must be developed. Different aspects of the system will set it apart from other similar systems. With any populated geographic region, there are hundreds of parameters which help to define some of these aspects. They include social and demographic characteristics, geographical characteristics, environmental and tangible infrastructural characteristics such as transportation network breadth or the number and types of schools within the region, as well as non-tangible infrastructural characteristics such as disaster response training programs.

A deep understanding of the system to be parameterized is also beneficial because from these many parameters metrics must be selected. However, some level of detail may be too much while backing off too much may reduce the amount of useful information which would be available to the designer. If some metrics have not yet been defined it is important that they are well-defined, or the designer may misunderstand what each metric is for and mis-develop relationships between parameters.

To reduce the complexity of the many parameters of a system, the parameters can be categorized hierarchically. This enables different levels of groupings and simplifies details for top-level or system-wide assessments, while retaining more detail in lower level parameters which may be where the data may be more available. Esoteric metrics such as "Stability" or "Development" may not have direct quantitative metrics but may be broken down into categories such as Type of Government, Average Debt per person, or Currency strength for “Stability” and Social, Economic, Environmental and Physical Development categories for “Development”. In the case of the parameters which make up Stability, those numbers may be directly quantifiable based on different available statistics, while the Development parameters may need to be broken down yet another level in order to be quantitatively defined with available statistical data. However, a user or planner may choose to leave the development parameters at their current level and define those values directly based on their experience or other reasonable means.

Part of the development of the parametric design capability in the disaster response planning field is due to the assignment of metrics within planning parameters. This enables some sort of performance definition or community status definition to be quantified. If quantification is too difficult, at first the metric can be developed through setting up two or three qualitative levels (such as low, medium, or high) which can then be assigned values.

In addition to developing a hierarchy of parameters to define a system, the relationships among these parameters must also be developed in a way that describes the behavior of the system as accurately as possible. This enables the user and planners to understand what happens to the rest of the system when some of the parameter values change. This may require the selection of or tracking of some measure or measures, similar to performance metrics which are assessed for performance measurement. Also because of the complexity of the system and because some aspects are not completely understood within the disaster response system, there may be some difficulty in determining the effect of some parameters on the performance measures. In those cases estimates should be used but enough flexibility should be retained within the parametric capability being developed which enables further refinement of the developed relationships among parameters and performance measures, if better knowledge becomes available.

4.6 Selection of Approach Methodology

The discussed approaches from the Systems Design, Military Planning, and Business Process Redesign Fields address some of the capability needs in Disaster Response Planning, a field whose requirements for complex system-of-systems planning is not too dissimilar. The developed framework will be based on concepts and steps specifically used in the complex systems design methodology. This methodology enables parametric design of complex interdependent multi-disciplinary, multi-objective system-of-systems and enables a more holistic exploration of the system-of-systems innate and emerging behaviors.

The tools and concept employed in this methodology are available to use in research through local resources and are familiar to the researcher. The roles of the tools and concept will be defined so that if this methodology is to be implemented in an environment where the specific tools are not suitable, the different roles of each tool will still be fulfilled.

Also, data, proprietary tools, and some analytical methods developed by or for military and private businesses may be "restricted-access" for external and non-military personnel.

4.6.1 Significance and Purpose

The overall steps outlined for this methodology are meant to enable a holistic perspective of the system as it is relevant to the designer or planner. For planners with access to more knowledge about particular communities, expert knowledge can be captured with the decomposition and definition steps, and can also be used to check for validity in system exploration. Figure 16 shows the different steps in the methodology.

4.6.2 Selection

4.6.2.1 Community Selection

First the system must be selected and described in some type of standard form in order to enable planners to understand the vulnerabilities, capabilities for response and restoration, and resiliency of the system. For disaster response planning the system may include a particular community and its respective phases within the disaster response cycle.

4.6.2.2 Disaster Event Selection

The type of disaster which the community is to be subjected to should also be selected.

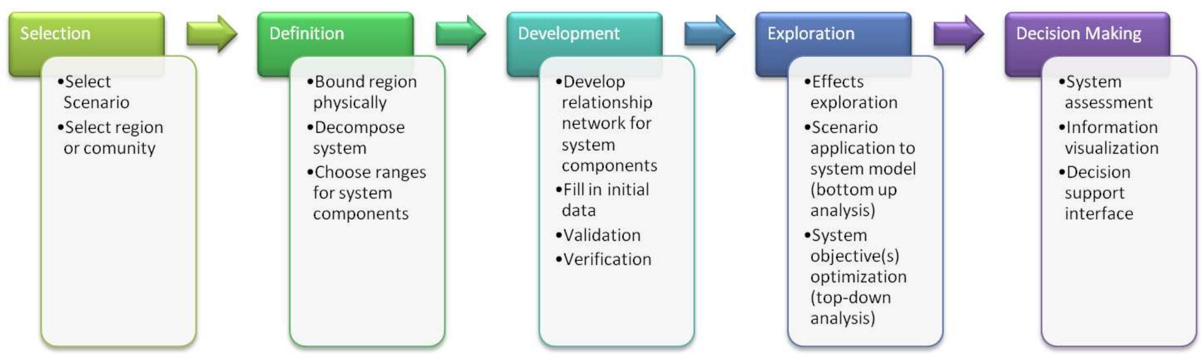


Figure 16: Methodology for Exploration of System-level Capability through Aggregation and Analysis of Parametric Elements (ESCAAPE)

4.6.3 Definition

4.6.3.1 System Decomposition

The system is decomposed to components at a number of different levels. This should also include components relating to the system preparedness, aid and response after a disaster, as well as different areas of community development. The system components can be further categorized and decomposed into more specific components. Several layers of hierarchical components may be developed, depending on the system itself and the level of detail needed.

4.6.3.2 Objective Measure Selection

An objective measure (or measures) is selected. The main objective used in the application of the framework is the Restoration Time. The Restoration Time is defined as the time from the occurrence of the disaster to the time when the community has redeveloped itself and rebuilt itself and continued building until a certain standard of development has been achieved. The metric used should be quantifiable or measurable in some form to enable comparison over time or with other communities.

The more knowledge a user or planner(s) has about the community of interest, the easier it will be to transform that knowledge into a developed system description model. Initially, some objective measures may be either selected or considered. As the model is developed, the planner may return to the objectives and assess which they would still like to consider or plan for within the framework. Figure 17 shows a simple example of a system decomposition.

Metric Development Within the disaster response planning field few standard metrics exist. While the infrastructure for this is slowly changing, it is important to use standard measures, or develop measures from standard available data for the system (community) to build a comprehensive system description.

The method for metric development used in this research encompassed the following steps:

1. Observation

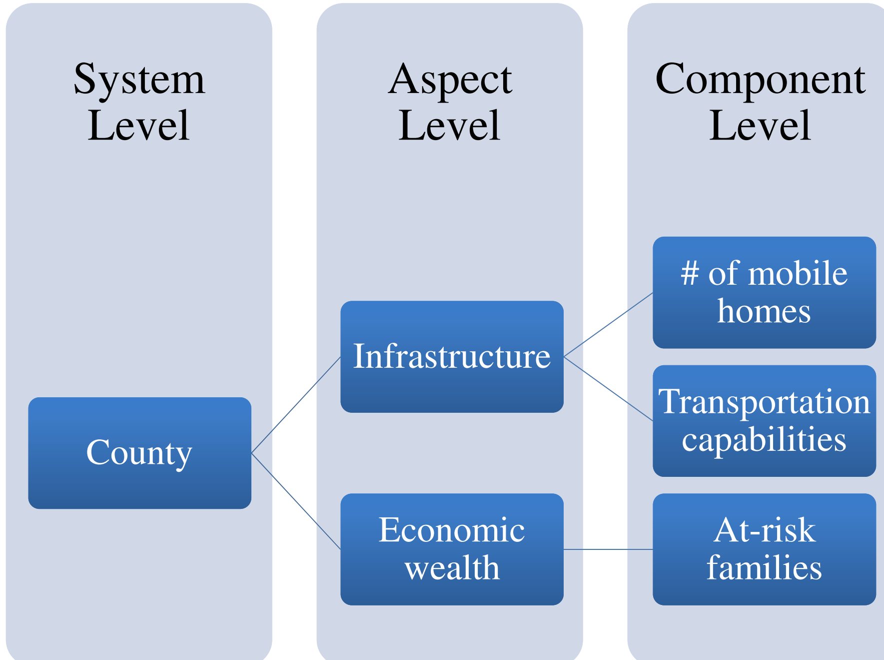


Figure 17: Example hierarchical system breakdown

2. Selection

3. Quantification

Observation Based on the literature review and any expert input available, certain indicators will emerge as more important and more monitored than others.

Selection Selection of the indicators is done based on its relevancy to the component which it will serve to quantify, whether or not statistical data will be available to quantify those indicators, and whether or not the indicator will be appropriately quantified by available statistical data.

Quantification The selected indicators must also be quantified, and the indicator and its selected data elements are quantified through the following steps:

1. Determine high and low boundary for data element

2. Determine quantitative values if qualitative
3. Input proper data element to make the value specific to the community
4. Normalize the value
5. Aggregate to input level in the developed model

The aggregation of the data is done with a weighted sum calculation. By default the weights are equal but that may be easily changed. Further discussion of this issue is done in Appendix A. Currently used indicators and a further discussion of metrics is done in Appendix B.

The term "aggregation" is used to encompass both the weighted sum calculation used for the input parameter calculations with data elements as well as the developed relationships within the model, which may not calculate the response parameter(s) using the same type of calculation.

4.6.4 Development

Once system aspects have been categorized and decomposed hierarchically, relationships must be developed among system components and parameters. This may be done in concurrence with the system component selection and definition, in order to reduce confusion about some of the relationships between different parameters. Relationships should be developed based on available data, but in the case of different disaster response systems, often these relationships are too generally documented, with no data, if documented at all. However, news media and different aid organizations, both national and intergovernmental, have begun to make more information available about disaster response.

4.6.4.1 Inter-component Relationship Definition

Careful reviewing of literature and reports reveals some patterns in the relationships among some of the variables. Additionally, relationships may be developed with the aid of not only published literature and media reports, but also with the input of seasoned experts who understand either the community itself which is being defined, or the response and restoration process. The relationships should all be checked in some form in order to show that any information that may be gathered from this model of the system will be as true as possible to the actual behavior of a community within the different phases of the disaster response cycle.

4.6.4.2 Data Element Selection

The most detailed parameters may not be defined by any available data points. If this is the case, the value (and/or relationships) may be assumed, or further decomposition may be done, using known available data elements to comprise those particular parameters.

For example, a vague parameter such as "Readiness" may be further decomposed into data elements which can be found already available for the particular community of interest. Some example data elements might be "Total shelter capacity in event of emergency (for the region)" and "Percent of city serviceable by power line repair companies within 24 hours of loss of power (for the region)", which are bits of data that are available within the FEMA HAZUS-MH program.

One thing to note is that more than one of the various data elements may be used for each particular parameter. Some of the parameters may re-use a data element. The aggregation method of these data elements up to the top-level system components should also be specified. The aggregation method used in this research was a simple equal-weighted sum of all the data elements for each parameter. This may not be the best method, especially for some parameters which had several data elements, compared to some which only had three or four elements. With more expert input or available data and reports the aggregation method of the data elements may be improved. Figure 18 shows a simple example of some relationships developed among some of the aspects and components of the system. The particular relationships in Figure 18 may initially just be that one parameter increase causes an increase or decrease in another parameter, but further research and model development will enable a more mathematical relationship to be specified.

A viewer can then easily see the relationships among the component level parameters, even if they are not grouped within the same aspect. Likewise, the aspect level parameters

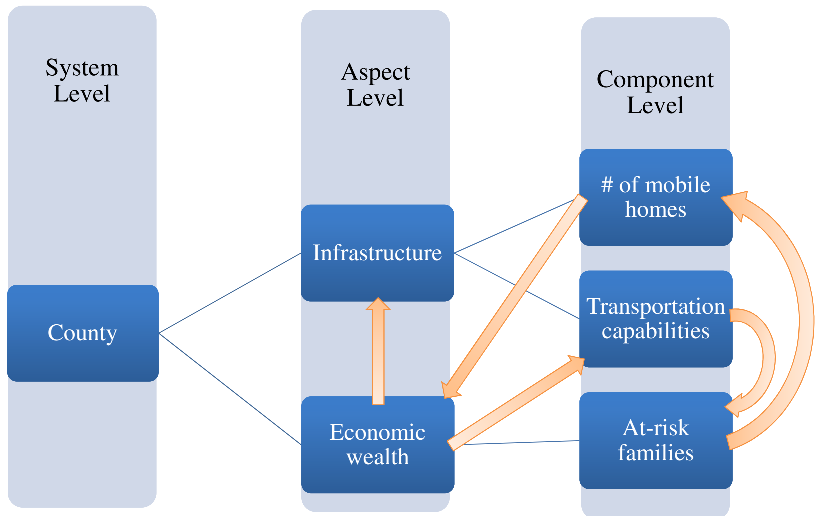


Figure 18: Example hierarchical system breakdown with inter-parameter relationships

have a defined relationship as well. There are also relationships developed among the aspect level parameters and component level parameters. Although the specific relationship formulas are not defined or shown for this example, it may be something as simple as "higher level of economic wealth (as measured through the percentage of the population which falls into the at-risk family category) is usually present for communities with greater transportation capabilities." Since transportation capabilities is a somewhat general term, it may need to be further decomposed, or different data elements defined for it.

Once the relationships among the system components have been developed for a hierarchical decomposition of the system, relevant data should be filled in where needed. For components which require data elements, this data must be input. There are various venues through which the developer of the system model might find the data. Some sources and venues are more reputable than others, and in some cases the data may not be available at the level of detail at which it is desired. Chapter 7 discusses what to do about the reliability of the data, or if data cannot be found. Once this part is done, more understanding of the system may be done through system exploration and the system validation.

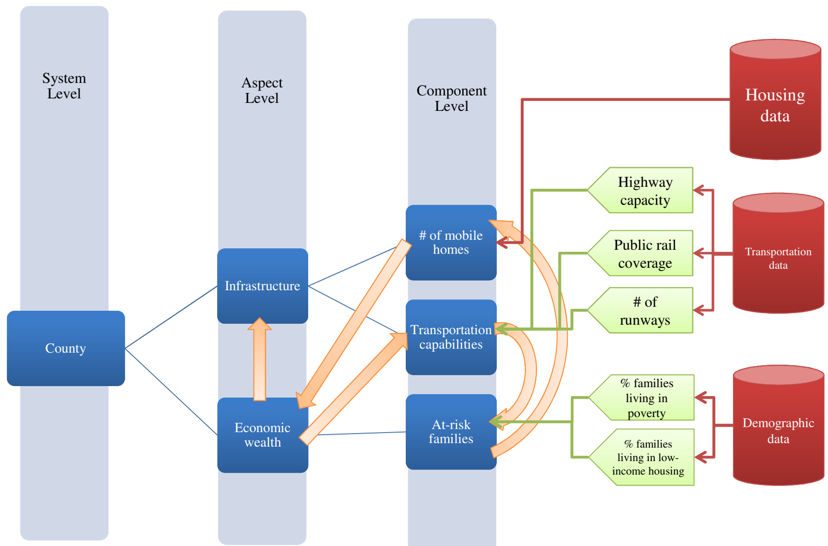


Figure 19: Example hierarchical system breakdown with inter-parameter relationships and data elements from different sources

4.6.4.3 System Model Development

The system model is also developed in this step in the framework. The process for the model development begins with selecting the approach, then the software environment, and then the data. Available literature and expert input should be utilized whenever possible through the development process.

1. Select Approach - based on literature and available expert input, a system development approach should be selected which is appropriate to the system
   (a) Select main aspects of the system
   (b) Show interactions among the main aspects through feedback loop diagram or similar diagram

    (c) Select main response variables through stock and flow diagram or similar diagram

    (d) Decompose system to desired level of detail

2. Select Development Environment

    (a) Adjust the feedback loop to show how each parameter may be affected by the disaster event

    (b) Implement any other inter-parameter interactions and effects in the development environment (software program)

    (c) Calibrate model - adjust the relationship factors so behavior of the top level parameters is reasonable and follows data trends if data is available

3. Select Data or Situation - most communities within the US have community data available, but may not have enough data available for use in the calibration of the model once it has been developed in the software environment. That was true for this research. The selected communities are examples of assessments which may be done for the selected counties, but because the available data was not enough to calibrate the model to the specific communities, the absolute assessment capability is incomplete. The developed examples show the implications of the ESCAAPE framework implementation and allow relative comparison of different example communities and exploratory tests.

Figures 20 and 21 show the graphical depiction of the model development steps and how the process fits into the ESCAAPE framework, respectively. The gray arrows under the "Tools Used" and "Selected Options" headings show the particular model development tools and options selected for the implementation of this research. The methodology for both the model development as well as the framework implementation are modular in nature, as long as the selected tool enables the completion of the same tasks or functions, and as long as the selected options are properly categorized and are selected at the proper hierarchical level.

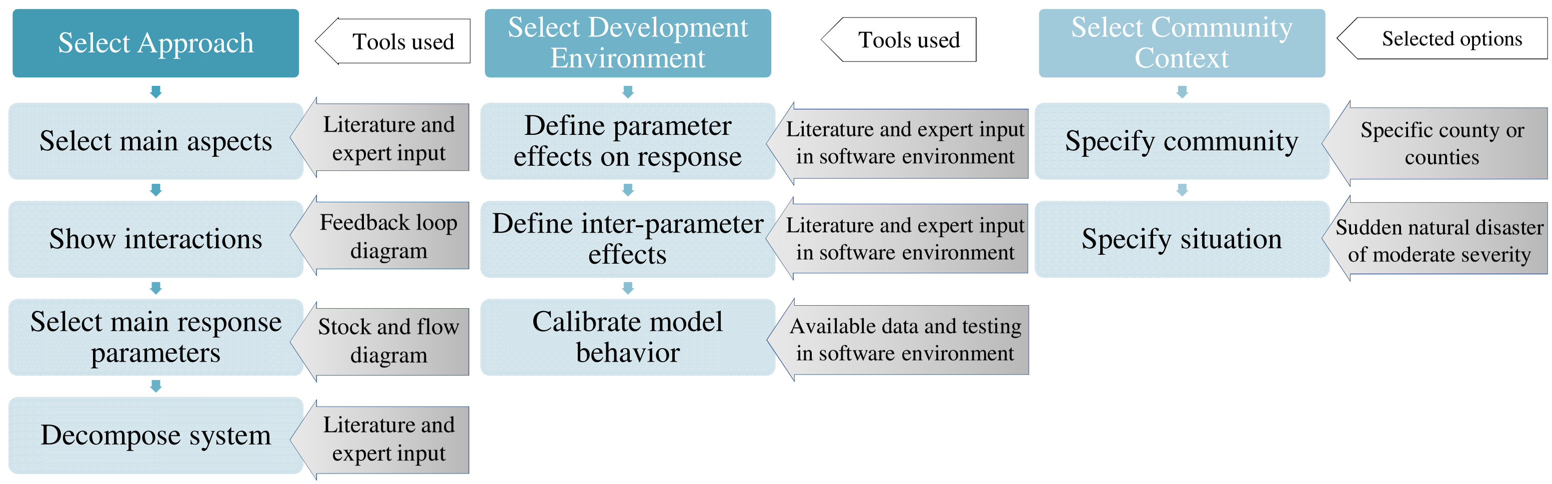


Figure 20: Model Development Steps

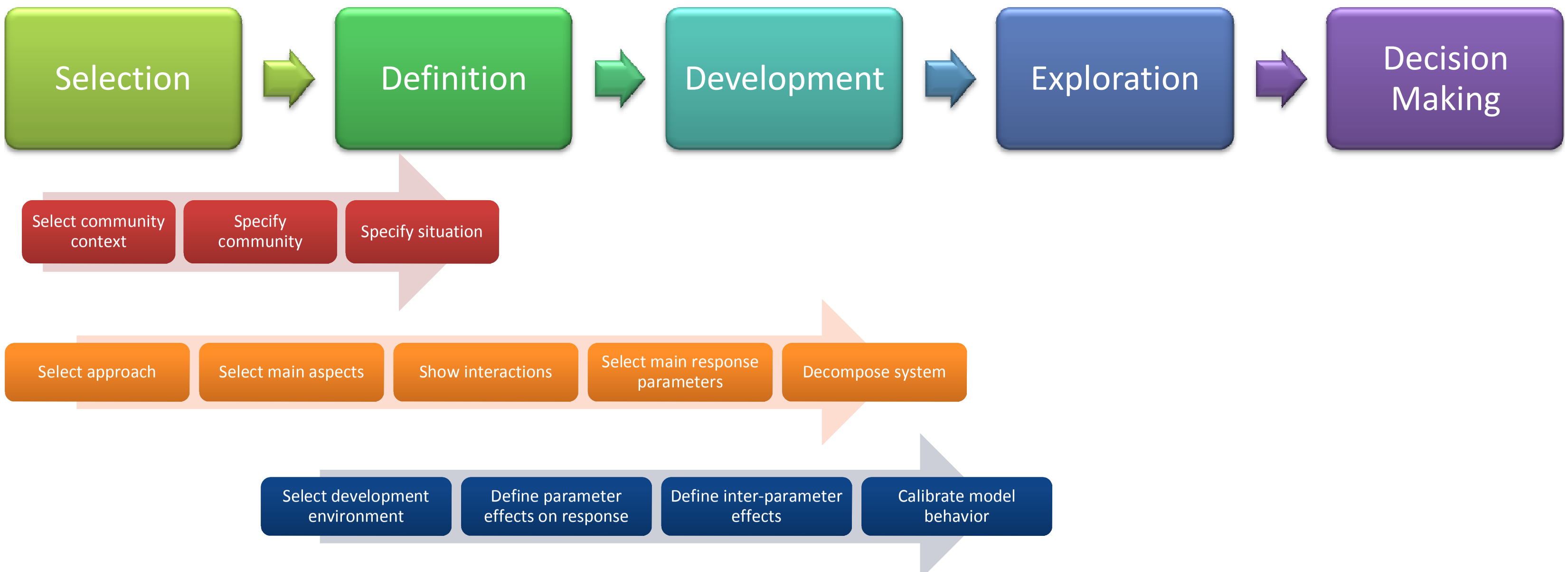


Figure 21: Methodology Development in ESCAAPE Framework

4.6.5 Exploration

Once the hierarchical decomposition of the system has been set up with as-best-as-possible inter-component relationships and as-best-as-possible data elements to help define the system as it is in real life, the system must be shown to be within a reasonable likeness to both what it has been designed to represent, which is the developed system model discussed in previous sections, and the actual community which it is to represent. Once it is shown to be thus, a thorough understanding of the system should be built through a means of system exploration.

For this research, the developed model was able to quickly explore small ranges of the system, but a complete system exploration test would take more time than was available. Once the original model was developed, verified, and validated, a surrogate model was built to represent the original model behavior but enable much faster system exploration. This model was also verified and validated. The process for both model developments and definitions are included in Chapters 7 and 8.

4.6.5.1 Original Model Verification

Because of the lack of precedents in disaster response cycle system measurements and observations, verification for the model was explained with the logic used to build the model if data was unavailable as far as the relationships of the different components and parameters. The software program which was used had the capability of observing the values for different components over the course of the simulation.

The simulation was set up to take place over a lengthy period of time in order to enable observation of pre- and post-disaster values of different parameters. The logic for the original system model was also checked against the output for these different parameters. If the simulation trendline followed the expected values based on the defined relationships and setup logic, it was considered verified unless better verification methods were available.

4.6.5.2 Original Model Validation

The system model must also be validated. This may be done within the ranges of its design, since for a well-designed model any testing which must be done will be most stable, with less risk of failed cases.

Throughout the simulation some of the more intuitive variables may be compared to some existing literature or explained in reasonable terms. More expertise input or community trend information would be helpful for improvements as well as for verification purposes.

4.6.5.3 Surrogate Model Verification

The surrogate model was developed based on data points which were generated by the original model. Once the model was developed, these points were chosen from the development set and tested to make sure that the surrogate model was capable of modeling those points.

4.6.5.4 Surrogate Model Validation

If time compression is needed, that is, the original system model is too cumbersome to explore the system in the available amount of time, a surrogate model may be used to enable system exploration. The surrogate model for this research was a Neural Network developed in Matlab, which was used in system exploration. The model was developed to represent the system in the selected ranges where the data was available. The validation for the surrogate model was done with extra solution points, the results of which were generated by the original model. However, the surrogate model development did not include these points.

4.6.5.5 System Behavior Exploration

After the system model is developed, or the surrogate model is created, more extensive system exploration may be done. The purpose of the system exploration is to provide an understanding of the behavior of the system so that design improvements may be made. In the case of the disaster response planning, such improvements are done developmentally. Also in the case of disaster response planning, many of the parameters have the possibility of changing over the course of the restoration process, and it is important to understand the implications of those changes on the overall restoration time.

The reason for this is that if a community has not completely restored itself, and a change in some parameters cause the restoration time to be pushed farther into the future, if a disaster occurred, the results would have a more significant effect on the community than if that restoration time had not been increased.

For the exploration itself, some type of simulation experiment design should be selected. This could be a space-filling design or another type as selected by the developer or planner. The choice should take into account the interdependence and complexity of the model, since the system relationships and complexity level are presumed to be known by the planner.

As a note, developing a surrogate model for the system is not the only means by which system exploration may be enabled. Other enablers include refining the model so that it is faster in simulation, using other approximation methods depending on the complexity of the original model, and if possible, utilizing cloud computing or super computing resources that are available.

For this research, the outcome of one and two-factor effects were explored. This information was then organized visually to provide information for a planner or other person or persons who may be interested in the effect of different parameter values on the system.

Other exploratory tests may also be done, which may include testing different scenarios and the system objective parameter behavior in those settings. The characteristic behavior of the system should also be understood during this step.

4.6.6 Decision Making

Once the system understanding is developed, that knowledge can be implemented in a fashion which improves a community's ability to focus different resources for development. This will maximize the effect of any improvements to speeding up the response and restoration time, as well as increasing a community's ability to effectively pursue different developmental projects which will aid in disaster preparedness.

4.6.6.1 Community Assessment

Analysis of the current system objective parameter values is done, as well as assessments of the different scenarios and system behavior tests. This assessment can provide information about system capabilities and areas for improvement. Assessment and the information presented therein should be presented in a receivable form.

4.6.6.2 Presentation of Information

Using the data from the system exploration, information about the current community situation can be shown both visually and quantitatively if proper metrics and measures have been set up. The model output data should indicate where the community falls within the allowed model range. If dynamic visualization is possible, with user interaction, planners may be able to interact with the data to assess the outcome of different community statuses for different input situations. This visualization should be visually understandable and updatable.

If uncertainties are known they may also be incorporated into the model so that variations in the community situation may also be considered. For example, poorer parts of one community may take longer to restore their part of town than wealthier parts of the same community, and this is one source of fluctuation in the restoration time.

If any sort of benchmark has been developed, the community may be compared to that if the data is available. Currently there are no widespread benchmarking methods for community development as it pertains to disaster response.

4.6.6.3 Community Improvement Planning

Community Goal While there are no standard benchmark methods for disaster response planning in the aspect of community development, within the assessment of the community situation, a goal value for the objective parameter may be developed.

The selection or development of the goal, or ideal value may be done as an understanding of the system is developed. Within the ranges defined for the system, particularly in terms of its variabilities and uncertainties, if changes are made in particular system parameters, the objective parameter may be improved.

In the case of using Restoration Time as the objective parameter, a lower Restoration time is always better than a higher restoration time, even if it is not possible. Being able to more quickly repair the community in an effective and efficient way enables a faster return to a community situation which is more capable of handling a disaster than if a disaster occurred in the midst of rebuilding processes.

Some of the system parameters within the developed system model will help to decrease the total restoration time. These parameters may be made up of data elements which would provide the tangible and observable basis for the change in the objective parameter.

If such a goal is identified, and the current community situation is able to be assessed, the quantified "distance" from the current situation to the goal will be known. Parameter relationships and component decomposition knowledge offer a way to begin planning for improving the objective parameter toward the goal.

Development Toward Community Goal Once the objective parameter goal is defined, planners have the opportunity to implement the assessment. In order to focus on areas which will improve the objective most effectively, the components and parameters must be assessed for the direction and distance of necessary improvement. Improvement should be sought through an objective parameter which improves the community as a whole, or at the system level.

Because there are so many parameters which help to define the community itself and the disaster preparedness, response, and restoration system, knowing which parameters will be easier to improve will help to give direction to any preparedness planning or developmental projects which aim to improve (lower) the restoration time.

Also, since the system parameter relationships are interdependent, as some parameters improve, others may change as well. Implementation of improvement plans should take this into account. One method might select an optimal "path" among various parameters, selecting to improve one parameter at a time until the entire system is optimized. Another method may include assessing improvement from different groups of parameters and changing their values until the objective parameter has reached its optimum for that combination. Multi-directional improvement methods may also aid in the optimization of the objective parameter in this case. Several options should be considered and the most appropriate chosen and implemented.

Expertise from knowledgeable field personnel may also be implemented. Having the whole of the community situation defined quantitatively may enable better expert decisions to be made. This may supersede decisions which may be selected as "optimal" based on the objective parameter optimization within the defined model. This will enable greater effectiveness with current methods, improve the implementation of available knowledge, and enable communities to assess themselves and select directions of development which suit their communities best while helping to develop better plans for future disaster occurrences.

4.7 Application of Methodology

4.7.1 Scope of Methodology

The scope of the methodology within this research context remains a long-term perspective on the community restoration capability. The level of detail must be specified or it may become confusing to develop the model to utilize the same level of detail. Although the high level of detail makes the data gathering somewhat cumbersome, further research may reduce the amount of data elements and variables needed to describe the community characteristics. It may be easy to generalize some detail areas where the details may be needed to help describe the community, or include details for the community which do not need to be included.

Each phase in the response cycle is included in this research. However, alternate model developments are capable of narrowing the scope to, for example, a near-term response assessment. While the disaster response phase is very important for the restoration of the community, it is assessed in context with the preparedness and development of the community, as well as the effects of the disaster event. The effects of the response phase may be tested, however, for their contribution to any changes in the restoration time (long term). Trade studies where, for example, asset allocation is varied may be done to observe any changes in the restoration time. Additionally, a shorter-term time frame may be used but it would require either a careful transposition of the long-term developed system model, or a redevelopment of the model and its parameters and relationships altogether.

4.7.2 Implementation Context

The implementation context of this methodology would be for persons planning restoration after a disaster at a community level or higher. There may be opportunity to implement some changes to the community before a disaster occurs and exposes existing vulnerabilities within the community. The methodology strength lies in addressing needed improvements or testing possible improvement plans prior to a disaster occurrence so that the effect of the disaster may be reduced or the restoration time of the community after the disaster occurs may be reduced.

The definition and system development would require expert input through workshops or other means of collaboration to ensure that the system behavior is representative of the community, and that the values in the model are reflective of similar values in the community. A morphological matrix would provide the opportunity to address several different situations that the community may face, and would also dictate the values of the specific input data elements.

Figure 22 shows the context within the disaster timeline for a community where the methodology would be implemented. Expert knowledge and gathered data from the previous disaster would be used to develop a morphological matrix which would provide some scenario alternatives for planners to address in planning. This may be done through collaborative planning exercises and workshops.

These scenarios would specify inputs such as community parameter values and behaviors to be used in the ESCAAPE Methodology with the available community data. The changes selected for implementation in the community would then be implemented. The implementation would ideally occur before the next disaster occurrence. Specific and selected responses would then be measured through different objective parameter values. The bottom of Figure 22 shows the different phases in the response and restoration phase and

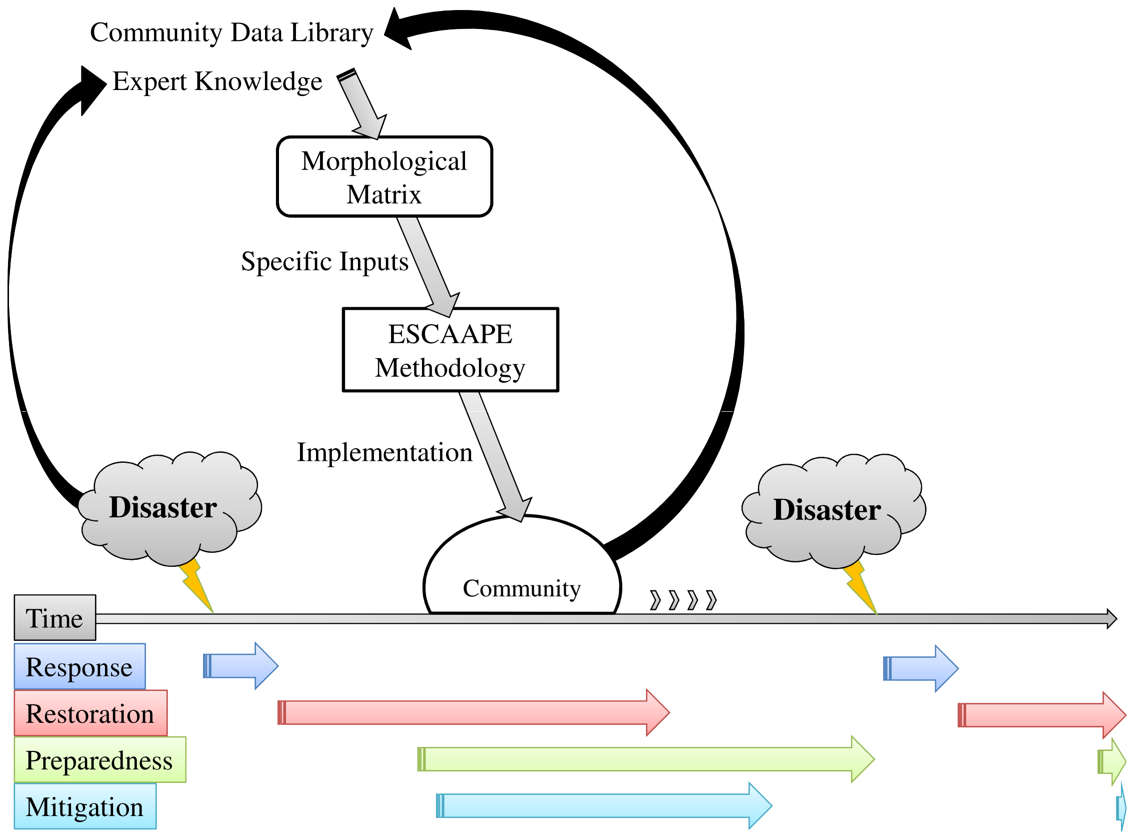


Figure 22: Methodology Implementation Context

their overlap if it occurs.

The ESCAAPE Methodology may be modified to provide real-time decision support during the disaster response phase, but it primarily enables planners to assess the long-term effects of implemented changes to the community to improve resiliency to disaster events. The following chapters document an example implementation of the ESCAAPE Methodology through an application to a specific community.

CHAPTER V

ESCAAPE STEP 1: SELECTION

5.1 Alternative Selection

For general selection alternatives, a matrix of alternatives may help in providing options for different community characteristics. The morphological matrix was used in a developed framework for risk assessment by Jimenez, Stults, and Mavris [80] for civil aviation security risk management.

A disaster response and community restoration example has been set up in Figure 23. Communities with historic disaster events have been selected from the options presented in Figure 23. These are shown in Figure 24. Having some available alternatives to select from will enable a more diverse perspective of the methodology application. More arbitrary communities and disasters may be selected for analysis. This enables an all-hazard approach for communities, who can then select particular disasters while having the different types of disasters available for selection.articular disasters while having the different types of disasters available for selection.

ALTERNATIVES FOR EACH FIELD

			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Disaster	Disaster Type	Chemical emergencies	Dam failure	Earthquake	Fire or Wildfire	Flood	Hazardous Material	Heat	Hurricane	Landslide	Nuclear Power Plant Emergency	Terrorism	Thunder-storm	Tornado	Tsunami	Volcano	Wildfire	Winter storm
	Disaster	Severity	Quantitative scale	Very Low	Low	Moderate	Somewhat severe	Severe	Very severe	Complete devastation									
	Disaster	Warning	None	Very little	Little	Moderate	Somewhat lengthy	Lengthy	Very lengthy										
Community	Environment	Weather & Climate	very vulnerable	vulnerable	somewhat vulnerable	somewhat protected	protected	very protected											
Community	Environment	Geography	very vulnerable	vulnerable	somewhat vulnerable	somewhat resilient	resilient	very resilient											
Community	Environment	Geology	very vulnerable	vulnerable	somewhat vulnerable	somewhat resilient	resilient	very resilient											
Community	Environment	Resources & Services	very vulnerable	vulnerable	somewhat vulnerable	somewhat resilient	resilient	very resilient											
Community	Environment	Human Populations	high total population, high percentage of vulnerable populations	high total population, medium percentage of vulnerable populations	high total population, low percentage of vulnerable populations	medium total population, high percentage of vulnerable populations	medium total population, medium percentage of vulnerable populations	medium total population, low percentage of vulnerable populations	low total population, high percentage of vulnerable populations	low total population, medium percentage of vulnerable populations	low total population, low percentage of vulnerable populations								
Community	Infrastructure	buildings	highly crowded, poor construction	highly crowded, medium construction	highly crowded, well-built	moderately crowded, poor construction	moderately crowded, medium construction	moderately crowded, well-built	low-crowded, poor construction	low-crowded, medium construction									
Community	Infrastructure	transportation	low capacity, poorly built	medium capacity, poorly built	high capacity, well built	low capacity, moderately built	medium capacity, moderately built	high capacity, moderately built	low capacity, well built	medium capacity, well built									
Community	Infrastructure	communication	low capacity, poorly built	medium capacity, poorly built	high capacity, well built	low capacity, moderately built	medium capacity, moderately built	high capacity, moderately buildt	low capacity, well built	medium capacity, well built									
Community	Infrastructure	utilities	very poorly built	poorly built	moderately built	somewhat well-built	well-built	very well-built											
Community	Economy	education	highly uneducated	uneducated	somewhat uneducated	somewhat educated	educated	very educated											
Community	Economy	health	low life expectancy, high infant mortality	low life expectancy, low infant mortality	average life expectancy, high infant mortality	average life expectancy, low infant mortality	high life expectancy, high infant mortality	high life expectancy, low infant mortality											
Community	Economy	income	high level of poverty	somewhat high level of poverty	medium level of poverty	somewhat low level of poverty	low level of poverty	no poverty											
Community	Economy	stability	very unstable	unstable	somewhat unstable	somewhat stable	stable	very stable											
Community	Social Development	population	high total population, high percentage of vulnerable populations	high total population, medium percentage of vulnerable populations	high total population, low percentage of vulnerable populations	medium total population, high percentage of vulnerable populations	medium total population, medium percentage of vulnerable populations	medium total population, low percentage of vulnerable populations	low total population, high percentage of vulnerable populations	low total population, medium percentage of vulnerable populations	low total population, low percentage of vulnerable populations								
Community	Social Development	health	low life expectancy, high infant mortality	low life expectancy, low infant mortality	average life expectancy, high infant mortality	average life expectancy, low infant mortality	high life expectancy, high infant mortality	high life expectancy, low infant mortality											
Community	Social Development	education	highly uneducated	uneducated	somewhat uneducated	somewhat educated	educated	very educated											
Community	Social Development	housing	highly crowded	crowded	somewhat crowded	somewhat spacious	spacious												
Community	Social Development	wealth	Highly Impoverished	Somewhat Impoverished	Impoverished	Somewhat middle class	Middle Class	Somewhat wealthy	Wealthy	Very wealthy									
	Preparedness	Procurement (assets)	None	A little	Some	More than some	A lot												
	Preparedness	Prepositioning	None	A little	Some	More than some	A lot												
	Preparedness	Collaboration	None	A little	Some	More than some	A lot												
	Preparedness	Training	None	A little	Some	More than some	A lot												
	Preparedness	Programs	None	A little	Some	More than some	A lot												
		External Aid	None	A little	Some	More than some	A lot												

Figure 23: Conceptual, Embodiment, and Detailed Design Phases

			Hurricane Katrina	Haiti 2010 Earthquake	Chile 2010 Earthquake	2011 Japan Earthquake
	Disaster	Disaster Type	Hurricane	Earthquake	Earthquake	Earthquake
	Disaster	Severity	Severe (CAT5)	Severe (M7.0)	Severe (M8.8)	Severe (M9.0)
	Disaster	Warning	Moderate	None	None	None
Community	Environment	Weather & Climate	somewhat vulnerable	somewhat vulnerable	somewhat vulnerable	somewhat vulnerable
Community	Environment	Geography	somewhat resilient	vulnerable	somewhat resilient	somewhat vulnerable
Community	Environment	Geology	vulnerable	vulnerable	somewhat vulnerable	vulnerable
Community	Environment	Resources & Services	vulnerable	vulnerable	resilient	resilient
Community	Environment	Human Populations	high total population, medium percentage of vulnerable populations	high total population, high percentage of vulnerable populations	high total population, low percentage of vulnerable populations	high total population, low percentage of vulnerable populations
Community	Infrastructure	buildings	highly crowded, medium construction	highly crowded, poor construction	highly crowded, well-built	highly crowded, well-built
Community	Infrastructure	transportation	high capacity, moderately built	medium capacity, poorly built	high capacity, well built	high capacity, well built
Community	Infrastructure	communication	medium capacity, moderately built	low capacity, poorly built	high capacity, moderately built	high capacity, moderately built
Community	Infrastructure	utilities	moderately built	poorly built	well-built	well-built
Community	Economy	education	somewhat educated	somewhat uneducated	somewhat educated	educated
Community	Economy	health	high life expectancy, low infant mortality	average life expectancy, high infant mortality	high life expectancy, low infant mortality	high life expectancy, low infant mortality
Community	Economy	income	medium level of poverty	somewhat high level of poverty	medium level of poverty	medium level of poverty
Community	Economy	stability	stable	somewhat stable	stable	stable
Community	Social Development	population	high total population, medium percentage of vulnerable populations	high total population, high percentage of vulnerable populations	high total population, medium percentage of vulnerable populations	high total population, medium percentage of vulnerable populations
Community	Social Development	health	high life expectancy, low infant mortality	average life expectancy, high infant mortality	high life expectancy, low infant mortality	high life expectancy, low infant mortality
Community	Social Development	education	somewhat uneducated	uneducated	educated	educated
Community	Social Development	housing	crowded	highly crowded	crowded	highly crowded
Community	Social Development	wealth	Somewhat middle class	Somewhat Impoverished	Somewhat middle class	Middle Class
	Preparedness	Procurement (assets)	A little	None	More than some	Some
	Preparedness	Prepositioning	Some	None	None	None
	Preparedness	Collaboration	a little	None	More than some	More than some
	Preparedness	Training	some	a little	More than some	a lot
	Preparedness	Programs	none	a little	some	some
		External Aid	More than some	a lot	some	a lot

Figure 24: Alternatives created from selection of alternatives in the Morphological Matrix

5.2 *Community Selection*

The chosen setting was in mid-mainland United States on or near the New Madrid Fault Line. Section 1.5 refines the research scope to a single community. In 2010 FEMA began to set up and plan for some response exercises in the event of a devastating earthquake at the New Madrid Fault Line. The nearest metropolitan area to the fault line is Memphis. If the earthquake is significant enough in magnitude and severity, however, other metropolitan areas nearby will also be affected.[6]

Because the Memphis Metropolitan Area (MMA) is so widespread, an even more specific down-selection was made. The chosen county for the main case study was Shelby County, TN. Shelby County holds a large portion of the central part of the MMA within its boundaries. Demographic data and other statistics are often measured by county, and selecting a specific county would reduce uncertainties in the numbers if more than one county were selected and some portions of additional counties were included. The county can also be broken up into different census tracts if more detail were required.

Figure 25 shows a map of major roads with the county outlined in gray. Part of the county is on the other side of the Mississippi River, and while a large portion of the Memphis Metropolitan Area (MMA) is in the county it extends into the surrounding counties as well. Shelby County was of interest because of historical significant earthquake activity from the nearby New Madrid Fault Line. With increasing awareness and priority for disaster response, preparedness and response officials have become concerned about the impact of a large earthquake on the Memphis Metropolitan Area. [6]

A second community region was selected after the model was developed for Shelby County. Orleans Parish was of interest because of the disaster occurrence in 2005 (Hurricane Katrina). See Figure 26 for a map of the parish. The response and restoration process came under a scrutinous public light after the immediate response, highly covered by the media, was revealed to be inadequate in several areas.

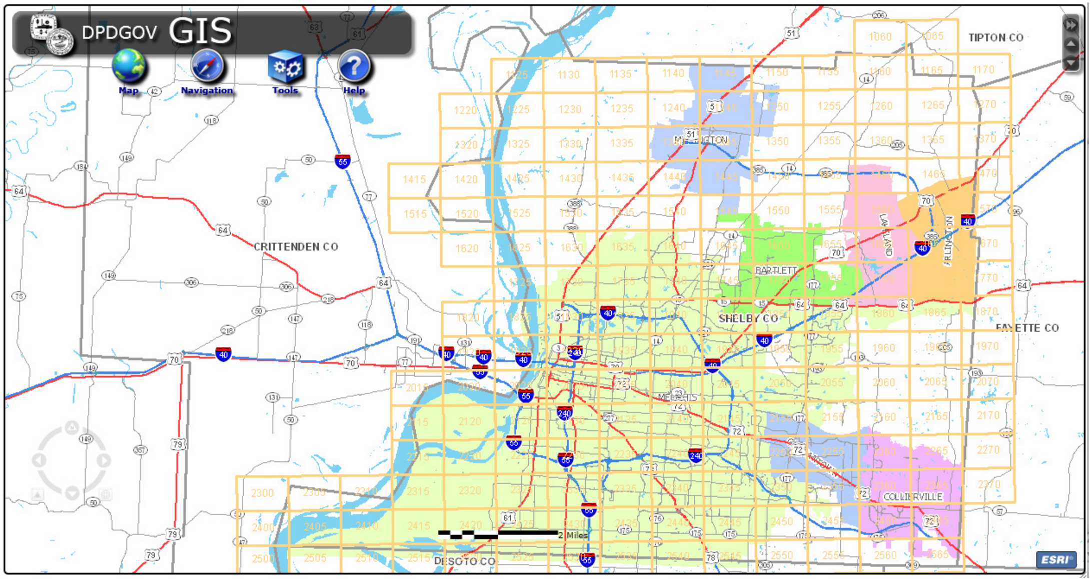


Figure 25: USGS GIS-generated map of Shelby County [162]

5.3 Disaster Event Selection

Disaster Type refers to the specific type of disaster. There are several different types of disasters. The list developed by the Federal Emergency Management Agency can be seen at `http://www.fema.gov/hazard/types.shtm` and includes the following:

- Chemical emergencies
- Dam failure
- Earthquake
- Fire or Wildfire
- Flood
- Hazardous Material
- Heat
- Hurricane
- Landslide

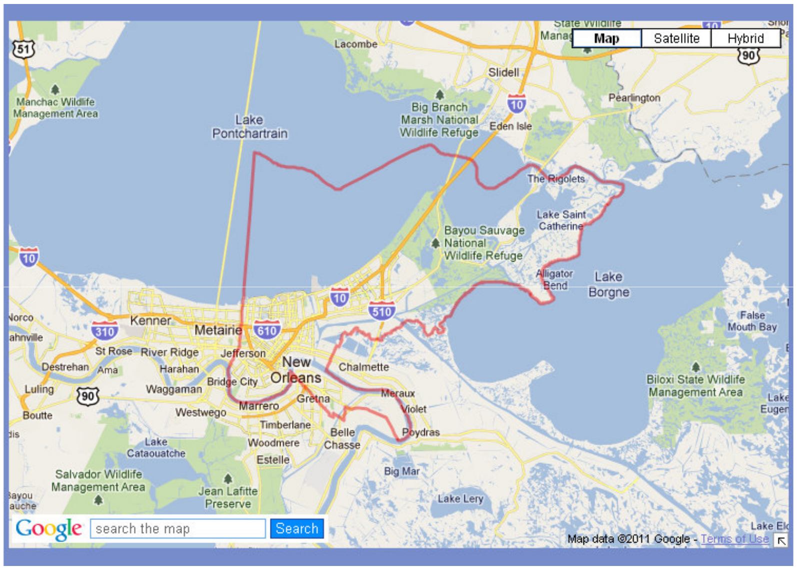


Figure 26: Orleans Parish Map from Google Maps

- Nuclear Power Plant Emergency
- Terrorism
- Thunderstorm
- Tornado
- Tsunami
- Volcano
- Wildfire
- Winter storm

The model was developed generally but some of the parameters regarding damage were given data from the earthquake aspect of a disaster simulation program. There remains a capability for incorporating more types of disaster with the correct adjustments to the model relationships as well as the input data. Within the selection of the earthquake as the type of disaster, the severity of the event needed to be defined, whether with a particular value or with a chosen range.

Disaster Development Type refers to how long it takes a disaster to come to full effect within a community. There are two main categories within this parameter:

- Developing - such as a famine, drought, etc.
- Sudden - such as an earthquake, tornado or hurricane, etc.

Types of disasters within the “sudden” category may have some warning but typically do not take more than a week or two to manifest. Floods should be included as having “sudden” disaster development types.

CHAPTER VI

ESCAAPE STEP 2: DEFINITION

6.1 Approach

This system definition was done from a system of systems perspective. Initially an agent-based system approach was considered, where the various response entities are considered as groups of agents interacting. With a system of systems perspective, the community of interest is seen as a group of systems which must interact to provide a needed capability.

For modeling and assessment purposes, an agent-based approach is useful to gather data about more detailed operations and behaviors but would be too complex for setting up an entire disaster response and the community that it would be benefiting. For doing system-wide assessments, at a top level, one of the objectives of enabling this type of methodology is to provide a way for decision makers and analysts to quickly be able to consider a particular plan and know what kind of impact that would have on the community. For, say someone at a decision making level, who has limited time available for this type of planning, this would enable more informed decisions which require less time on their part.

Another consideration was to approach the system as a series of discrete events. In that case, however, the entire gamut of possible events would need to be considered. While this is possible, the decided approach was to assume a certain type of event (large scale natural disaster) and enable the system-wide approach to have a better overall response and recovery, which is the period during which the infrastructure, social system, and economic system is rebuilt.

The approach which enables that objective to be fulfilled comes from the field of system dynamics. Using a system dynamics approach puts each of the different metrics into a stock-and-flow system. The metrics can be seen as levels, and relationships between and among them are defined to flow data from one stock to another.

Although a community system is very complex and nuances of each aspect may be difficult to fully capture using a system dynamics model, the system dynamics model will enable a simplification of these complexities. Instead of attempting to identically reproduce the entire system, the system designer must select the most important aspects and relate them to each other as stocks and flows. In addition, there must be a level of customizability or modularity for the model, although it does not need to be too general. Some customization will enable more flexibility in the types of communities and situations for different types of disasters.

A more detailed discussion is included in Chapter 7 when the selection for the type of system model is developed, but it is important to take the system type approach into consideration during the system definition step.

6.2 Level 1 Decomposition

For the top level, or Level 1 decomposition, the system selected, county, is decomposed into the components of the county. Figure 27 shows the components of the county.

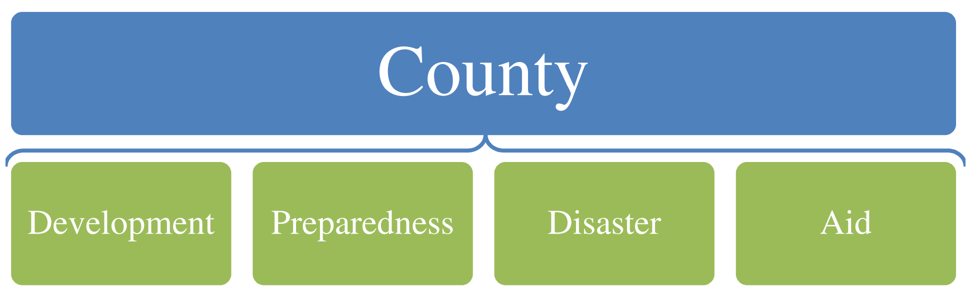


Figure 27: Level 1 Decomposition - County

Development The Development component includes elements of the physical community (infrastructure, socio-economic entities, geographic and environmental entities). This component is important because it enables parametrization of elements in the community which contribute to the effect of the disaster and response on the community.

Preparedness The Preparedness component includes the elements of the activities in preparation of and resources procured before the disaster occurrence. This includes both long and short term actions. This component enables parametrization of elements which contribute to the effect of the response on the community.

Disaster The Disaster component includes different elements of the disaster event. Specifying these different parameters of the disaster will enable different types of disasters to be specified in the system exploration. Although the primary disaster concern in this community selection is an earthquake, the model will retain flexibility for assessment of other types of disasters and their effects on the community.

Aid The Aid component includes aid dispersed during the short and long term response periods, and enables the performance response effects to be considered. This component is important because the resilience of the community is affected by the aid received in short and long term periods after the disaster.

6.3 Level 2 Decomposition

6.3.1 Development

The Level 2 component, Development, is decomposed into four different components, as shown in Figure 28.

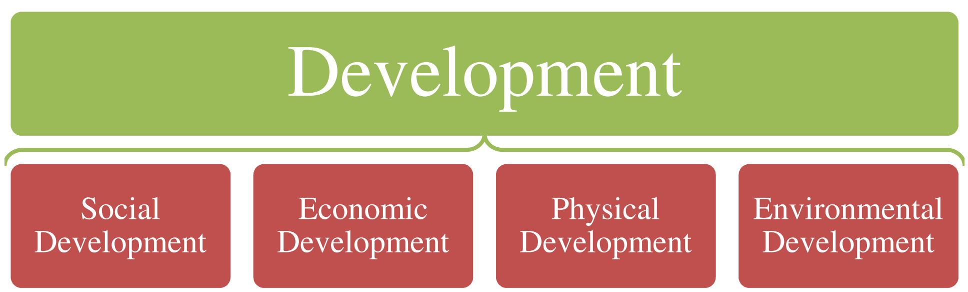


Figure 28: Level 2 Decomposition - Development

Social Development The Social Development component includes the different sociodemographic aspects of a community. This includes the health, education, and wealth of the people residing in a particular community, sanitation, population demographics, etc. Most of the variability within communities in the continental United States can be found in this aspect.

Economic Development The Economic Development component includes the financial and commercial aspect of a community. This includes the financial purchasing power of the people within the community, the amount of debt that is prevalent within the community, and the education and activity of citizens within the community.

Physical Development The Physical Development component includes the different physical infrastructures present within a developed community. This includes all different types of buildings (residential, commercial, fire stations, hospitals, schools, emergency response operation centers), transportation systems (buses, rail - people, rail - goods, roads, runways, ports), etc.

Environmental Development The Environmental Development component includes the natural environment within the community. This includes various aspects of local ecosystems and the health of the environment in general which may be measured by amount of pollution of different types, droughts or flooding which changes the ability of the ground to absorb water or sustain vegetation, etc.

6.3.2 Preparedness

Preparedness is one of the lesser defined aspects of the community but based on available literature and response resources available on the web, it is broken into several different components. Figure 29 shows these components.

Training The Training component includes any disaster response training or preparedness training offered locally or that local citizens participate in, even if the training itself takes place outside of the selected community. This includes emergency operations training, emergency management training, emergency medical services training, logistics training specifically for disaster response, etc. If an approaching disaster is forecast or if awareness

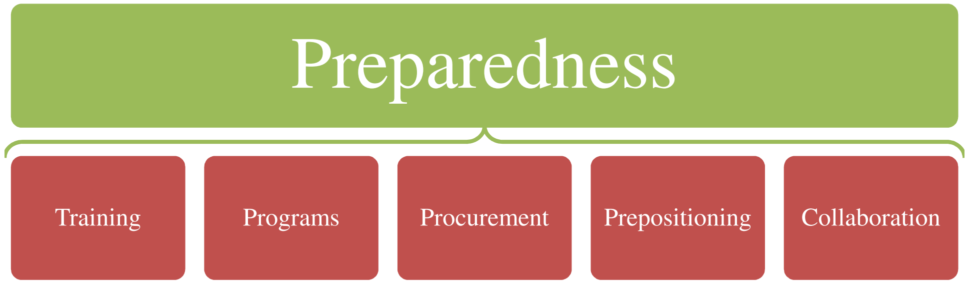


Figure 29: Level 2 Decomposition - Preparedness

is being raised about a particular type of disaster, training may be at a higher level than if these things were not also simultaneously occurring.

Programs The Programs component refers to different community programs which serve to increase preparedness. There may be some redundancy with the Training component but if the differences are specified then redundancy may be decreased. These programs may include awareness programs in which citizens are encouraged to develop their own disaster contingency and evacuation plans or arrange the proper insurance for their possessions, etc., or the programs may include training and other preparedness checklists which enable individuals and commercial entities to assess their different areas of vulnerability so that they can begin to address them. Programs may also include different warning systems or other networking enablers, such as increasing the use of social media to help with disaster response.

Procurement The Procurement component includes the acquisition of supplies which are anticipated critical needs in a post-disaster environment. This could include food, water, and shelter as well as medical supplies, ice, central operation locations, and logistical enablers such as trucks and emergency communication networks. While not as much of an issue in the United States, in lesser developed countries, procuring food for communities in need after a disaster may be difficult for small island nations or nations experiencing food shortages. [29, 119, 24]

For types of disasters where the warning period is short or non-existent, procurement activities may be greatly reduced. Some organizations have been working with pre-procurement, which at times may be costly and red-taped especially for organizations attempting to do so in other nations.

Prepositioning The Prepositioning component includes the readying of the procured supplies for transport to areas where they will be consumed. Since different organizations provide different types of transport or prepositioning services, collaboration levels may affect the prepositioning. The warning level of disasters also affects prepositioning. Hurricanes may provide a little bit of preposition time, but disasters such as earthquakes provide very little warning time. Additionally, a significant earthquake may damage transportation infrastructure, making it necessary for alternate routes of transport of procured supplies.

Collaboration The Collaboration component describes different levels of collaboration, which for communities may be different from disaster type to disaster type. This is an important aspect of disaster response planning in that it enables different inter-community entities to learn to operate in conjunction with one another to conduct preparedness and response activities. Collaboration may include simple electronic communication with members of external groups, or the conducting of training sessions, or more elaborate execution of response drills.

6.3.3 Disaster

The disaster specifications for a system model may be difficult to assess, since there is a level of uncertainty within the type of disaster (depending on the location of the community), the severity of the disaster, any secondary occurrences or other disturbances caused by the first one. The components selected for this research include the ones shown in Figure 30.

Distance The Distance component includes the distance of the community to the event occurrence. The component is important because as the distance from a disaster increases, the effects weaken, and this will have an effect on the community resilience.

Figure 30: Level 2 Decomposition - Disaster

Duration The Duration component describes the length of time which characterizes the disaster occurrence. The capability to include assessment of secondary events and after-shocks exists as long as the relationship of secondary events to the effects on the community are specified. The current developed model included one secondary quake which occurs several days after the first event, but the secondary quake was not activated for the system exploration.

Severity The earthquake severity may be measured in a quantified scale through both the Richter scale, which measures magnitude, and the Modified Mercalli Intensity Scale (MM), which measures intensity and enables the effect of the earthquake to be included in the value. The Richter scale does not include effects of the earthquake. Both scales are defined at `http://pubs.usgs.gov/gip/earthq4/severitygip.html`. The Modified Mercalli Intensity Scale segments the severity values based on the developments of the earthquake which reflect the effects of the magnitude of the earthquake event itself. The number used in the developed system model was an arbitrary value, and would be a significant quake which would require a response from at least the local level, which would probably be a 7.5(MM) or higher. Because disaster severities can always be greater, it is difficult to standardize the damage since the scale may need to be changed if the severity increases beyond what was allowed in the model.

The system dynamics model and this set up in general are for an earthquake event but changing the type of disaster would mainly require the effects relationships to be changed if needed. For example a hurricane may affect building infrastructure more than an earthquake would depending on the earthquake's location, and this would need to be changed in the system dynamics model. Some of the background data for the development of the relationships may come from more detailed simulation programs such as the HAZUS-MH program developed by ARC-GIS.

Type The Disaster Type component is important because the effects of the disaster vary depending on the type. Chapter 5 includes a list developed by FEMA of the different disaster types.

Warning The Warning component of the Disaster refers to whether or not there was a warning. If there was, a specific amount of time prior to the warning can be specified. Based on this component, the procurement and pre-positioning aspects of preparedness may increase to reflect the change in activity if a community becomes aware of an approaching or impending disaster.

6.3.4 Aid

The Aid aspect of the system includes the response and restoration of the community as well as any aid coming from sources governing the community and external sources. The components for this aspect are shown in Figure 31.

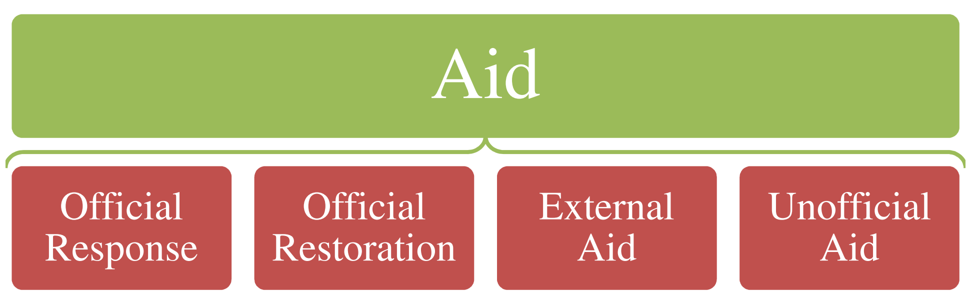


Figure 31: Level 2 Decomposition - Aid

Official Response Official aid is aid which has gone through official channels to be given to those in need, meaning that the government is aware of or has approved a presiding organization to receive and distribute the aid supplies and services. This role in the US is governed by the Federal Emergency Management Agency and state and local emergency management agencies and local, state, and national governing authorities as well. Response Aid is provided by the government and official aid organizations immediately after the disaster has occurred. This includes emergency medical aid and emergency shelter, as well as food and water for those who are unable to cook or do not have access to food sources. Rubble may also need to be cleared and this is considered a part of the response.

Official Restoration Restoration Aid is long-term aid which is provided to help rebuild the community and restore common economic and social functions. This includes rebuilding physical and transportation infrastructure to an equal or greater degree than prior to the disaster. [72]

Unofficial Aid The unofficial aid is considered to be aid which is provided but not through official means. An example of this would be local business persons filling their personal vehicles with goods that they and their colleagues and friends procured. The business person or someone selected to deliver the aid would then transport the supplies to areas of need or simply going into the affected areas to find persons who would need the supplies. In non-US nations this is often the most effective way to send aid into a region. This type of aid became critical after the Indonesian earthquake and tsunami [13], when government issues heavily delayed or prevented the needed aid to be supplied to persons in need.

External Aid External Aid is donated through official channels but comes from sources external to the governing region. In the case of hurricane Katrina, many nations donated goods and services which were filtered through the government, which could not accept some of the goods and services. Acceptance was more difficult for some goods and services because of specifications in food and safety standards as well as practitioner certification standards. [36]

6.4 Level 3 Decomposition

6.4.1 Development Components

6.4.1.1 Social Development

The Social Development component is decomposed into several categories which are shown in Figure 32. The Level 4 Decomposition will include more detail about the parameters which compose this category.

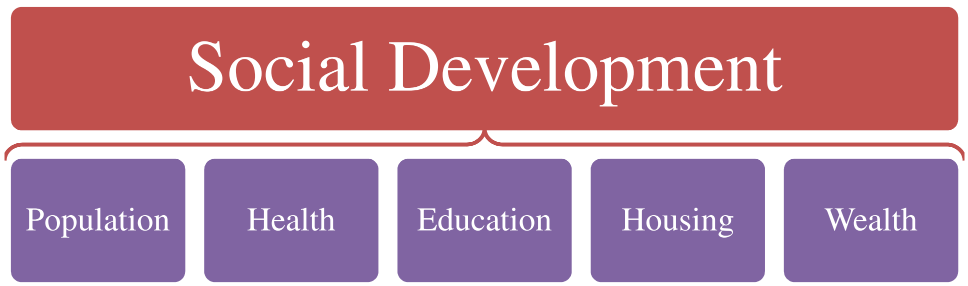


Figure 32: Level 3 Decomposition - Social Development

Population The Population component of Social Development includes the parameters which help to describe the aspects of the population which contribute to the vulnerability of a community to a disaster and the consequent resilience capability.

Health The Health component of Social Development includes the parameters which help to describe the health of the population. The parameters included in the category affect the vulnerability of a population to the disaster as well as the resilience capability of the community from a social perspective.

Education The Education component of Social Development includes parameters which describe the educational level of the population. Education parameters affect the vulnerability of the population to disasters. More details will be given with the description of the Level 4 and 5 decomposition parameters.

Housing The Housing component of Social Development includes parameters which characterize the housing situations, on an average, for the community. These parameters will be further discussed with the description of Level 4 and 5 decomposition parameters.

Wealth The Wealth component of Social Development includes parameters which describe individual wealth within the community. These parameters affect the vulnerability of the population to disasters as well as the resilience capability of the population after a disaster has occurred.

6.4.1.2 Economic Development

The Economic Development component is decomposed into several categories which are shown in Figure 33. The Level 4 Decomposition will include more detail about the parameters which compose this category.

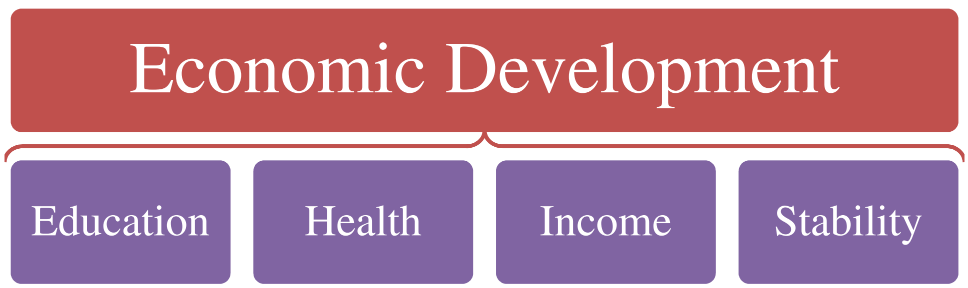


Figure 33: Level 3 Decomposition - Economic Development

Education The education component of the economic development includes indicators which characterize the education level of the community and the affect on the community's ability to recover from a disaster. Further discussion is given these indicators in Chapter7.

Health The health component of the economic development includes indicators which characterize the general health of the population in the community, and the affect of this on the community's restoration ability. Further discussion is given these indicators in Chapter 7.

Income The income component of the economic development includes indicators which characterize the wealth of the population within the community. Further discussion is given these indicators in Chapter 7.

Stability The stability of the community includes indicators which characterize the population's ability to be economically involved in the community. Further discussion of these indicators is done in Chapter 7.

6.4.1.3 Physical Development

The Physical Development Level includes components describing the physical infrastructure development level of the community. The physical infrastructure includes transportation infrastructure such as roads and bridges; building structures, both residential, commercial, and specific structures which are a part of the emergency response for the community; and the physical parts of utility and communications systems. Further discussion of the components is done in Chapter 7.

6.4.1.4 Environmental Development

The environmental development includes the components describing the environmental state of the community. Aspects of the environment contribute to the vulnerability of a community to natural disasters. The information for the selected communities was unavailable for a lot of the parameters described by the Environmental Vulnerability Index. Appendix B.2.2.3 contains a description of the different parameters in the EVI. The inclusion of this parameter in the model development is discussed in Chapter 11 as a future work item.

6.4.2 Aid Components

The aid being sent to the community is decomposed into four different components.

6.4.2.1 Official Response

The Official Response includes components which are implemented by the responders and planners in the days and weeks immediately following the disaster. The Official Response component of Aid is decomposed in Figure 34.

The components cover different aspects of the immediate response.

Figure 34: Level 3 Decomposition - Official Response

Infrastructure This component includes the physical buildings, transportation infrastructure, and other physical infrastructure which provides necessary utilities.

Emergency Care, Support, and Management This component includes the post-disaster medical support, other support, and emergency management.

Environmental Concerns This component includes immediate environmental concerns which need to be dealt with after the disaster.

Public Safety and Security This component includes law enforcement and other measures which may be needed to ensure that public safety and security is maintained in the communities.

External Affairs This component includes aspects of the immediate response for which the community needs to deal with external governments or authorities.

6.4.2.2 Official Restoration

The Official Restoration parameter includes components which help to rebuild the community. The components are further discussed in Chapter 7 and include:

- Clean up time
- Long-term counseling
- Reconnection time

- Relocation time
- Reassimilation time
- Building repair time
- Utility repair time
- Transportation repair time

6.4.2.3 Unofficial Aid

The Unofficial Aid parameter includes aid which is donated through unofficial channels to the community. Chapter 7 contains a more detailed discussion of this parameter.

6.4.2.4 External Aid

The External Aid parameter includes aid which is donated through official channels by external governments and international organizations and businesses. Chapter 7 contains a more detailed discussion of this parameter.

6.5 Further Decomposition

Decomposition past this level is included in Chapter 7. The developed model must have parameters which are further connected to data which enables the model to be specified for a particular community.

A system decomposition done by a community for the purposes of implementing the developed ESCAAPE methodology for disaster response and restoration planning may be more complex or simpler. A more complex model may require greater computational resources and more detailed data, while a simpler model may not be able to capture the system behavior as accurately as a more complex model. However, the determination of the number of levels of detail should be done by planners with the input of experts and other available information about the community.

CHAPTER VII

ESCAAPE STEP 3: DEVELOPMENT

Much of the recorded data regarding disaster response systems and the communities in which those systems are developed comes from tacit knowledge from the minds of experts in the field of disaster response or humanitarian logistics. [62] Federal officers and employees may have spent several years working in that particular field and understand the behavior of environments and communities and their interactions, as well as the laws and regulations needed to enable a speedy and lawful response where the governing body is granted access to accounting and personnel data that it needs during and after the response.

In a time of disaster, however, this knowledge may be unavailable to decision makers who are trying to make system-level calls for resource distribution and immediate responses, depending on the severity of the disaster. Additionally when planning at that level, the various experts in the field may have time restrictions since many of them have other responsibility roles which they fulfill during the time between disaster occurrences. Understanding of the inter-component relationships and the implementation of that knowledge in a system model will provide another source of information about the community behavior for planners.

Several modeling options and the selected modeling type and environment are discussed as well as the development of the system models and the logical basis for the developed inter-component relationships.

7.1 Modeling Options

7.1.1 Physical Model

For planning purposes, the actual, or physical system, might be considered for use, since it would provide the most accurate result. However, with the physical system, time compression (or expansion) is impossible with a physical system due to an inability to control time travel. Adding time for personnel and resource coordination would make simple tasks even more time consuming. Because the physical system cannot be used to test different preparedness, response, and restoration approaches, a simulation approach was selected. There are a few different simulation approaches which were considered.

7.1.2 System Dynamics Modeling

System dynamics models use the concept of stocks and flows and also enable the model to be developed with feedback mechanisms. This type of modeling enables a system level view but can also be linked with more detailed aspects of the system. With this modeling, the different components of the system can collectively affect an outcome or result variable.

For complex systems, macro-level system behavior may be monitored over a simulated period of time. This enables emergent community behaviors to be identified. Also, for micro-level system parameter changes, the effects on the macro-level behavior may be observed, which enables assessment and improvement of the macro-level response metrics.

Available software packages for this type of modeling include Anylogic and VENSIM. The full VENSIM software package was available for this research.

7.1.3 Econometric Solution

Other than using the physical system, a higher level of detail might be provided by a well-developed model based on econometric data. The behavior of the system must be captured mathematically and at detailed levels through available data gathered in the form of a time series.[71] For the purposes of the system where the response, restoration, and preparedness are included as phases, an econometric solution has not been developed, since the needed data is undefined and unquantified for communities in the US. If, as time goes on, quantifying data is defined and gathered from different disaster occurrences, an econometric solution may be developed. With the detailed disaster simulation through HAZUS-MH, more detail is available for the system but only for the disaster event and its effect on the existing and defined infrastructure.

Geographic Information Systems (GIS) provide access to large databases which contain information about a community's development, preparedness, and response in the event of a particular type of disaster. Some data which is missing may be gathered from programs which access the GIS databases. One highly detailed program available is the HAZUS-MH program which uses ARC-GIS technologies to show the effect of a disastrous event. HAZUS-MH has pre-defined damage relationship scenarios. Figure 35 shows a community setup in HAZUS. The parameters from these relationship definitions are customizable by users if they are privy to more accurate information about the relationships.

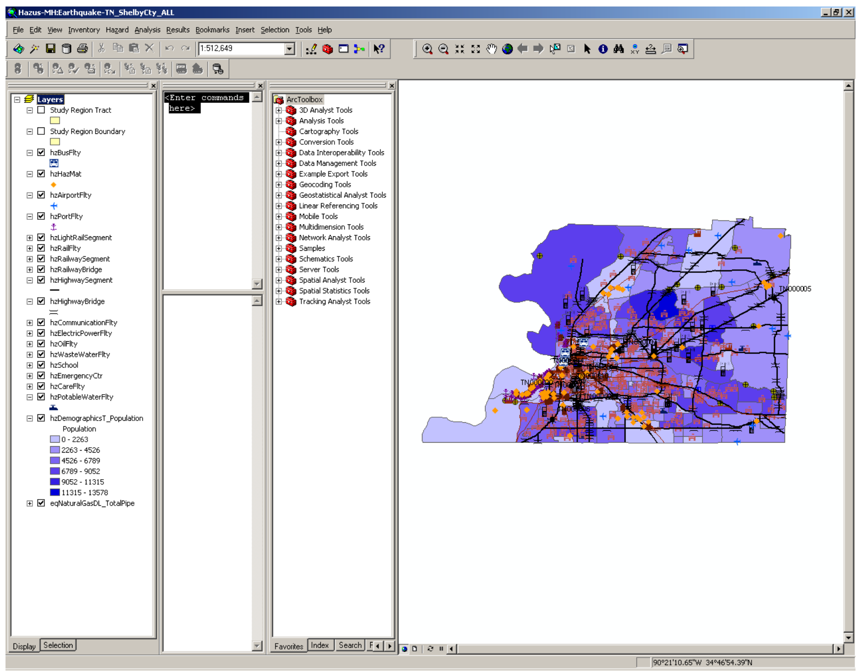


Figure 35: Example of HAZUS-MH system screenshot

This program is the main program in use through some of the federal level emergency management planning agencies in the United States. However, the main drawback to using the HAZUS program is that the runtime is on the order of 5 minutes or more, and there are numerous infrastructural parameters and ways to gather data which must also be processed and the correct parameters recorded in order to produce usable information from the simulation. Currently the HAZUS program simulates the immediate post-disaster damages as well as estimates of the infrastructural repair times but does not include analysis of the social and economic restoration processes. With further customization this may be possible.

7.1.4 Agent-Based Models

Agent-Based modeling also offers a way to generate some detailed community state and response data for approximation and integration into the dynamic system model. However, the relationships in agent-based modeling programs need to be set up among the variables and parameters and also defined by the user/designer. Once the parameters and relationships are all set up, however, running dynamic time simulations is done quickly. As long as the initial setup and relationships were done well, the data generated may be within acceptable quality for use in the dynamic system model.

Possible programs in this realm include Netlogo, SimPy, MASON, RePast, as well as included capabilities in hybrid system dynamics programs such as AnyLogic and VENSIM. Access to Netlogo, SimPy, MASON are licensed to the general public, while AnyLogic and VENSIM are proprietary programs and require specifically purchased licenses to operate.

7.1.5 Discrete Event Simulation

Discrete Event Simulation provides more system-level data than the detailed ground-level programs that have been discussed in this section. Stochastic or probabilistic assessments are enabled in a discrete event simulation environment, and with the proper inputs, system level output metrics are generated. The simulation runs as a series of events which affect the values of the different metrics. With the use of a discrete event simulation model, the data would be more seamlessly integrated into the dynamic model and would not need approximating to the same degree that the GIS-based models would. Through the agent-based models, however, system level metrics can also be monitored depending on the user setup.

The parameters of interest considered in selection of modeling option were the following:

- CS - (Complex System) capability of modeling complex system behaviors
- DV - (DeVelopment) can be developed quickly, clearly, and easily by non-software-programmers

- ID- (InterDependencies) capability of representing high level of system interdependencies
- M - (Measures) capability of capturing system level measures
- IF - (InterFace) integrable interface at the data level, or ability to use large amounts of input data
- TC - (Time Compression) level of time compression capability

Table 4: Selection of Modeling Options for System Model

Modeling Options	Parameters					
	CS	DV	ID	M	IF	TC
Physical Model	5	2	5	2	3	–
Econometric Solution Model	5	3	5	4	3	2
System Dynamics Model	4	4	5	5	5	4
Other Agent-based Model	4	3	4	4	5	4
Discrete Event Simulation Model	3	2	3	4	5	4

In this case and in light of those statements, a system dynamics approach is taken. For different situations and communities (or areas of concern) planners and analysts will be able to customize the system dynamics equations and the system behaviors to represent their specific situations. The relationships between the different system aspects also is specific to the particular communities.

A model of the system enables different response and recovery scenarios to be considered during planning stages. If planners, analysts, and decision makers understand the relationship between the community behavior, impact on the community, and the response and restorative planning, this information may be used to benefit the community long-term and improve overall disaster response and restoration. If the proper behavior and relationships are designed and built into the model, planners and analysts using long-term effects of response planning and restoration activities are able to use information provided by the model.

By incorporating the modeling and simulation aspect in the planning methodology, more knowledge is available to decision makers and analysts earlier in the planning project. If their objective is to maximize their resources over a simulated disaster situation, the model may contribute to more efficient response and rebuild phases.

7.2 SD Model Application Software

7.2.1 MATLAB

More custom development capabilities are available in Matlab without the user needing to learn significant amounts about the operation of the program. The program can also handle processing a large amount of numbers at once, which reduces time spent waiting for a simulation to complete. If conducting an uncertainty analysis or sensitivity analysis there will be a large number of runs needed and a shorter simulation time is preferable for this.

The program itself was fully available. However, the amount of customized programing required to properly set up the systems dynamic aspect of the model was beyond the user comprehension for developing this level of detail. Figure 36 shows the initial attempt made to develop the system dynamics model in MATLAB. As far as a humanitarian logistics perspective is concerned, MATLAB may have direct applications in disaster response, but it is not widely used. However, this could be a powerful tool if properly built up and integrated into the design of disaster response planning.

7.2.2 VENSIM

This program is more widely used in the system dynamics field and the DSS version enables more custom interface design for user input as well as custom integration with external programs.

For system dynamics use this may be the most widely used, but within the system design and analysis community, and not necessarily the disaster response planning field. This program was fully available to this research.

7.2.3 AnyLogic

This program is perhaps the one with the most developed front user interface, and setting up a system dynamics model was very simple to do. Because of numerous proprietary restrictions and accessibility issues, a model was built in AnyLogic but then rebuilt in

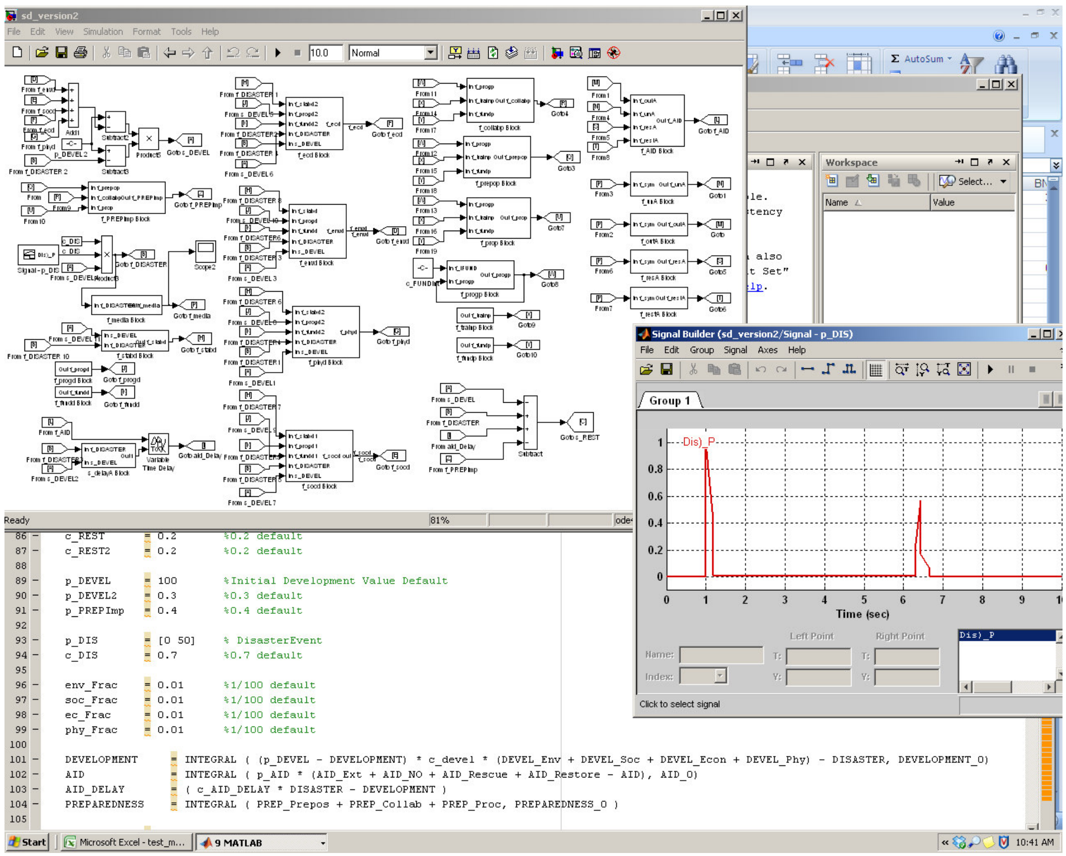


Figure 36: MATLAB SD Model Attempt (www.mathworks.com)

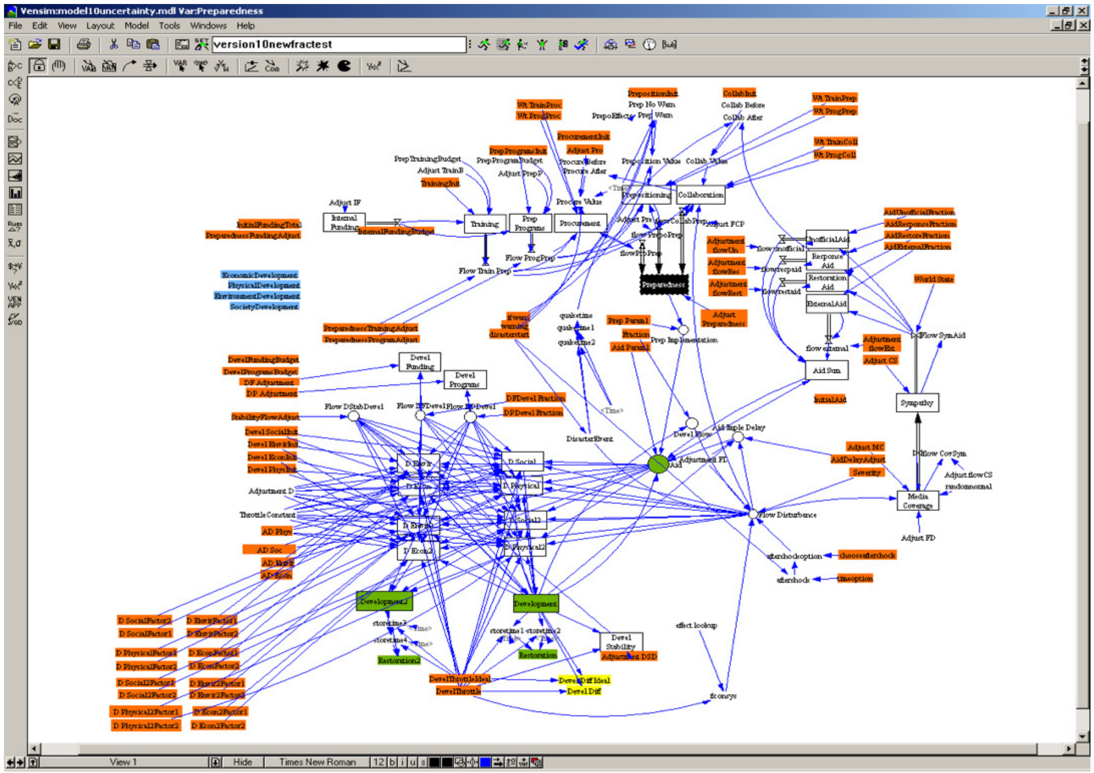


Figure 37: Screenshot of System Model development in VENSIM (www.vensim.com)

Table 5: Selection of Modeling Options for System Model

SD Software Options	Parameters		
	Accessible	Development	Interface
MATLAB	5	1	5
VENSIM	5	4	4
AnyLogic	2	5	3

VENSIM where the rest of the development was done.

Three criteria taken into account when selecting the software were:

- Accessible - Accessibility of the software to the person developing the system model
- Development - Ease of system development
- Interface - Capability of the software to interface exchange of data, particularly for input purposes, at large volumes

While AnyLogic may be better for the setting up of the system dynamics model, the VENSIM DSS program was fully available and relatively simple to use. This program was

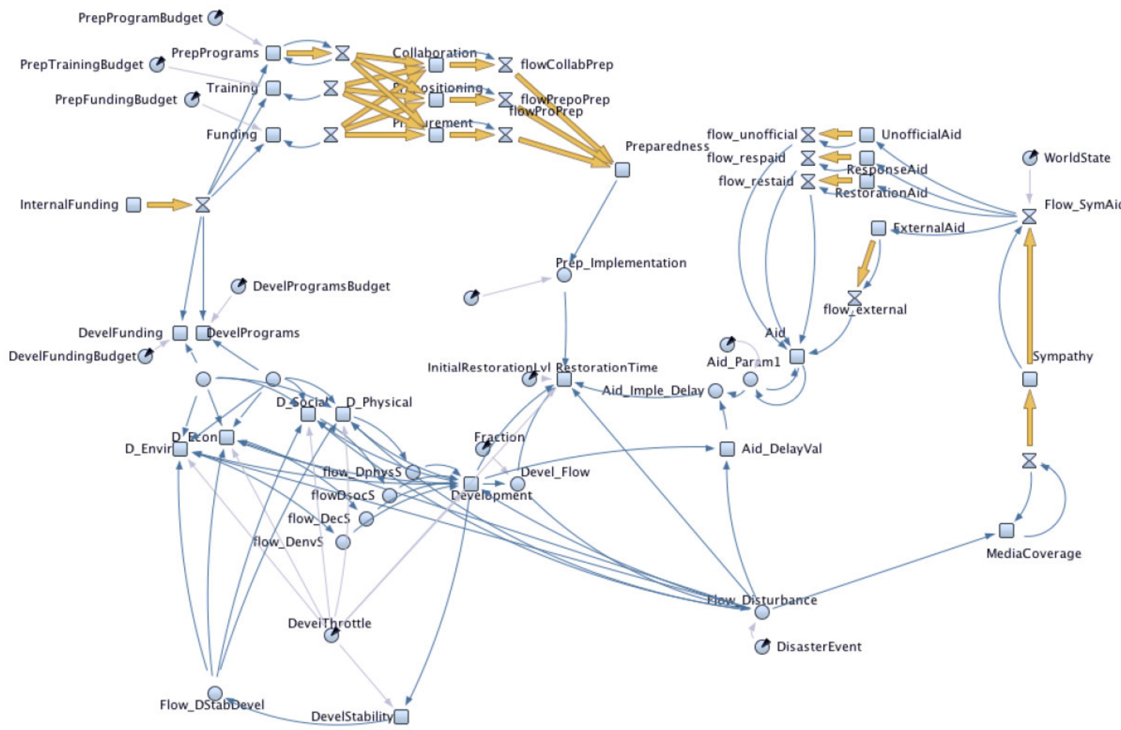


Figure 38: AnyLogic Software screenshot

selected to develop the model, refining the detailed one originally developed in AnyLogic. See Figure 38 for a screenshot of the AnyLogic model.

7.3 System Dynamics Model Development

A disaster response system complete with community/area characteristics is a very complex entity to model. Various aspects and parameters must be incorporated in order to capture some of the system behaviors of concern. Other modeling options included agent-based modeling and other conditional probability and discrete event models. The system dynamics model will better be able to capture system level behaviors over the restoration cycle if a resource can be used as the unit of flow. The system dynamics model also enables a view of the system metrics at the macro level, which will give more helpful information during

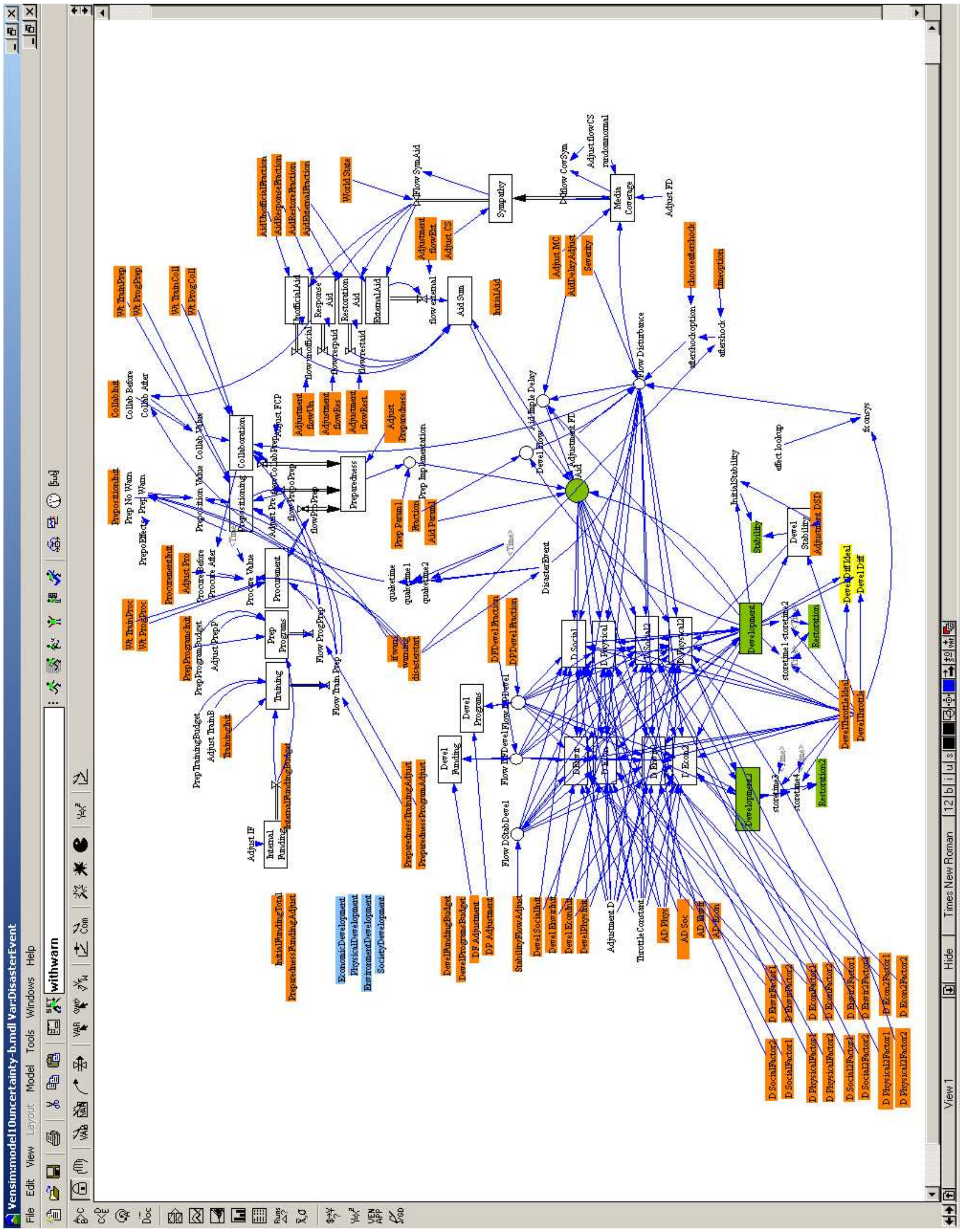


Figure 39: Screenshot of VENSIM System Dynamics Model

the response planning phase. The different phases will act alongside aspects of the system in passing "resources" back and forth. A loss of resources would occur for the community if a disaster occurs, for example, but this value might be returned as aid is received and implemented back into the community.

The other available modeling methods may also be implemented if that level of detail is needed, and a community does not have a lot of available parameter information. These other modeling methods may be helpful in simulating some information to put in the system dynamics model. The user and planner can control the level of detail that the system goes to. With more expert input or more information about a community or region, a higher level of detail may be used, but with the caution that greater detail often requires more computational power for the simulations done during the initial sensitivity and behavioral analyses.

For response planning such a perspective is the most helpful. Agent-based and discrete event models of a disaster would help with some of the response data, and much research is already being done in those areas. Chapter 11 discusses some potential future options which may incorporate more of these models in the system model development phase. For disaster response there will be a bit of data gap remaining once the system dynamics have been set up, because

- a) currently there are no metrics that have been standardized, so any data that is required may not be currently recorded in any quantitative way.
- b) the data may not be gathered in any way in the first place.

This data gap also needs to be addressed, and with a system dynamics perspective on the system model there are several ways to supplement data.

Physical boundaries were not the only chosen boundaries for the system. Previously discussed was the concept of the disaster response cycle. Because each phase in the cycle is integral to the restoration capability of the city, the different aspects were also included in the system definition. The top level aspects are, as they pertain to the community, development, preparedness, the disaster itself, and aid, which includes response and restoration. These components were broken down into parameters and some into sub-parameters which required an aggregate group of different data points. The data points were gathered based on the community boundaries, and depended on demographic and economic statistics for the community within those boundaries. These components were developed and selected based on available resources (literature, community preparedness websites, federal aid information, etc.), and for disaster response planners, some components may be missing or unnecessarily included. The system should be customized based on included expert opinion as well as available literature, and this system model will demonstrate the concept.

At the beginning of the model development, a couple different forms of system diagrams are helpful in visually expressing the system and some of the effects and interactions.

7.3.1 Feedback Loop Diagram

For this research, it will not be assumed that the various factor effects are isolated from the other main effects categories or the other main effects factors. This is shown by using the same effects and factors in the form of a feedback loop diagram.

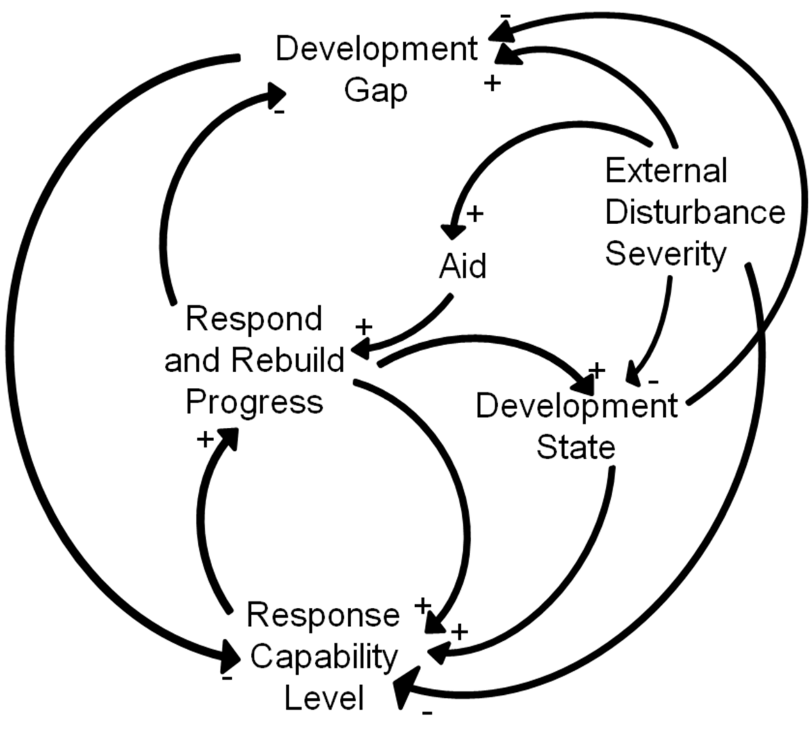


Figure 40: Feedback Flow Diagram for System Level with direction of increase marked

To develop this diagram, first the main effects were listed, and their effects on each other were marked. If a decrease in one effect, such as "Aid", caused a decrease in another effect, such as “Respond and Rebuild Progress”, and an increase in Aid caused the Respond and Build Progress to also increase, then the relationship arrow was marked with a “+” at the arrowhead. At this point in the model development the relationships have not been quantified yet. In order to develop this first diagram, the user asked the question, “If more aid is received and implemented, how would this affect the response and rebuilding progress?”. If the answer is that the response and rebuilding progress would benefit or improve if more aid is received and implemented, then that main effect is considered to have increased. This diagram is used to develop the initial system dynamics model, which is then added to in complexity, hierarchy, and dimension as more research is done and more system knowledge is implemented in the model.

Once these feedback loops have been diagrammed, and with the arrows the direction of increase or improvement has been labeled on the system diagram, a qualitative system model has been developed. Next, these qualitative relationships will be defined quantitatively. The objective of all of this work is to be able to test what the outcome of particular response capability levels would be in the case of the defined external disturbance.

7.3.2 System Flow Diagram

The system diagram used to develop system stocks and flows was the system flow diagram. [144] The resource is Capability which is defined for this research as the net flow of changes put into a community, or removed, which affect how well a community is able to prepare, respond, and restore before and after a disaster occurs.

The main category of concern is the response and rebuild capability of the community. The other characteristic categories contributing to this main category will be referred to as main effects. The main effects categories considered were the preparedness and development of the community as well as the aid received and/or distributed by the community both before, during and after a disastrous event has occurred. The main effect category which most commonly has a negative impact on the community are external disturbances. The occurring natural disaster is included in this category, but other examples of external disturbances may be a war attack from another country or an economic downfall or natural

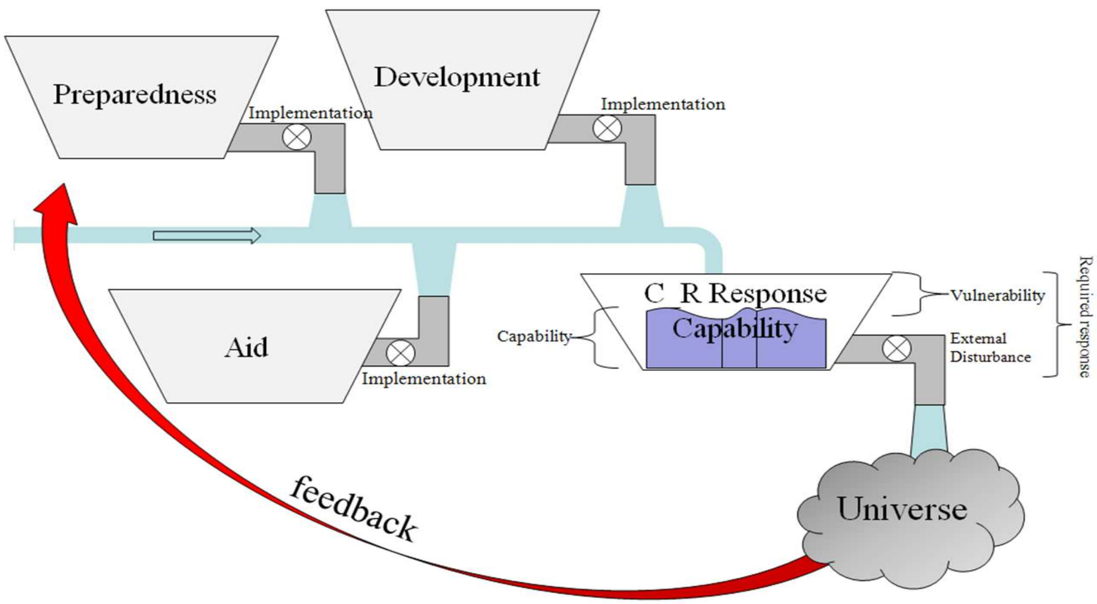


Figure 41: General Stocks and flows in Response-Capability-Driven Flow Diagram

disasters which are developing and not necessarily sudden and disastrous.

The system diagram depicts the response capability as a stock, with the main effects categories as stock which feed into or remove from the response capability. Each of the stocks can be broken down into smaller effects which make up the whole effect. The revised diagram, Figure 42 shows this.

7.3.3 Develop Relationship among components

Relationship development must be done at each of the hierarchical levels in the system parameter breakdown. General relationships followed what was available in literature and if no information was available the relationship was developed based on reasonable conclusions. In both cases the relationship was kept as simple as possible.

7.3.3.1 General Relationships

General reasoning for relationships for Level 1 components is discussed in this section. The section following will cover the specific relationships developed within the system model.

The Level 1 Components of the system, Development, Preparedness, Aid, and the Disaster change value with the fluctuation of the value of their components. Components of

Disaster are options which can be changed by user selection.

Disaster - Development

- A more highly developed community tends to be more resilient to the effects of a disaster. [91]
- A more highly developed community tends to have spent more time developing their infrastructure and preparedness situations. [91]
- A more highly developed community tends to have more complex buildings that will be more costly to replace if they do end up being damaged or destroyed. [91]
- Lesser developed communities tend to be less resilient to the effects of the disaster because there is less likelihood of insurance on damage properties and items. [91] [29] [73]
- Lesser developed communities tend to have had fewer resources which allow them to develop infrastructure to be more robust toward disasters. [91] [92] [73]
- Lesser developed communities may contain residents which are less aware of the importance of preparedness or investing in more resilient structures or retrofitting. [91] [79]

If a disaster has already occurred in the recent weeks or years, and the community is still in the process of restoration from that disaster, the occurrence of another disaster will further increase the amount of work to be done and resources to be used to restore the community to its former pre-first-disaster-state. [29] [92]

Specific resource flow, however (such as Aid) goes to the components of this aspect instead of directly to the development at the system level. The components are then summed to compose the development level.

Development - Disaster More highly developed infrastructure and certain preparedness infrastructural elements may mitigate some of a disaster's severity. This depends on the disaster components as well as the type of infrastructure which will help to decrease the effects of the disaster. For example, natural flood barriers or man-made levees may help to decrease the effects of a flood following a hurricane, but may worsen the effects if the hurricane is too strong and brings volumes of water which breach or overtop the levees or surpass the natural flood barriers. [153]

Building infrastructure may be implemented to absorb some of the motion during an earthquake [67], but this does not eliminate the effects of the disaster. If the disaster is severe enough, the preventative infrastructure will still be affected. [153]

If a disaster has occurred within a few years but the community has been restored, a more severe historical disaster may prompt communities to reorganize and rebuild while improving their ability to withstand the same type of disaster. [67] [26] More mitigation measures may be built, and more successfully since the community has experienced a prior disaster and will know which parts of their infrastructure are the most susceptible. Some rebuilding and mitigation measures include retro-fitting houses with flood proofing materials, and in some cases relocating parts of a community to safer areas (on higher ground, onto more stable land, etc). [73]

Disaster - Aid A more severe disaster does not always mean that more aid is being donated or dispersed. The amount of aid donated seems to be more to scale with the capability of the community to handle the results of the disaster. An example of this is the contrast between the earthquakes which occurred in Chile shortly after an earthquake which occurred near Port-au-Prince, Haiti.

Because the Chilean government had developed its earthquake mitigation and response measures from prior experiences, and was not as devastated by the quake as the Haitian government, the communities required less aid from external sources and were supported more through the local and national governments. The Haitian community was immediately flooded with large amounts of aid which organizations and external governments wanted to send to aid in the recovery process. The disaster may also hinder attempts to transport and distribute aid, an item of importance which is included in the components of the Aid aspect. [91]

Aid - Development Aid being donated from external sources or being sent from local/state/national governments is ideally, and eventually, distributed through the proper channels and implemented or absorbed into the community in a way that increases the "level" of development.

The different components of the aid coming into the community are summed together and directly benefit the different components of development. The different types of aid offered and received are not limited to tangible goods and medical emergency services. There are increased offerings of psychological and grief counseling and post-trauma counseling as well as relocation aid. [36]

Development - Aid Higher levels of development do not necessarily mean that greater amounts of aid are received. Higher levels of development do not necessarily mean that all of the aid is capable of being distributed and/or implemented by the community.

Preparedness - Development Preparedness does not have a strong influence on the development level. However, preparedness can indirectly influence the development level by efficiently redirecting resource implementation. [73] The implementation of these resources would then improve the components of the development aspect and in turn, improve the development level.

Development - Preparedness A higher developed community may invest more into preparedness and mitigation measures, particularly in infrastructure and community citizen awareness. [79] This may be more possible if more citizens in the community have less debt and fewer live in poverty. [39]

If prior disasters have occurred in communities with higher levels of development, planners may have utilized resources to increase the preparedness of the community in order to help mitigate some of the effects of future disasters.[26]

Preparedness - Aid Increased preparedness may enable more channels for aid to be received after a disaster occurs. Increased preparedness may also result in a little bit less of an amount of aid needed after a disaster occurs.[73]

Increased preparedness, particularly in the area of collaboration, may increase the effectiveness of the aid which is contributed. After the Indian Ocean Earthquake and Tsunami in 2004 aid organizations received boxes of winter coats and teddy bears from external aid sources, both things which were unable to be used for immediate aid needs and restoration purposes. [29] Prior collaboration as a part of preparedness efforts may have prevented these useless aid items from being sent. Additionally, decreased preparedness may reduce the ability for a community to properly implement or receive the provided aid. [7]

Aid - Preparedness A community receiving aid after a disaster may be able to use some of its resources to develop preparedness plans and implement them. These resources become freed up because aid is coming into the community, the resources may also be compartmentalized, so that part of the immediate aid may be designated for funding some of the preparedness plans.

However, receiving aid might also reduce the amount of planning that is done if too much aid is being contributed to the community. This must be considered in conjunction with restoration of preparedness as well as tangible community infrastructure when developing long-term restoration aid plans.

7.3.3.2 Specific Relationship Descriptions

The relationship descriptions are done by variable within the developed system model. Figure 39 provides a visual presentation of the relationships developed. The arrows drawn in the system dynamics model in Figure 39 show the inter-parameter relationships. If a particular parameter is a constant in the developed model, the value is selected by the user or determined based on some supplied data. If supplied data elements were chosen to provide a value, they are listed with the value available for the selected community.

If there are more than one data elements for a particular parameter, the combination, or aggregation of these values is done by using an equal weighted sum for the elements within the parameter. This enables each of the data elements to affect the parameter without biasing the parameter toward one or more of the elements. After the model development was completed, adjustments in the weightings for the data element aggregation was tested. The details for those tests can be seen in Appendix A.

Development *Description* This parameter is a measurement of the sum of the various components contributing to the overall development level of the community. The sum is not weighted, but only provides a total measure of the four components of development of a community. Lower values mean a greater amount of values in the measures which make the community more vulnerable to disasters and less capable of restoration.

Values- Low: 0, community is very vulnerable to disasters, unable to respond immediately, and will have a very difficult time with restoration projects. High:100, community has reduced vulnerability to disasters, capable of immediate response, and able to move into restoration phase easily after the initial response has completed.

Equation in Model

$$D = D_{Envir} + D_{Soc} + D_{Econ} + D_{Phys} \tag{1}$$

Where

D=Development level of the community

D_A=Components of developments

A=Envir (Environment), Soc (Sociological), Econ (Economic), and Phys (Physics)

Within the VENSIM model, the equation is as follows:

$$DEVELOPMENT = DEnvir + DSocial + DEcon + DPhysical \tag{2}$$

Development2 *Description* This parameter is a measurement of the sum of the various components contributing to the overall development level of the community. The sum is not weighted, but only provides a total measure of the four components of development of a community. Lower values mean a greater amount of values in the measures which make the community more vulnerable to disasters and less capable of restoration.

Values Low: 0, community is very vulnerable to disasters, unable to respond immediately, and will have a very difficult time with restoration projects. High:100, community has reduced vulnerability to disasters, capable of immediate response, and able to move into restoration phase easily after the initial response has completed.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$Development2 = DSocial2 + DEnvir2 + DEcon2 + DPhysical2 \tag{3}$$

Stability *Description* This parameter calculates a stability value scaled from the initial stability.

Values The value will be a scaled value of the Initial Stability parameter. The value drops after the disaster occurs and then increases as the development level increases.

Equations in Model

Within the VENSIM model the equation is as follows:

$$Stability = 0.9 \times (InitialStability/100) \tag{4}$$

Restoration *Description*

Restoration is another system level metric that measures the amount of time, beginning just as a disaster is occurring, until the level of development in the community has returned to the level that it was prior to the disaster. In the developed model, this value is measured when the development level deviates from one unit of its original value. This metric was chosen because of the importance of restoration of communities before a disaster recurrence. With the relationships developed and defined among the system level metrics, the user could assess what changes in planning would reduce the time until restoration is complete.

Values In the system dynamics model, the value is zero until both time values have been sampled, one when the development level first drops due to a disaster event, and the second when the development level has been restored to within one unit of the predetermined goal value.

Equation in Model

$$RESTORATION = storetime2 - storetime1 \quad (5)$$

Restoration2 *Description*

Restoration2 is another system level metric that measures the amount of time, beginning just as a disaster is occurring, until the level of development in the community has returned to the specified development level set as a goal in DevelThrottleIdeal. In the developed model, this value is measured when the development level deviates from one unit of its original value. Having two parameters which measure Restoration time enables 2 different development goals to be assessed. Both Restoration and Restoration2 are calculated the same way.

Values

In the system dynamics model, the value is zero until both time values have been sampled, one when the development level first drops due to a disaster event, and the second when the development level has been restored to within one unit of the predetermined goal value.

Equations in Model

RESTORATION2 = storetime4 - storetime3

Aid *Description*Aid includes external aid being received into the community from observing nations, etc. and also aid brought and donated by private citizens. Both of these categories of aid are used during the restoration and response phases, but for simplicity purposes it is assumed that this aid contributes where needed during those two phases, and that all incoming aid is properly processed and utilized except for provisions which will also be specified. Internally or officially (federal, FEMA, etc) supplied aid is also included in a separate category. Some provision is made for delays, which reduce the amount of currently available aid. Other factors that reduce the aid flowing into the community are addressed via parameter-level factors which multiply into the amount of aid for each type of aid. Also the rate at which each type of aid is donated and received can be modified by the user. The model also includes effects from the development level (which should increase the ability to receive aid) and effects from preparedness (which should increase the ability to receive aid) Its value is a number with a monetary value per time value.

Values The value will be zero if there is no aid, and a number greater than zero with aid.

Equations in Model

$$A = (A_{tot} - A_{delay}) \times a_{aid} + \frac{D}{100} + I_{prep} \tag{6}$$

Where

A=The amount of aid which is available to the community

A_{tot}=The amount of aid which external (and/or internal) communities are attempting to provide to the community in need

A_{delay}=The amount of aid which is unavailable due to delays

a_{aid}=The fraction of the combined effect of disaster severity with development, which actually arrives

D=Development level of community (affects how easily a community will be able to receive and implement provided aid)

I_{prep}=Preparedness level of community which can be counted as implemented actions and contributes toward a community being able to receive and implement aid

Within the VENSIM model, the equation is as follows:

$$\begin{aligned} AID = {} & (AidSum - AidImpleDelay) \times AidParam1 \\ & + Development/100 \\ & + PrepImplementation \end{aligned} \tag{7}$$

DevelDiffIdeal *Description*

DevelDiffIdeal is the difference between the current development level and the ideal development goal value. This parameter enables a measurement of that difference but it not utilized in any other relationships.

Values

For values of 0, the current development level has reached the ideal development goal value. For negative values, the current development level is greater than the ideal development goal level. This will be very rare, unless the ideal development goal value is set to a low value. For positive values, the current development level is less than the ideal development goal level. As the community recovers from the disaster the value will be positive and decreasing.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$DevelDiffIdeal = DevelThrottleIdeal - Development \tag{8}$$

DevelDiff *Description*

DevelDiff is the difference between the current development level and the original development value (prior to disaster). This parameter enables a measurement of that difference but it not utilized in any other relationships.

Values

For values of 0, the current development level has reached the original development value. For negative values, the current development level is greater than the original development level. This will occur if there is an ideal development goal value. For positive values, the current development level is less than the original development level. As the community recovers from the disaster the value will be positive and decreasing.r if there is an ideal development goal value. For positive values, the current development level is less than the original development level. As the community recovers from the disaster the value will be positive and decreasing.

Equations in Model Within the VENSIM model, the equation is as follows:

$$DevelDiffIdeal = DevelThrottle - Development \tag{9}$$

Devel Stability *Description*

Devel Stability represents the stability of the community development.

Values

Equations in Model

The equation is as follows:

$$Devel_{Stability} = D_{Diff} \times a_{stability} \tag{10}$$

Where

$Devel_{Stability}$=Development Stability

D_{Diff}=DevelThrottle - Development

$a_{stability}$=$0.1 \times StabilityFactor$

Within the VENSIM model, the equation is as follows:

$$DevelStability = (DevelThrottle - Development) \times AdjustmentDSD \times 0.1 \tag{11}$$

Development Components The four components of Development are comprised of three main terms which define each component's rate of change. The generic equation with the three parts is as follows:

$$\begin{aligned} C_A = \int (&RD_A \times (D_{Ai} - D_{An}) \times w_A \\ &- RX_A \times b \\ &+ RA_A \times (D_{Ai} - D_{An}) \times w_{aid,A} \times f_{aid,A}) \end{aligned} \tag{12}$$

where

$$C_A = \text{Component Development} \tag{13}$$

and within the integral,

RD_A=Development Resource Inflow

$(D_{Ai} - D_{An})$=Nearness to Ideal or Initial Component Development Level at time n

w_A=Influence of this term on Component Development Rate

RX_A=Development Capital Outflow due to disaster

b=Predefined Constant

RA_A=Aid Resource Inflow

$w_{aid,A}$=Influence of this term on Component Development Rate

$f_{aid,A}$=fraction of Aid which can be (or IS) used toward component development

A=One of the Development Components

D_{Ai}=Development Component Initial Value

D_{An}=Value of Development Component at time n

D Envir *Description* This parameter is the environmental component of the development.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model

Within the VENSIM model, the equations are as follows:

$$\begin{aligned} DEnvir = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\ & \times (DevelThrottle \times DevelEnvirInit - Development \times DevelEnvirInit) \\ & \times 0.0001 \times DEnvirFactor1 \times ThrottleConstant - FlowDisturbance \\ & \times AdjustmentD + Aid \times ADEnvir \\ & \times (DevelThrottle \times DevelEnvirInit - Development \times DevelEnvirInit) \\ & \times 0.001 \times DEnvirFactor2 \end{aligned} \tag{14}$$

With an initial value of:

$$DEnvir_{Initial} = DevelEnvirInit \times DevelThrottle \tag{15}$$

D Social *Description*

D Social is the social development level of the community.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model

Within the VENSIM model, the equations are as follows:

$$\begin{aligned} DSocial = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\ & \times 0.0001 \times DSocialFactor1 \\ & \times (DevelThrottle \times DevelSocialInit - Development \times DevelSocialInit) \\ & \times ThrottleConstant - FlowDisturbance \times AdjustmentD + Aid \times ADSoc \\ & \times (DevelThrottle \times DevelSocialInit - Development \times DevelSocialInit) \\ & \times 0.001 \times DSocialFactor2 \end{aligned} \tag{16}$$

With an initial value of:

$$DSocial_{Initial} = DevelSocialInit \times DevelThrottle \tag{17}$$

D Econ *Description* This parameter is the economic development level of the community.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model

Within the VENSIM model, the equations are as follows:

$$
\begin{aligned}
DEcon = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\
& \times 0.0001 \times DEconFactor1 \\
& \times (DevelThrottle \times DevelEconInit - Development * DevelEconInit) \\
& \times ThrottleConstant - FlowDisturbance \times AdjustmentD + Aid \times ADPhys \\
& \times (DevelThrottle \times DevelEconInit - Development \times DevelEconInit) \\
& \times 0.001 \times DEconFactor2
\end{aligned} \tag{18}
$$

with an initial value of:

$$
DEcon_{Initial} = DevelEconInit \times DevelThrottle \tag{19}
$$

D Physical *Description* This parameter is the physical component of the development.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model

Within the VENSIM model, the equations are as follows:

$$
\begin{aligned}
DPhysical = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\
& \times 0.0001 \times DPhysicalFactor1 \\
& \times (DevelThrottle \times DevelPhysInit - Development \times DevelPhysInit) \\
& \times ThrottleConstant - FlowDisturbance \times AdjustmentD + ADPhys \times Aid \\
& \times (DevelThrottle \times DevelPhysInit - Development \times DevelPhysInit) \\
& \times 0.001 \times DPhysicalFactor2
\end{aligned} \tag{20}
$$

with an initial value of:

$$DPhysical_{Initial} = DevelPhysInit \times DevelThrottle \tag{21}$$

D Envir2 *Description* This parameter is the Environmental component of development.

*Values*The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model

Within the VENSIM model, the equations are as follows:

$$\begin{aligned} DEnvir2 = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\ & \times (DevelThrottleIdeal \times DevelEnvirInit - Development \times DevelEnvirInit) \\ & \times 0.0001 \times DEnvir2Factor1 \times ThrottleConstant - FlowDisturbance \\ & \times AdjustmentD + Aid \times ADEnvir \\ & \times (DevelThrottleIdeal \times DevelEnvirInit - Development \times DevelEnvirInit) \\ & \times 0.001 \times DEnvir2Factor2 \end{aligned} \tag{22}$$

With an initial value of:

$$DEnvir2_{Initial} = DevelEnvirInit \times DevelThrottle \tag{23}$$

D Social2 *Description* This parameter is the social aspect of the development.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model Within the VENSIM model, the equations are as follows:

$$
\begin{aligned}
DSocial2 = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\
& \times 0.0001 \times DSocial2Factor1 \\
& \times (DevelThrottleIdeal \times DevelSocialInit - Development \times DevelSocialInit) \\
& \times ThrottleConstant - FlowDisturbance \times AdjustmentD + Aid \times ADSoc \\
& \times (DevelThrottleIdeal \times DevelSocialInit - Development \times DevelSocialInit) \\
& \times 0.001 \times DSocial2Factor2
\end{aligned}
\tag{24}
$$

With an initial value of:

$$
DSocial2_{Initial} = DevelSocialInit \times DevelThrottle \tag{25}
$$

D Econ2 *Description* This parameter is the economic aspect of the development.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model Within the VENSIM model, the equations are as follows:

$$
\begin{aligned}
DEcon2 = \int & (FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\
& \times 0.0001 \times DEcon2Factor1 \\
& \times (DevelThrottleIdeal \times DevelEconInit - Development * DevelEconInit) \\
& \times ThrottleConstant - FlowDisturbance \times AdjustmentD + Aid \times ADPhys \\
& \times (DevelThrottleIdeal \times DevelEconInit - Development \times DevelEconInit) \\
& \times 0.001 \times DEcon2Factor2
\end{aligned}
\tag{26}
$$

with an initial value of:

$$
DEcon2_{Initial} = DevelEconInit \times DevelThrottle \tag{27}
$$

D Physical2 *Description* This parameter is the physical aspect of the development.

Values The values for this parameter is a value greater than zero, with a maximum value of 100.

Equations in Model Within the VENSIM model, the equations are as follows:

$$\begin{aligned} DPhysical2 = \int &(FlowDStabDevel + FlowDPDevel + FlowDFDevel) \\ &\times 0.0001 \times DPhysical2Factor1 \\ &\times (DevelThrottleIdeal \times DevelPhysInit - Development \times DevelPhysInit) \\ &\times ThrottleConstant - FlowDisturbance \times AdjustmentD + ADPhys \times Aid \\ &\times (DevelThrottleIdeal \times DevelPhysInit - Development \times DevelPhysInit) \\ &\times 0.001 \times DPhysical2Factor2 \end{aligned} \tag{28}$$

with an initial value of:

$$DPhysical2_{Initial} = DevelPhysInit \times DevelThrottle \tag{29}$$

Devel Funding *Description* This parameter is funding stock which flows to the different components of development.

Values The value is a number greater than or equal to zero.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$DevelFunding = \int -FlowDFDevel \times DFAdjustment \tag{30}$$

with an initial value of:

$$DevelFunding_{Initial} = InternalFundingBudget \times DevelFundingBudget \tag{31}$$

Devel Programs *Description* This parameter is the resource stock for programs which influence the development level of the community.

Values The initial value is a fraction of the available resources for the community, and the value of the parameter remains at or above zero throughout the simulation.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$DevelPrograms = \int -FlowDPDevel \times DPAdjustment \tag{32}$$

with the initial value of:

$$DevelPrograms_{Initial} = InternalFundingBudget \times DevelProgramsBudget \tag{33}$$

Internal Funding *Description*Internal Funding was considered as the available funding, in the form of a fraction of the needed amount. A value of 1 means that the needed funds were all available. Because the cost aspect of the system is quite complex, the simplification was done so that the example may be developed. This is easier than adding another aspect wherein cash amounts were flowing through the entire system when having that number may be too specific or if the effect of the parameter is more complex than initially thought.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$InternalFunding = \int -InternalFundingBudget \times AdjustIF \tag{34}$$

with an initial value of:

$$InternalFunding_{Initial} = InitialFundingTotal \tag{35}$$

Training *Description*: Training is a component of the preparedness of the community. It includes different exercises and drills which may help disaster response managers and other members of the community. Training may include emergency exit drills, appropriate disaster drills such as earthquake or tornado drills, and responder training.

Increasing the amount of training implemented in a community will aid in the disaster response and may reduce the restoration time if the training is effective during the implementation after a disaster. [73]

Equations in Model

$$P_{train} = \int (B_{IF} \times B_{prep,train} \times a_{train} \times P_{train,0} - RP_{train} \times b_{train}) \tag{36}$$

P_{train}=Amount of preparedness training available and utilized in the community

Within the VENSIM model, the equation is:

$$\begin{aligned} Training = \int (&InternalFundingBudget \times PrepTrainingBudget) \\ &\times AdjustTrainB \times TrainingInit \\ &- FlowTrainPrep \times 0.1 \end{aligned} \tag{37}$$

with an initial value of:

$$Training_{Initial} = TrainingInit \tag{38}$$

Prep Programs *Description* This parameter is a component of the Preparedness of the community. It includes the effect from organized preparedness programs. These programs may be targeted to families and individuals or may address disaster management at a higher level.

Increasing the amount of programs implemented in a community will aid in the disaster response and may reduce the restoration time after a disaster because the programs enable a community to adhere to preparedness standards as well as initiate and maintain awareness of potential hazards and contingency plans in case of their occurrence. The community can then take steps to reduce some of the effects of the event or be ready to deal with the disaster effects. [73]

Equations in Model

$$P_{prog} = \int (B_{IF} \times B_{prep,prog} \times a_{prep,prog} \times P_{prog,0} - RP_{prog}) \times a_{prep,prog} \tag{39}$$

Where

B_{IF}=available funding, in the form of a fraction of the needed amount based on budgeted funding (1 means that the needed funds are all available, <1 means there is a shortage, >1 means there is a surplus)

$B_{prep,prog}$=funding for preparedness programs

$a_{prep,prog}$=scaling amount of how much of the preparedness programs contribute to preparedness

P_{prog}=Amount of preparedness programming active in the community

RP_{prog}=Amount of programming which actually contributes to the level of preparedness

$a_{prep,prog}$=scaling amount of how much of the preparedness programs contribute to preparedness

Within the VENSIM model, the equation is as follows:

$$\begin{aligned} PrepPrograms = \int & (InternalFundingBudget \times PrepProgramBudget) \\ & \times AdjustPrepP \times PrepProgramsInit \\ & - FlowProgPrep \times AdjustPrepP \end{aligned} \tag{40}$$

$$PrepPrograms_{Initial} = PrepProgramsInit \tag{41}$$

Procurement *Description*: Procurement is the amount of post-disaster supplies which are acquired prior to the disaster. A greater amount of procurement implies a greater readiness for the disaster. However, the pre-disaster stored supplies must be distributed and utilized after the disaster for the procurement to have an effect on the response and restoration time. [73]

Equations in Model

The developed equation is as follows:

$$P_{pro} = \int (V_{pro} + w_{train,proc} \times RP_{train} + w_{prog,proc} \times RP_{prog} - RP_{pro}) \tag{42}$$

Where

P_{pro}=Amount of procurement done leading up to the disturbance

V_{pro}=Value of the items which have been procured

$w_{train,proc}$=effect of training on procurement

RP_{train}=Amount of training which actually contributes to the level of preparedness

$w_{prog,proc}$=effect of preparedness programs on procurement

RP_{prog}=Amount of programming which actually contributes to the level of preparedness

RP_{pro}=Amount of procurement which actually contributes to the level of preparedness

Within the VENSIM model, the equation is as follows:

$$\begin{aligned} Procurement = \int (&ProcureValue + WtTrainProc \times FlowTrainPrep \\ &+ WtProgProc \times FlowProgPrep - flowProPrep) \end{aligned} \tag{43}$$

Prepositioning *Description* This parameter is a component of the Preparedness of the community. It includes any prepositioning of resources prior to an event which has some amount of warning time. If there is a warning time before the disaster, prepositioning resources enable a faster distribution of resources after the disaster. [73] [29]

Equations in Model

The equation for this parameter is:

$$P_{prepo} = \int (V_{prepo} + w_{prep,train} \times RP_{train} + w_{prog,prep} \times RP_{prog} - RP_{prepo}) \tag{44}$$

Where

P_{prepo}=Amount of prepositioning done leading up to the disturbance

V_{prepo}=Value of the items which have been pre-positioned

$w_{prep,train}$=effect of prepositioning on training

RP_{train}=Amount of training which actually contributes to the level of preparedness

$w_{prog,prep}$=effect of preparedness programs on prepositioning

RP_{prog}=Amount of programming which actually contributes to the level of preparedness

RP_{prepo}=Amount of prepositioning which actually contributes to the level of preparedness

RP_{collab}=Amount of collaboration which actually contributes to the level of preparedness

Within the VENSIM model, the equation is as follows:

$$\begin{aligned} Prepositioning = \int (&PrepositionValue + WtTrainPrep \times FlowTrainPrep \\ &+ WtProgPrep \times FlowProgPrep - flowPrepoPrep) \end{aligned} \quad (45)$$

with an initial value of:

$$Prepositioning_{Initial} = PrepositionInit \quad (46)$$

Collaboration *Description* This parameter is a component of the Preparedness of the community. It includes collaboration of different entities involved in the disaster response. This component of the preparedness is different from the training and program parameters and refers to collaboration for the purposes of response and restoration planning. This enables planners from different authority regions to develop common response and restoration standards. [6]

Equation in Model

$$P_{collab} = \begin{cases} -\int RP_{collab} & \text{if } RX > 0 \\ \int (V_{collab} + w_{train,coll} \times RP_{train} + w_{prog,coll} \times RP_{prog} - RP_{collab}) & \text{otherwise} \end{cases} \tag{47}$$

Where

P_{collab}=Amount of collaboration done leading up to the disturbance

RP_{collab}=Amount of collaboration which actually contributes to the level of preparedness

RX=Disaster event occurring

V_{collab}=Value of the collaborating which has been done

$w_{train,coll}$=effect of training on collaboration

RP_{train}=Amount of training which actually contributes to the level of preparedness

$w_{prog,coll}$=effect of preparedness programs on collaboration

RP_{prog}=Amount of programming which actually contributes to the level of preparedness

RP_{collab}=Amount of collaboration which actually contributes to the level of preparedness

Within the VENSIM model, the equation is as follows:

$$Collaboration = \begin{cases} -\int flowCollabPrep & \text{if } FlowDisturbance > 0 \\ \int (CollabValue & \\ \quad +WtTrainColl \times FlowTrainPrep & \\ \quad +WtProgColl \times FlowProgPrep) & \text{otherwise} \end{cases} \tag{48}$$

with an initial value of:

$$Collaboration_{Initial} = CollabInit \tag{49}$$

Preparedness *Description*: Preparedness measures the amount of activities done in the community which deal directly with preparing for a disaster. It is also given a factor which represents the effective amount of preparedness on the system - that is, some measures of preparedness may not apply or be utilized in a disaster, and a factor is included in order to allow for that.

Values: The initial value for Preparedness is set to 5, a value which represents an initial level of preparedness. The preparedness value increases throughout the simulation, which means that future modifications to the model may need to include the effect of the disaster on the preparedness so that the behavior of the parameter during the simulation reflects a stock parameter.

Equation in Model:

$$P = \int (RP_{prepo} + RP_{collab} + RP_{pro}) \times a_p \tag{50}$$

Where

P=Preparedness level of the community

RP_{prepo}=Amount of prepositioning which actually contributes to the level of preparedness

RP_{collab}=Amount of collaboration which actually contributes to the level of preparedness

RP_{pro}=Amount of procurement which actually contributes to the level of preparedness

RP_{prog}=Amount of programming which actually contributes to the level of preparedness

RP_{train}=Amount of training which actually contributes to the level of preparedness

a_p=scaling factor for other effects on the preparedness

Within the VENSIM model, the equations are as follows:

$$PREPAREDNESS = \int flowPrepoPrep + flowCollabPrep + flowProPrep) \times AdjustPreparedness \tag{51}$$

Unofficial Aid *Description* This parameter is the stock of the aid which is brought into the community by unofficial sources. This component of the aid becomes more important and the value may be higher in communities experiencing a disaster in which the official response may be unable to reach a majority of the citizens. Disasters in nations where the government is unable or unwilling to accept external aid increase the amount of unofficial aid which is received into the country. [101, 13] This aid may be referred to as remittance aid.

Equations in Model

$$A_{un} = \int (f_{A,un} \times RS_{Aid} - RA_{un}) \tag{52}$$

Where

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

$f_{A,i}$=Fraction of total aid which is used as aid type 'i'

RS_{Aid}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

RA_i=Amount of aid (of type 'i' being contributed to the community

Within the VENSIM model, the equation is as follows:

$$UnofficialAid = \int AidUnofficialFraction \times FlowSymAid - flowunofficial \tag{53}$$

Other Parameter Effects

Response Aid *Description* This parameter is the stock of the aid which is sent to the community to respond to the disaster effects. Response aid includes first responder services such as medical treatment resources, search and rescue parties, authorities to restore order to the community, and firefighting. This aid is extremely critical in the days following a disaster occurrence. An increase in the amount of response aid going to the community improves the life and livelihood of community citizens. [73, 29, 153]

Equations in Model

The equation in the model is as follows:

$$A_{resp} = \int (f_{A,resp} \times RS_{Aid} - RA_{resp}) \tag{54}$$

Where

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

$f_{A,i}$=Fraction of total aid which is used as aid type 'i'

RA_i=Amount of aid (of type 'i' being contributed to the community

RS_{Aid}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

Within the VENSIM model, the equation is as follows:

$$ResponseAid = \int AidResponseFraction \times FlowSymAid - flowrespaid \tag{55}$$

Restoration Aid *Description* This parameter is a component of the total aid and includes the aid resources being sent to the community for long term rebuilding and restoration. An increase in response aid will enable the community to rebuild the damage done by the disaster. This includes assistance recovery programs, making changes to infrastructure and procedures, and increasing the awareness of the community residents. [73]

Values

Equations in Model In the model, the equation is as follows:

$$A_{rest} = \int (f_{A,rest} \times RS_{Aid} - RA_{rest}) \tag{56}$$

Where

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

$f_{A,i}$=Fraction of total aid which is used as aid type 'i'

RS_{Aid}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

RA_i=Amount of aid (of type 'i' being contributed to the community

Within the VENSIM model, the equation is as follows:

$$RestorationAid = \int AidRestoreFraction \times FlowSymAid - flowrestaid \tag{57}$$

External Aid *Description* This parameter is a component of the aid coming into the community. External aid comes from sources outside of the parameter. An increased amount of external aid in the community will improve the response and aid in the response and restoration of the community if it is properly implemented. [29, 73]

Equations in Model

In the model, the equation is as follows:

$$A_{ext} = \int (f_{A,ext} \times RS_{SymAid} - RA_{ext}) \tag{58}$$

Where

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

RS_{SymAid}=The rate that persons who have become interested in providing aid actually act on their sympathy/interest

$f_{A,i}$=Fraction of total aid which is used as aid type 'i'

RA_i=Amount of aid (of type 'i' being contributed to the community

Within the VENSIM model, the equation is as follows:

$$ExternalAid = \int AidExternalFraction \times FlowSymAid - flowexternal \tag{59}$$

Aid Sum *Description*

The Aid Sum is the amount of aid coming into the community after the disaster. Within the Aid measurement, the Aid Sum is the grouping of various incoming aid categories. The incoming aid is related by the flow rate of the aid in each aspect of the aid.

Equation in Model

$$A_{tot} = \int (RA_{ext} + RA_{resp} + RA_{rest} + RA_{un} - A \tag{60}$$

$$RA_{ext} = b_{A,ext} \times A_{ext} \times a_{R,ext} \tag{61a}$$

$$RA_{rest} = A_{rest} \times a_{R,rest} \tag{61b}$$

(61c)

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

RS_{Aid}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

RS_{SymAid}=The rate that persons who have become interested in providing aid actually act on their sympathy/interest

RA_i=Amount of aid (of type 'i' being contributed to the community)

$f_{A,i}$=Fraction of total aid which is used as aid type 'i'

Within the VENSIM model, the equations are as follows:

$$\begin{aligned} AidSum = \int & flowexternal + flowrespaid + flowrestaid \\ & + flowunofficial - Aid \end{aligned} \tag{62}$$

$$flowexternal = 0.1 \times ExternalAid \times AdjustmentflowExt \tag{63a}$$

$$flowrestaid = RestorationAid \times AdjustmentflowRest \tag{63b}$$

(63c)

Each of the different types of aid come from calculations of aid being received, which is influenced by media coverage along with a collective desire to donate aid (this desire is designated with the term "Sympathy") of which a fraction is designated for each of the different categories of aid.

Where

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

RS_{Aid}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

RS_{SymAid}=The rate that persons who have become interested in providing aid actually act on their sympathy/interest

RA_i=Amount of aid (of type 'i' being contributed to the community

$f_{A,i}$=Fraction of total aid which is used as aid type 'i'

Sympathy *Description* This parameter represents the response of the community to the coverage of the disaster. If a greater amount of persons and organizations respond to the media coverage of the disaster, the assumption is that a greater amount of those persons and organizations will provide external aid.

Equations in Model

The equation in the model is as follows:

$$S = \int (RS_{CovSym} - RS_{SymAid}) \times a_{CS} \tag{64}$$

Where

S=Sympathy from those outside of the community based on the media coverage

RS_{CovSym}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

RS_{SymAid}=The rate that persons who have become interested in providing aid actually act on their sympathy/interest

a_{CS}=Scale for unaccounted factors which might further reduce the amount of media coverage which is received by persons after a disaster event

Within the VENSIM model, the equation is as follows:

$$Sympathy = \int (flowCovSym - FlowSymAid) \times AdjustCS \tag{65}$$

Media Coverage *Description*

Media Coverage and media involvement in disaster aid have become more and more of a factor in the past couple of years with the rise of social media networks. Through these networks and news networks, aid can be sought to a much wider audience of people. [73] As the social media involvement has linked up with response organizations and technological entities to enable quick small amount donation methods [1], it has become easier and easier for persons not affected by the disaster to give financially. Awareness of different needs and response opportunities are also propagated through social media networks, which were utilized to help relocate and reconnect families after some recent disasters. [29] Not everyone who is exposed to these messages will donate, however, so there is a fraction of difference between the persons exposed to the need through the media and the amount that they actually donate.

Values

The media coverage surrounding a disastrous event follows a trend similar to the one shown in Figures 43 and 44. There is a sudden spike after the occurrence of the event, and then the coverage reduces sharply, but the rate of reduction also reduces as the coverage decreases.

The data for this curve is from a series of searches using the Google News search engine. The terms "Haiti Earthquake" and "Hurricane Katrina" were entered into the search text box and the specific date search was conducted for each day in the week leading up to the event and for several months to a year afterward, depending on the decrease in amount of articles found. The number used in the data sets is the number of results given once the search was complete. Although the Google News search engine groups certain articles together if they are similar or from the same source, the assumption is made that this is

[1] An example is the mGive Foundation, whose work is available at `http://www.mgivefoundation.org/terms-of-service.aspx`

always the case and that duplicate articles were not included in the results.

In Figure 43 the increase in media coverage occurred as soon as the event happened but since there was little warning of the earthquake, the increase is very sudden. However before Hurricane Katrina made landfall in New Orleans it had spent a few days crossing over Florida and the Gulf of Mexico, and the increase which can be seen in Figure 44 is still significant but not as sudden as seen in Figure 43 for the Haiti Earthquake.

Equations in Model

Media Coverage is represented in the system model as:

$$M = \int (b_{CovSym} \times RX \times a_{FD} - b_{RS,CovSym} \times RS_{CovSym})) \times N_{Random} \times a_{MC} \tag{66}$$

Where

RS_{CovSym}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

a_{RS}=Scale for unaccounted factors which might further reduce the amount of interest in providing aid which is acted upon

M=Media Coverage of an event, which is explained in paragraph following the equations from the model.

Within the VENSIM model, the equation for Media Coverage is:

$$\begin{aligned} MediaCoverage = \int (&20 \times FlowDisturbance \times AdjustFD \\ &- (0.1 \times flowCovSym)) \times randomnormal \times AdjustMC \end{aligned} \tag{67}$$

Flow Disturbance *Description*

The Event or Disaster metric is named Flow Disturbance in the system dynamics model and is composed of a unit spike at a certain time with the option of an aftershock as well.

Equations in Model

$$RX = (E + E_A) \times \frac{RD}{a_{FD}} \times \frac{a_{fx} \times E_{sev}}{b_{sev}} \tag{68}$$

Where

RX=Amount of disturbance which is propagated through the community

E=Disaster component of disturbance

E_A=Disaster component disturbance if aftershock occurs

RD=Development level which affects the community

a_{FD}=denominator scale for RD

a_{fx}=effects of disaster on the system (scale of severity)

E_{sev}=Severity of disaster - value factor which is multiplied with the event / disaster occurrence to provide a sort of magnitude or severity measure

b_{sev}=constant for scale of effects on system

Within the VENSIM model, the equations are as follows:

$$FlowDisturbance = (DisasterEvent + aftershockoption) \times \frac{DevelFlow}{AdjustmentFD} \times \frac{fxonsys \times Severity}{15} \tag{69}$$

Flow DStabDevel *Description* This parameter describes the flow of the community stability into the development of the community as an increase (or decrease) of the resilience capability. This parameter is composed of the Development Stability and also the scaling factor for the stability flow.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$FlowDStabDevel = DevelStability \times StabilityFlowAdjust \tag{70}$$

Flow DFDevel *Description* This parameter describes the amount of implemented funding. The funding for community development may be designated prior to its use or implementation. Once it is spent, it is considered implemented.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$FlowDFDevel = DFDevelFraction \times DevelFunding \tag{71}$$

Flow DPDevel *Description*

This parameter describes the fraction of implemented programs for development within the community. The Development programs are considered implemented once the practices and training from the program become known or used by the majority of the community.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$FlowDPDevel = DPDevelFraction \times DevelPrograms \tag{72}$$

Devel Flow *Description*

The Devel Flow is the fraction of the Development level which is affected by the disaster disturbance.

Equations in Model Within the VENSIM model, the equation is as follows:

$$DevelFlow = Development \times Fraction \tag{73}$$

Aid Imple Delay *Description* The Aid Imple Delay parameter describes the delay in the aid implementation. The aid may be sent and received very soon after the disaster, but the severity of the disaster may increase the time before the aid is implemented. If a community also has a greater development level, however, this decreases the parameter value, and this means the community experiences a lesser delay in receiving aid.

Values The Aid Implementation Delay has a default value of 30 but the ideal value would be a zero delay in aid implementation. *Equations in Model*

Within the VENSIM model, the equation is as follows:

$$AidImpleDelay = AidDelayAdjust \times (AdjustmentFD \times FlowDisturbance - Development) + 30 \tag{74}$$

Prep Implementation *Description* This parameter describes the preparedness which is implemented after the disaster occurs. While this should be a number close to one, this may not be the case.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$PrepImplementation = Preparednesss \times PrepParam1 \tag{75}$$

flow CovSym *Description* flow CovSym is the transfer of media coverage into sympathy from viewers and external sources who learn about the disaster through the media. Not all observers feel compelled to contribute to the aid process, and not all who feel compelled to contribute to the aid process actually contribute. The values restrict the contribution potential to the amount of media coverage but this may be adjusted in future models and may not be the case.

Equations in Model The equation is as follows:

$$RS_{CovSym} = M \times a_{RS} \tag{76}$$

Where

RS_{CovSym}=The rate that persons who observe media coverage of the event become sympathetic, or interested in providing aid by some means

M=Media Coverage of an event, which is explained in paragraph following the equations from the model.

a_{RS}=Scale for unaccounted factors which might further reduce the amount of interest in providing aid which is acted upon

Within the VENSIM model, the equation is as follows:

$$FlowCovSym = MediaCoverage \times AdjustflowCS \tag{77}$$

Flow SymAid *Description*

This parameter provides a measure on the rate which the generated donation potential (sympathy) is implemented as actual aid. This will depend on the stability of the aiding nations. If aiding nations are dealing with internal issues and possibly even internal disasters there may not be a high amount of donations resulting from persons in those communities learning about the disaster occurrence.

Equations in Model The model relationship for Flow Sym Aid is:

$$RS_{SymAid} = \frac{W}{100} \times S \tag{78}$$

Where

RS_{SymAid}=The rate that persons who have become interested in providing aid actually act on their sympathy/interest

W=WorldState, which is the capability of responding nations to provide external aid

S=Sympathy from those outside of the community based on the media coverage

Within the VENSIM model, the equation is as follows:

$$FlowSymAid = \frac{WorldState}{100} \times Sympathy \tag{79}$$

flow unofficial *Description* This parameter describes the flow rate of the unofficial aid stock to the available aid flowing into the community.

Equations in Model The model equation is as follows:

$$RA_{un} = A_{un} \times a_{R,un} \tag{80}$$

Where

A_{un}=Unofficial Aid

$a_{A,un}$=Fraction of total aid which is used as unofficial aid

Within the VENSIM model the equation is as follows:

$$flowunofficial = UnofficialAid \times AdjustmentflowUn \tag{81}$$

flowrespaid *Description*This parameter describes the flow rate of the response aid stock to the available aid flowing into the community.

Equations in Model The equation is as follows:

$$RA_{resp} = A_{resp} \times a_{A,resp} \tag{82}$$

Where

RA_i=Amount of aid (of type 'i' being contributed to the community)

A_i=Type 'i' of aid, ext=external, rest=restoration, resp=response, un=unofficial

$a_{A,i}$=Fraction of total aid which is used as aid type 'i'

Within the VENSIM model, the equations are as follows:

$$flowrespaid = ResponseAid \times AdjustmentflowRes \tag{83}$$

flowrestaid *Description* This parameter describes the flow rate of the restoration aid stock to the available aid flowing into the community.

Equations in Model

Within the VENSIM model the equation is as follows:

$$flowrestaid = RestorationAid \times AdjustmentflowRest \tag{84}$$

flow external *Description*This parameter describes the flow rate of the external aid stock to the available aid flowing into the community.

Equations in Model Within the VENSIM model, the equation is as follows:

$$flowexternal = 0.1 \times ExternalAid \times AdjustmentflowExt \tag{85}$$

Flow Train Prep *Description*

Flow Train Prep is the amount of training which contributes to the preparedness of the community. If looking at the community from the perspective of stocks and flows, it is the part of training which actually flows into the preparedness of the community.

Equations in Model

The equation is as follows:

$$RP_{train} = a_{prep,train} \times P_{train} \tag{86}$$

Where

RP_{train}=Amount of training which actually contributes to the level of preparedness

$a_{prep,train}$=Scaling amount of how much of the preparedness training contributes to preparedness

P_{train}=Amount of preparedness training available and utilized in the community

Within the VENSIM model, the equation is as follows:

$$FlowTrainPrep = PreparednessTrainingAdjust \times Training \tag{87}$$

Flow ProgPrep *Description*

Flow ProgPrep is the amount of preparedness programs which contribute to the preparedness of the community. If looking at the community from the perspective of stocks and flows, it is the part of programs which actually flows into the preparedness of the community. Ideally all of the programs would contribute to the preparedness of the community but this may not be the case. Some programs may be redundant or cover topics which are not an issue in the community.

Equations in Model

The equation in the model is as follows:

$$RP_{prog} = a_{prep,prog} \times P_{prog} \tag{88}$$

Where

RP_{prog}=Amount of programming which actually contributes to the level of preparedness

$a_{prep,prog}$=Scaling amount of how much of the preparedness programs contribute to preparedness

P_{prog}=Amount of preparedness programming active in the community

Within the VENSIM model, the equation is as follows:

$$FlowProgPrep = PreparednessProgramAdjust \times PrepPrograms \tag{89}$$

flowProPrep *Description*

flowProPrep is the amount of procurement which contributes to the preparedness of the community. If looking at the community from the perspective of stocks and flows, it is the part of procurement which actually flows into the preparedness of the community. Ideally all procured resources would increase the preparedness of the community, but if a community is procuring resources for different disasters and one type of disaster occurs, some procured resources may not be relevant in the response or restoration of the community.

Equations in Model In the model, the equation is as follows:

$$RP_{pro} = \frac{a_{pro}}{b_{pro}} \times P_{pro} \tag{90}$$

Where

RP_{pro}=Amount of procurement which actually contributes to the level of preparedness

a_{pro}=Fraction numerator of how much of the procurement contributes to preparedness

b_{pro}=Fraction denominator of how much of the procurement contributes to preparedness

P_{pro}=Amount of procurement done leading up to the disturbance

Within the VENSIM model, the equation is as follows:

$$flowProPrep = 0.1 \times Procurement \tag{91}$$

flowPrepoPrep *Description*

flowPrepoPrep is the amount of prepositioning done before the disaster occurs which contributes to the preparedness of the community. If looking at the community from the perspective of stocks and flows, it is the part of prepositioning which actually flows into the preparedness of the community. Ideally all of the prepositioning would contribute to the preparedness of the community but this may not be the case. Some types of disaster with little to no warning time will not allow for prepositioning to be done before the disaster occurrence.

Equations in Model

The equation is as follows:

$$RP_{prepo} = \frac{a_{pre}}{b_{pre}} \times P_{prepo} \tag{92}$$

Where

RP_{prepo}=Amount of prepositioning which actually contributes to the level of preparedness

a_{pre}=Fraction numerator of how much of the prepositioning contributes to preparedness

b_{pre}=Fraction denominator of how much of the prepositioning contributes to preparedness

P_{prepo}=Amount of prepositioning done leading up to the disturbance

Within the VENSIM model, the equation is as follows:

$$flowPrepoPrep = \frac{AdjustPre}{10} \times Prepositioning \tag{93}$$

flow CollabPrep *Description*

flow CollabPrep is the amount of collaboration done before the disaster occurs which contributes to the preparedness of the community. If looking at the community from the perspective of stocks and flows, it is the part of collaboration which actually flows into the preparedness of the community. Ideally all of the collaboration should contribute to the preparedness of the community.

Equations in Model

The equation is as follows:

$$RP_{collab} = \frac{a_{collab}}{b_{collab}} \times P_{collab} \tag{94}$$

Where

RP_{collab}=Amount of collaboration which actually contributes to the level of preparedness

a_{collab}=fraction numerator of how much of the collaboration contributes to preparedness

b_{collab}=fraction denominator of how much of the collaboration contributes to preparedness

P_{collab}=Amount of collaboration done leading up to the disturbance

The equation in the VENSIM model is as follows:

$$flowCollabPrep = \frac{AdjustFCP}{10} \times Collaboration \tag{95}$$

DevelSocialInit *Description*

The DevelSocialInit represents the initial level of social development of the community. Existing social indicators used in the United Nations Statistics Division can be found at: `http://unstats.un.org/unsd/demographic/products/socind/` and were each defined with values for the selected community.ity. Existing social indicators used in the United Nations Statistics Division can be found at: `http://unstats.un.org/unsd/demographic/products/socind/` and were each defined with values for the selected community.

There are twelve social development indicators which are used by the United Nations Statistics Division. Each Indicator has one or more parameters which provide insight on the level of development in that area. All definitions, unless otherwise noted, come from the UN Statistics Division website for Social Development Indicators [160]. The data for the indicators comes from assessment of many nations globally, and not just the United States, the region in which this research focuses. Determination of the impact of different indicator or sub-indicator values, then, is done based on these global effects, taking into account a possible expansion to non-US nations in the future.

Indicators on Childbearing

Adolescent Fertility Rate is defined as "the annual number of live births born to women aged 15 to 19 years per 1,000 women in the same age group." This statistic provides information on teen pregnancies and affects the development level, including in conducting disaster response planning. Children born to single teen mothers are more likely to grow up in poverty, and nationally about 60% (in 2004) of teen mothers lived in poverty. The likelihood of the mother becoming engaged in other problematic lifestyles (dropping out of school, committing crimes or being involved in criminal activity, doing drugs and excessive drinking), is also higher. [151] The assumption is that higher development would make a community more resilient for rebuilding after a disaster occurs. With higher adolescent fertility rates, the likelihood of children being raised in impoverished single mother homes is higher. Impoverished families have more difficulty recouping after a disaster occurs. If belongings are lost or damaged by the disaster, some demographic groups experience greater difficulty in replacing them.

Total Fertility Rate is defined as "the number of children a woman would bear if her child-bearing follows the current fertility patterns and she lives through her entire child-bearing years." This statistic provides information on how many children are being born into a community in a period of time. With regard to disaster response if a community has a higher fertility rate this means that there are more infants and newborns (and also thus young children) in the community. Young children (including infants and toddlers) are more vulnerable to disasters in that they are less able to protect themselves from some of the disaster effects but also are less able to take care of themselves than older children or adults if something should happen to their guardians.

Estimated Maternal Mortality Ratio is defined as "the number of maternal deaths per 100,000 live births in a given year. Maternal deaths are defined as those caused by deliveries and complications of pregnancy, child-birth and the puerperium. However, the exact definition varies from source to source and is not always clear in the original, particularly as regards the inclusion of abortion-related deaths." A higher maternal mortality ratio is set as a sign of lower social development level. Higher maternal mortality may be reflective of lacking technologies or doctoral skills or more vulnerable pregnant mothers within a community. All of these things are detrimental to pregnant mothers and make them more vulnerable, particularly within the context of an occurring disaster.

Indicators on Child and Elderly Populations

Percentage of Population < 15 years is "the percentage of the total population aged 0 to 14 years." Higher percentages in this indicator represent a greater child population, who are more vulnerable to disasters. Therefore a higher percentage of population which is under fifteen years will be more vulnerable to disaster, so this is represented by a lower development level.

Percentage of Population > 60 years is the "percentage of the male population who are 60 years and older and the percentage of the female population who are 60 years and older, respectively." A similar rule follows for this indicator as well. Elderly populations are more vulnerable to disasters since there is a greater number of persons with limited mobility, higher dependency on medicines and routine medical procedures, and more difficulty with injury and health resilience. Greater percentages of populations which are over sixty years are considered at a lower development level for this reason.

Sex Ratio in 60+ age group is "calculated as the number of males per 100 females in the respective age group." A balanced sex ratio for communities is desirable. Off-balanced sex ratios can lead to further social problems and impact other aspects of a community's development. For communities where gender imbalance was caused by non-natural forces there are long-term effects. [16] For a sex ratio greater than 100, social impacts are seen in the areas of prostitution and human trafficking, as women may be kidnapped from one place in order to be available for marriage in another community. Particularly in Asian nations this shift has become more common for various political or economic reasons. [3]

Contraceptive Use

Contraceptive Prevalence "refers to the percentage of women of reproductive age (usually aged 15-49 years), married or in union, currently using contraception, unless otherwise specified."

Contraceptive Prevalence: Any method is defined as "the use of contraception regardless of method." High prevalence for use of any method reduces the social vulnerability of a community particularly in areas where single females may already be living in poverty and would not be able to support a child. Higher prevalence values would be subject to higher development levels within the model.

Contraceptive Prevalence: Modern methods is defined as “the use of the following methods: female and male sterilization, the contraceptive pill, the intrauterine device (IUD), injectables, implants, female and male condom, cervical cap, diaphragm, spermicidal foams, jelly, cream, sponges and emergency contraception; and excludes the lactational amenorrhea method (LAM), abortions, periodic abstinence and withdrawal.” High prevalence for use of any method reduces the social vulnerability of a community particularly in areas where single females may already be living in poverty and would not be able to support a child. Higher prevalence values would be subject to higher development levels within the model.

Education

School life expectancy (in years). Primary to tertiary education: Total is defined as “the total number of years of schooling which a child can expect to receive, assuming that the probability of his or her being enrolled in school at any particular future age is equal to the current enrollment ratio at that age.” The indicator is not a predictor and the calculation assumes that the value will not change significantly in the near future.

School life expectancy (in years). Primary to tertiary education: Men is the school life expectancy (SLE) for males within the community.

School life expectancy (in years). Primary to tertiary education: Women is the SLE for females within the community.

For the US these figures are very close in value. However a number of years spent in school repeating grades is not separated from this statistic, nor does the statistic give any indication as to the quality of the education. For disaster response planning purposes the higher SLE a community has, the more resilient they may be presumed to be toward a disaster occurrence. Higher levels of education may enable people to get higher paying jobs and reduce vulnerability by reducing the risk of these people living in poverty. However complexity arises because if the unemployment rate is high or the community economy is suffering, a higher level of education within a community may not increase the resilience of the residents.

Health

*Life expectancy at birth: Men*is defined as “an estimate of the number of years to be lived by a male newborn, based on current age-specific mortality rates.” The life expectancy at birth statistic is of course influenced by the infant and under 5 mortality rate. A lower life expectancy for both women and men may mean that harmful or health-detrimental factors are present in the community and residents are more vulnerable to these things. If a disaster occurred in addition to these factors it may be more difficult to recover from the disaster as a community. For this reason a lower life expectancy becomes a lower value in the social development.

Life expectancy at birth: Women is defined as “an estimate of the number of years to be lived by a female newborn, based on current age-specific mortality rates.”

*Infant mortality rate*is defined as ”total number of infants dying before reaching the age of one year per 1,000 live births in a given year. It is an approximation of the number of deaths per 1,000 children born alive who die within one year of birth.” For both the infant and under 5 mortality rate, higher mortality rates may be caused by vulnerability of the infants and young children to conditions in their environment or lack of adequate care. This is represented in the model with higher mortality rates having lower development values.

Under 5 mortality rate is defined as “the probability of dying before reaching age 5 and is expressed as the number of deaths under age 5 per 1,000 live births.”

Housing

Average number of persons per room: Total is defined by “by dividing the total population in occupied housing units by the total number of rooms as reported by countries. If the total number of occupants, i.e., total population occupying housing units, was not available, the total population figure was used in the numerator. ”

Average number of persons per room: Urban refers to the persons per room based on the number of urban housing units.

Average number of persons per room: Rural refers to the persons per room based on the number of rural housing units.

The rooms are defined as any living space having enclosing walls or roof, at least 2 meters tall, and large enough to hold an adult bed (4 m^2). The number is estimated based on the available data. Higher numbers of persons per room may be indicative of lower income residents and families for whom post-disaster rebuilding may be more difficult. The development trend for this indicator and its parameters is an increased development level for lower numbers of persons per room.

Human Settlements

Population Distribution (%): Urban is defined as "the percentage of the total population in urban areas."

Population Distribution (%): Rural is defined as " the percentage of the total population in rural areas."

In the developed system model both population distribution metrics are neutral. While a large urban population distribution may be more vulnerable to a disaster because larger clusters of residents may share water, sanitation, and shelter resources, they may be more easily reached in the event of disaster, depending on the condition of the transportation and communication networks. Also, if a city has been urbanized too quickly there was not enough time to adjust the local resources to handle the increase in the urban population density, and would make the community less stable and more vulnerable in the event of a disaster.

A more rural population distribution may have fewer people affected by a particular disaster because of the lower density of persons throughout a region, but those people may also be more difficult to reach if aid is needed, depending on the condition of the transportation and communication networks. Because the relationships between these metrics and the disaster response are not well understood they remained as neutral factors. Among different countries this metric may also be accounted for differently, depending on the definition of urban and rural areas. Some categories which may be used to define these are listed in the UN Stats website as follows:

- size of population in a locality
- population density

- distance between built-up areas
- predominant type of economic activity
- legal or administrative boundaries and urban characteristics such as specific services and facilities.

Annual rate of population change(%): Urban is defined as "the rate at which the urban populations are increasing or decreasing (negative sign) on average in each year within the five-year period, expressed as a percentage of the base population."

Annual rate of population change(%): Rural is defined as "the rate at which the rural populations are increasing or decreasing (negative sign) on average in each year within the five-year period, expressed as a percentage of the base population."

Annual rate of population change (%): Total: For the model, the available metric used was the total rate of population change which was available at a more detailed level than the split population change data. The split urban and rural population data for a national level was available through the UN Stats website but the total rate was available for the test region elsewhere. A higher rate of population change, as briefly mentioned above, may surpass the capability of some shared resources which would provide essential goods and services to residents. if a disaster were to occur before the resource distribution infrastructure has been updated or adjusted, recovering from the disaster effects may take longer than if the city had been properly developed as the population increased. However, if the rate of population change is negative, or residents are moving out of the region, this affects the development level of the region as well. Because the nature of this relationship was unclear it is also counted as neutral in the social development level.

Income and Economic Activity

Per Capita GDP (US $) is "calculated by the Statistics Division of the United Nations Secretariat primarily from official national accounts statistics in national currencies provided by national statistical services. GDP is the total unduplicated output of economic goods and services produced within a country as measured in monetary terms according to the United Nations System of National Accounts (SNA)."

Adult (15+) economic activity rate: Total is defined as "the percentage of the population aged 15 and over, unless otherwise specified, which is economically active." More specifically, "economically active" is referred to so that a standard definition is held via the definition from the System of National Accounts. This definition includes all persons working, seeking work, unemployed, and seeking work for the first time. These persons include the following, which are taken from the UN Stats website:

- employers operating unincorporated enterprises
- persons working on their own account
- employees
- unpaid contributing family workers
- members of producers cooperatives
- members of the armed forces

Also, international definitions include:

- persons engaged in production of primary products such as food stuffs for own consumption
- persons engaged in certain other non-monetary activities

A higher economic activity rate means that more citizens are participating in the economic aspect of their communities. This metric also may be measured differently depending on the country within which they are measured. Persons who are engaged in economic activity may be less dependent on others and also able to work or seek employment. In consideration of a disaster occurrence they may be more capable of protecting themselves or evacuating, and may also be able to seek employment and work to rebuild their own properties and the community after a disaster. Because of this, a higher rate of economic activity increases the social development level in the system model.

Adult (15+) economic activity rate: Men refers to the economic activity rate of the men in the region of interest. *Adult (15+) economic activity rate: Women* refers to the economic activity rate of the women in the region of interest.

Literacy

"The United Nations Educational, Scientific and Cultural Organization (UNESCO) defines a literate person as someone who can both read and write with understanding, a short, simple statement on his or her everyday life. A person who can only read but not write, or can write but not read is considered to be illiterate. A person who can only write figures, his or her name or a memorized ritual phrase is also not considered literate." The definition of literate may also be different for the US which uses other measures for literacy and including different levels of literacy. However the UNESCO definition is considered the standard particularly for international considerations of literacy. For data within the US the level corresponding the most to the UNESCO definition is selected.

For literacy rates the following data categories were given through the UN Stats website:

- Adult (15+) literacy rate: Total
- Adult (15+) literacy rate: Men
- Adult (15+) literacy rate: Women
- Youth (15-24) literacy rate: Total
- Youth (15-24) literacy rate: Men
- Youth (15-24) literacy rate: Women

Because the only regional data available (not on the national level) was the total adult literacy rate, the rest of the data points were not used. In the first world literacy rates tend to be higher than for countries in the third world, and resiliency may be higher for literate citizens who may have a wider range of jobs available if they lose their jobs after a disaster. Literacy also enables communities to rebuild and transform economically, and has other similar effects in other parts of a community. [157] Higher total literacy rates would result in higher social development levels through the developed system model. If data became available for the rest of the data categories in the Literacy indicator, these would all also follow the rule that higher literacy rates would mean higher social development levels within the model.

Population

Population (in thousands): Total is defined as the total "population enumerated at the most recent census for which data are available."

Population (in thousands): Men is defined as the male "population enumerated at the most recent census for which data are available."

Population (in thousands): Women is defined as the female "population enumerated at the most recent census for which data are available."

The population data is considered neutral in the developed model because of the complexity of the relationship with other development indicators before its effect on the social development can be determined. At the indicator and indicator data level the relationships among the elements are not defined. For example, a high population for a smaller region size may mean that the population density is higher and may pose a higher level of vulnerability to disaster occurrences.

Sex ratio of population is defined as "the number of males per 100 females". See Section 7.3.3.2 for an explanation of the impacts of this indicator on social development.

Annual population growth rate, 2010-2015 is estimated based on an assumed fertility rate projected through the selected years. It is "the rate at which the population is increasing or decreasing (negative sign) in a given year, expressed as a percentage of the base population." Again, as discussed in Section 7.3.3.2 for a similar indicator data element, a population which will grow too quickly poses some developmental problems in infrastructure planning areas and other aspects of the regional development. Populations in decline may be reflective of some development issues in each aspect of a community's development.

Unemployment

Standards and data sources vary from country to country, making unemployment data elements difficult to compare internationally. An existing international standard includes:

- age limits
- reference periods
- criteria for seeking work
- treatment of persons temporarily laid off
- persons seeking work for the first time

Additionally, differences in source scope and coverage makes it difficult to set up comparisons between nations. Additionally, the base group from which the unemployment rate is calculated is drawn from the adult economic activity rate discussed in previously.

Adult (15+) unemployment rate: Total is defined as "the proportion of the adult labour force that is unemployed(currently without work, currently available for work, and are seeking or have sought work recently), unless otherwise specified.

Adult (15+) unemployment rate: Men is defined then, as the male proportion of the adult labor force that is unemployed.

*Adult (15+) unemployment rate: Women*is defined then, as the female proportion of the adult labor force that is unemployed.

For all data elements of the Unemployment indicator, the lower unemployment rates result in lower social development levels. More unemployed residents of an area leaves more people with a greater vulnerability to not only natural disasters but economic disasters as well.

Water Supply and Sanitation

Improved Drinking Water Coverage(%): Total is defined as "the percentage of the population using improved drinking water sources." Because some people have access to improved water sources but do not use them, the usage is the part considered in the data element. Improved drinking water technologies increase the likelihood of having safe drinking water, which reduces some of the population vulnerability to diseases. This increases the development level because in a disaster setting if improved water sources are available or become

Table 6: Improved and Unimproved Water Sources

Water Supply Sources	
Improved	Unimproved
household connections	unprotected wells
public standpipes	unprotected springs
boreholes	rivers or ponds
protected dug wells	vendor-provided water
protected springs	bottled water[2]
rainwater collection	tanker truck water

available, survivors will have one less factor making them vulnerable to diseases.

Improved Drinking Water Coverage(%): Urban is the percentage of the population from urban regions who use improved drinking water sources.

*Improved Drinking Water Coverage(%): Rural*is the percentage of the population from rural regions who use improved drinking water sources.

The UN Stats division lists improved and unimproved drinking water sources as categorized in Table 7.3.3.2.

Improved Sanitation Coverage (%): Total is defined as "the percentage of the population using improved sanitation facilities." Similar to the improved drinking water coverage, improved sanitation facilities make hygienic use of sanitation facilities more likely, reducing some vulnerability to diseases. This is also considered to increase the development level in a disaster setting for similar reasons as improved water sources.

Improved Sanitation Coverage (%): Urban is the percentage of urban population in the region of interest who use improved sanitation facilities.

*Improved Sanitation Coverage (%): Rural*is the percentage of rural population in the region of interest who use improved sanitation facilities.

The UN Stats division lists the improved and unimproved sanitation facilities in Table 7:

Values

The values of the different social indicators are[3]:

[2]Bottled water is limited at times in its quantity, not necessarily quality.
[3]Sources are identified in Table 50 in Appendix B.6

Table 7: Improved and Unimproved types of Sanitation Facilities

Sanitation Facilities	
Improved	Unimproved
connections to a public sewer	public latrines
connections to a septic system	shared latrines
pour-flush latrines	open pit latrines
simple pit latrines	bucket latrines
ventilated improved pit latrines	

Table 8: Shelby County Input Values

Indicator	Data Element	Value
Childbearing	Adolescent Fertility Rate	66
	Total Fertility Rate	2
	Estimated Maternal Mortality Ratio	24
Child and Elderly Populations	% population <15 yr	22.85
	% population >60 yr	14.27
	sex ratio in 60+ age group	64.25
Contraceptive Use	Contraceptive Prevalence - any methods	0.62
	Contraceptive Prevalence - modern methods	0.584
Education	school life expectancy - total	11.56
	school life expectancy - men	11.55
	school life expectancy - women	11.57
Health	Life expectancy at birth - men	72.4
	Life expectancy at birth - women	78.4
	Infant mortality rate	13.8
Housing	Avg # of persons / room - total	0.4839
Human settlements	population distribution (%) - urban	0.93
	population distribution (%) - rural	0.03
	annual rate of pop change (%) - total	0.004
Income and Economic Activity	per capita GDP (US$)	38420.78
	adult (15+) economic activity rate	0.65
Literacy	adult (15+) literacy rate - total	0.86
Population	population (in thousands) - total	918
	population (in thousands) - men	438
	population (in thousands) - women	480
	sex ratio of population - men / 100 women	91.28
	annual population growth rate, 2010-2015 (%)	0.004
Unemployment	adult (15+) unemployment rate - total	0.097
	adult (15+) unemployment rate - men	0.088
	adult (15+) unemployment rate - women	0.087
Water supply and sanitation	improved drinking water coverage (%) - total	0.98
	improved sanitation coverage (%) - total	0.98

The value in the VENSIM model is a constant supplied by the aggregation of the selected data elements.

Equations in Model

The normalization of the values to calculate the parameter is done as follows:

Devel EnvirInit *Description* The Initial Environmental Development Level is referred to in the model as "Devel EnvirInit". This parameter was difficult to define with indicators because for many regions the data is difficult to acquire. The developed system model uses the indicators defined here. Another option for quantifying an environmental development level was to base the measures off the Environmental Vulnerability Index (EVI) developed in 2004 by the United Nations Environment Programme (UNEP) and the Applied Geoscience and Technology Division of Secretariat of the Pacific Community (SOPAC).

There are fifty indicators defined in the EVI which is discussed at more length in Section B.2.2.3. Several of these indicators also included interdependency on other aspects of the community. Many of the indicators which pertained directly to the state of the environment were very detailed and county-level data would not have been readily available from relevant data sources. However this index and its list of indicators may provide more quantification for communities if data is available or selected measures can be provided with data. If only a few values are available however, the parameter may be defined by those values.

The included measures in the environmental development level pertain mainly to the stability of the ground. The data for these measures was unavailable and the parameter Devel EnvirInit was given an average constant value for the system definition as well as the simulations with the chosen scenarios.

Soil and water - inherent soil productivity. The data elements for this parameter were Topsoil depth, soil organic carbon, total available water capacity, and bulk density.

Soil and water - ground water availability. The data element for this parameter was the annual aquifer recharge budget.

Losses from agricultural systems - surface processes. The data elements for this parameter were nutrients, sediment, and pesticides.

More knowledge about the environmental parameters and their relationships would be needed for an effective inclusion of this group of parameters in the model definition.

Values The value for this input parameter in the model was set to 0.5 and did not change through the system exploration.

Devel Econ Init *Description*

The selected indicators are based on the indicators used in the Human Development Index or HDI. The HDI is used by the U.N. to quantify via index a nation's level of achievement in health, knowledge, and income aspects. (see `http://hdr.undp.org/en/statistics/hdi`). The indicators are not purely financial in nature, since economic development must also be reflected in other aspects. However, further definition may be given by the addition of more indicators which are relevant in quantifying a region's level of economic development. The HDI is not just calculated on the national scale. It may also be used to assess the state of sub-national regions or peoples.

The indicators also show the cross-influence from other development aspects, and for this research were used in normalized equal weightings to give an economic development level for different communities. Figure 33 shows a categorical decomposition of the parameters. The Economic Development component also includes a Stability category, which enables the effect of political stability on economic development to be included in the system decomposition.

Education

*Adult literacy rate*is defined as the percentage of adults which are literate. Within the model, the value used is 1 minus the percentage of literate adults, assuming that represents the percentage of illiterate adults. If the percentage of illiterate adults is available that value is used. The definition of literate is definition per UNESCO, defined above in the Initial Social Development Level indicator within the "Literacy" category. This definition requires adults to be able to read and write.

Literacy and education which is measured by the next indicator, are both influential in reducing poverty rates in communities for the reason that both enable persons residing in the community to get higher paying jobs if those jobs are available. Of the two example communities selected for the simulated implementation of this research, the community with the higher literacy rate also had a higher unemployment rate. Literacy and education may also improve other aspects of the community. As with many of these indices, the inter-related effects from other indicators and metrics are present, and must continue to be developed in order to continue to refine any developed system models.

*Gross enrollment ratio*is defined as the percentage of children enrolled in school of those who are of the proper age to be enrolled in school. The Human Development Index uses the two statistics of: "Mean years of schooling" and "Expected years of schooling" as its education indicator. For US communities the gross enrollment ratio is more readily available in the US Census Bureau data, so it is used for this research.

Health

*Life expectancy at birth*is defined as the number of years that an infant is expected to live at the time and place of its birth. It is the same value discussed in the Initial Social Development Level indicator within the "Health" category.

Income

*GDP per capita(PPP $)*is "calculated by the Statistics Division of the United Nations Secretariat primarily from official national accounts statistics in national currencies provided by national statistical services. GDP is the total unduplicated output of economic goods and services produced within a country as measured in monetary terms according to the United Nations System of National Accounts (SNA)." [160]

Stability

Community Stability Communities which are more unstable may not be as resilient as communities which are more stable, and will need a longer time for restoration after a disaster.[29, 119] The measures included in this parameter are defined below. Each of the factors must be currently or recently occurring within the community. Nearby events which significantly affect the community of interest should also be included in this parameter.

Occurrences include:

- Genocide
- Adverse or Sudden Regime Change (such as a takeover or coup)
- Ethnic War
- Civil War
- Very recent disaster
- Recent disaster
- Past disaster (if effects are still significant)

If any of these events have occurred the overall metric is adversely affected.

Global Stability The global stability is assumed to be constant in this research under the assumption that it is not likely to change suddenly. For low values of global stability, currently aiding nations may be less able to provide aid for other nations or communities which experience a disaster. This assumption is not upheld for slight changes in the global state, since several disasters have happened during the recent recession and it has not significantly affected the amount of aid which is donated to the devastated communities.

The term "aiding nations" refers to developed nations which are assumed to provide the most aid. The term "developing nations" refers to nations which may be still developing or considered third world. These nations may be less able to deal with a disaster coming through their land, and also may be less able to provide aid to another nation dealing with a disaster.[119]

Any increase in situations in both developing and aiding nations is detrimental to the objective parameter measure. Currently each sub-parameter is equally weighted but future revisions or implementations of this method may need to be adjust this weighting to give more bias to developed nations which have a greater effect on the global economy.

Specific influences on Global Stability include:

- *Stability of global economy* - refers to an overall level of economic stability. Financial crises or unstable currencies would contribute adversely to the value of this sub-parameter. A very stable global economy would have a value of one, and a global economy with occurrences of currency instability and ongoing financial crises in different nations would have a lower value, closer to zero.

- *Ongoing wars in aiding nations*refers to the war or non-war state of developed nations. Wars affect the stability of the nation itself, but also may deter this nation from aiding other communities or other nations who become needing of aid.

- *Social crises (non-war) in aiding nations*refers to situations which may not be considered developing disasters or political situations in developed nations. An example of this might be if social oppression were occurring in a nation, global stability might be affected if it is a leading developed nation which became unstable and was unable to properly deal with the situation.

- *Current disasters in aiding nations*gives priority to those particular nations or the affected nation first dealing with the disaster occurring in their own region before any aid is sent to other regions and communities.

- *Developing disasters in aiding nations*are another event which would give priority to the internal well being of the nation before any aid may be dispersed to others.

- *Ongoing wars in developing nations*consume physical and personnel resources and may also result in no clear definition of who or what group is in control of the developing region or nation, which will affect its ability to contribute aid to other nations experiencing disasters or deal with a disaster that happens within its own boundaries.

- *Social crises (non-war) in developing nations*refers to situations which may not be considered developing disasters or political situations in developing nations. As with other non-disaster issues occurring in developing nations, the ability to contribute aid to other or deal with internal disasters may be hampered.

- *Current disasters in developing nations*- for developing nations which may already be experiencing a shortage of resources, further demand for these resources is put on the nation as a community if a disaster occurs suddenly. If they are unable to respond properly and begin restoration of their own regions they will be less able to contribute to aiding others outside of their own boundaries. There will also be less contribution from this nation to the global economy due to its own instability.

- *Developing disasters in developing nations*- similar to the previous definition, developing disasters in developing nations will put those nations even further into a place where all available resources may be used to deal with the disaster, instead of contributing to the economic growth and stability of the nation.

Values In the model and the VENSIM model, this parameter is an initial value input to another variable. The value for this parameter does not change during the simulation.

DevelPhysInit *Description* The initial value for the Physical Development level is given by the parameter DevelPhysInit. This parameter includes data indicators which describe the physical infrastructure development level of the community. This includes transportation infrastructure, building structures, and physical parts of utility and communications systems.

For the developed system, the building structures and emergency response structures were included in the parameter measures. The data for each of these categories of data elements was taken from the default data for the region in the HAZUS-MH software program. Both selected example communities were defined in this parameter using this data.

Buildings

The Buildings component of Physical Development includes parameters which help to describe the level of physical development which the community possesses. The community-wide parameters are the following:

- *Dollar exposure by general occupancy - total*is set up in the model so that greater exposure values have an adverse effect on the objective parameter.

- *Building exposure* refers to the dollar exposure of the building for all types of buildings.
  - *Content exposure* refers to the dollar exposure of the content of the buildings for all types of buildings.
  - *Total* refers to the total exposure for all types of buildings within the community.

The selected building types were:

- Medical Care facilities
- Emergency Operations Centers
- Police Stations
- Fire Stations
- School facilities

For specific types of buildings, different parameters were selected which help to describe the effect of the buildings on the resilience of the community after a disaster has occurred. These type-specific parameters common to the selected building types are the following:

- *Replacement cost* refers to the cost for replacing the facilities, should they be destroyed by a disaster. This cost is the financial cost of rebuilding the facility and does not include any other non-monetary losses. The model is set up so that an increase in this number will result in a degradation of the objective parameter. This should be adjusted in the future so that construction of additional facilities does not adversely affect the objective parameter. A possible change might be to use the cost per building for replacing. The additional response capability enabled by constructing another hospital (with functioning administration, staff, and residents) should also be included in the considerations for the objective parameter.
- *Backup power availability* refers to the facility capability of backup power, which would help to prolong the amount of response treatments which can be done if the power is not quickly restored. Most facilities by default do not possess this capability.

- *Number of facilities* is self-explanatory. The model is set up so that more facilities are desirable but must remain within the range of the developed model.

- *Design level* refers to the seismic design level of the building. This is specific for earthquake disasters in the context of the HAZUS-MH software, but this data element is generalized to include the resistance level of a building to the particular disaster which is being considered. If the resistance is mid-level, then the design level should be medium. A higher design level is the more desirable one, but for buildings with medium design levels the replacement cost would need to increase if outfitting a medium design level building to be a high design level one.

- *Number of beds* is self-explanatory. A greater number of beds enables more patients to be seen at the facilities but may increase the risk of further injury if the facility itself succumbs to severe structural damage or structural failure. Within the model the setup assigns increasing desirability to higher numbers of beds. This parameter is included for medical facilities only.

- *Number of students* is also a parameter used to describe the building type development level. More students is more desirable within this model but arguments might also be made as to why it would also adversely affect the overall metric. The logic for selecting more students as more desirable was because if there are more students who attend a school, it may be able to accommodate more displaced persons in a shelter function.

Equations in Model The model values are provided by a normalized equal weighted sum of the provided data values. Within the VENSIM model, this parameter is a constant input by the user and supplies the initial value for the Development level.

Proportional Aid Each component of the community development receives aid flow after a disaster. The amount of aid coming into the community to improve that component of development is not largely recorded historically. The fraction of aid for all of the components

[4] Total by general occupancy

Table 9: Initial Values for Physical Development Parameter

Indicator	Data Element	Value
Dollar exposure[4]	building exposure	70370025
	content exposure	46974755
	total	117344780
Medical care facilities	replacement cost	117040
	backup power (y/n)	0
	# of facilities	12
	# beds	4163
	design level	HC
Emergency Operation Centers	replacement cost	1760
	# facilities	2
	design level	MC
	backup power (y/n)	0
Police stations	replacement cost	44352
	# facilities	36
	design level	MC
	backup power (y/n)	0
Fire stations	replacement cost	6864
	# facilities	13
	design level	MC
	backup power (y/n)	0
School facilities	replacement cost	134640
	# facilities	306
	design level	MC
	backup power (y/n)	0
	# students	182978

should sum to 1, which is all of the aid which flows into the community. For this research the process to calculate these aid fractions, data from the Financial Tracking Service from the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) was used. This and similar data can be accessed from this website: `http://fts.unocha.org/`. The 2010 Haiti Earthquake relief funding was selected from this website.

While Haiti data may not be of the same proportions as US aid, in the case of the Haiti Earthquake restoration, most of the aid flowing into the community came from external sources. Data from Hurricane Katrina was unavailable from this search database. Other US disasters would have been potential data sources, however there are greater amounts of unofficial aid and governmental aid which flow into US communities in the process of post-disaster restoration. Most aid flowing into the Haiti community after the 2010 earthquake could be separated into implementation in different community components which would enable a better representation of the fraction of the total aid flowing into the community.

Once the data had been downloaded, the aid task items were categorized into the different community components where each item was perceived to be implemented. The proportions were not based on the amount of the aid tasks but calculations might also be done in that way. The proportions were based on the number of tasks which were implemented in each community components. The number of tasks for each component were summed and a fraction of the total number of tasks was included. If a task was perceived to benefit two different community components, the task was counted once for each component's total number of tasks. This was done provide a starting value for estimating the fraction of aid flowing into each component of the community. Further data could be selected from the FTS database and used to refine the fractions.

The four component aid fractions should sum to 1. A truncated table with a sample of the aid task items is shown in Table 10 with the totals included and fractional totals calculated at the bottom of the table. If a particular item was perceived to be implemented as a part of the general response, none of the development components were counted as receiving the aid item.

Table 10: Truncated List of Aid Task Items (with Totals)

No.	Description	Funding (USD)	Pledges[5] (USD)	PPAA[6] P	S	En	Ec
1	Disaster relief	10,000	0	-	-	-	-
2	3M medical products	0	1,000,000	x	-	-	-
3	10 houses through UNIFEM	0	100,000	x	x	-	-
4	NGO medical and nutritional products	5,000,000	0	-	x	-	-
.	.	.					
.	.	.					
.	.	.					
1990	World Hunger Relief food for victims	0	500,000	-	x	-	-
1991	IFRC Haiti Emergency Appeal contribution	220	0	-	-	-	-
	Grand Total (USD)	3,535,767,543	1,034,879,025				
	Total Count			94	868	54	133
	Component Fraction			.082	.755	.047	.116

AD Phys *Description* AD Phys is a factor which controls the portion of the aid flowing into the community which is directed toward the physical development of the community.

Values For this research the values for aid flow to all components was assumed to be equal. However, this value may be adjusted based on input from experts if available.

Equations in Model Within the model, the value used is 0.62.

AD Soc *Description* AD Soc is a factor which controls the portion of the aid flowing into the community which is directed toward the social development of the community. *Values* For this research the values for aid flow to all components was assumed to be equal. However, this value may be adjusted based on input from experts if available.

Equations in Model Within the model, the value used is 0.62.

[6]Uncommitted Funding
[6]Primary Perceived Application of Aid

AD Envir *Description* AD Envir is a factor which controls the portion of the aid flowing into the community which is directed toward the environmental development of the community.

Values For this research the values for aid flow to all components was assumed to be equal. However, this value may be adjusted based on input from experts if available.

Equations in Model Within the model, the value used is 0.62.

AD Econ *Description* AD Econ is a factor which controls the portion of the aid flowing into the community which is directed toward the economic development of the community.

Values For this research the values for aid flow to all components was assumed to be equal. However, this value may be adjusted based on input from experts if available.

Equations in Model Within the model, the value used is 0.62.

Stability Flow Adjust *Description* This parameter is a factor of the flow of stability resources into the community. It is based on the Development level and the stability of the community.

Values The value for this parameter is dependent on two of the other parameter values, Development level and Stability. The values are normalized and combined with an equal weighted sum as shown in Table 11.

Table 11: Stability Flow Adjust Value Calculation

Parameter	Value	Norm. Val.	Norm. Wt.
Development	60.81	0.608	0.304
Stability	0.4736	0.364	0.182
Total Stability Flow Adjust Value =			0.4862

Equations in Model This value is a constant input to the VENSIM model and does not change value.

DevelThrottleIdeal *Description* This parameter describes the development level which the community is restoring itself toward. This value is higher than the DevelThrottle value.

Values For representing a community development goal which includes development beyond the average pre-disaster development level the value will be higher than the DevelThrottle value.

For representing the development goal which is the same as the average pre-disaster development level, the value is equal to the DevelThrottle Value.

Equations in Model Within the model, the value was 70 for the average development level, and 85 for an improved development level.

DevelThrottle *Description* This represents a development level the community will rebuild itself to after the disaster occurs.

Values The value is a goal development level of the community.

Equations in Model Within the model, the value was 70 for the average development level, and 85 for an improved development level.

AdjustmentDSD *Description* This parameter affects the stability factor, but for its initial value the input comes from an aggregation of factors which affect community stability. These factors are:

- Currently occurring genocide within the community
- Current or recently occurring adverse regime change within the community
- Currently occurring ethnic war within the community
- Currently occurring civil war within the community
- Occurrence of a disaster 0-3 years ago
- Occurrence of a disaster 3-10 years ago
- Occurrence of a disaster 10+ years ago

If any of these factors are true for the community, their data elements are assigned a value of 1. If they are not true, the data element has a value of 0. 1 is detrimental to the community stability, and a value of 0 is not.

Values

Equations in Model Within the VENSIM model, the Adjustment DSD parameter is a constant value. For the community selected for this research the value of the parameter was 1.

DFDevelFraction *Description*

This parameter describes the amount of the available funding which is implemented to the community to aid in development of the different components of the community.

Equations in Model

For the selected community the value of this parameter was 0.9. The value was selected because implementation of development funding may not be complete, or may experience delays or some type of losses during implementation.

DPDevelFraction *Description*

This parameter describes the amount of implementation of the available programs which aid in development of the different components of the community.

Equations in Model

For the selected community the value of this parameter was 0.9. The value was selected because implementation of development programs may not be complete, or may experience delays or some type of losses during implementation.

DSocialFactor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the social development of the community. In the model it is set to be dependent on the capability the community has to implement changes, the priority for implementation of changes in that component of community development, and the distance from the community at which the disaster occurred. Rate of development improvements will increase if community has greater capability to implement changes. [29, 73] Rate of development improvements will increase if community gives those changes greater implementation priority. [29, 73] Rate of development improvements will decrease if disaster occurs closer rather than farther. This is because the event will affect the development of the community, and it will need to be rebuilt before improvements may be implemented.

There is also a factor which includes other development factors. This parameter may also be adjusted to reflect other factors which may affect the rate of improvement implementation.

Equations in Model Within the model, the value for this parameter is 0.6. The calculation for this parameter is as follows:

$$d_{l,i} = \sum w_{l,i} \times f_{norm}(x_{l,i,j}) \tag{96}$$

where

$d_{l,i}$ = parameter i at level l (D SocialFactor1)

$w_{l,i}$ = weight for data elements for parameter l, i [7]

f_{norm} = normalization function

$x_{l,i,j}$ = data element j for parameter l, i

With the values shown in Table 12:

Table 12: DSocialFactor1 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[8] $w_{l,i}f_{norm}(x_{l,i,j})$
Implement Capability	0.5	0.5	0.125
Implement Priority	0.9	0.9	0.225
Nearness to event	0.1	0.1	0.025
Other Factors	0.9	0.9	0.225
Parameter Value for:	DSocialFactor1 ($d_{l,i}$):		0.6

DSocialFactor2 *Description* This parameter is a scaling factor which affects the aid flow into the social development parameter of the community. In the model it is set to be dependent on the the amount of damage that has occurred in the community, the status of communications capability after the disaster, the influx of aid into the community, how

[7] Equal weighting used for this research. This means all x_j data elements will use the same value $w_{l,i}$. If using biased weighting, each $x_{l,i,j}$ data element will also have its own weight $w_{l,i,j}$.

well the response went, and also any other factors from the pre-disaster development level.

Rate of aid inflow will decrease with an increase in the damage aggregate due to infrastructural and communications barriers which may delay or prevent the aid from being received by the community. [29, 153, 91]

Rate of aid inflow will increase with an increase in post-disaster communications capability. [73, 29]

Rate of aid inflow will increase with an increase in the amount of aid being sent. This is true if the aid is able to be received into the community and if the aid is applicable to the community situation. [29]

Rate of aid inflow will increase with an increase in the response performance. [29]

Equations in Model

Within the model, the value for this parameter is 0.26. The calculation for this parameter is as follows using Equation 96 and the values in Table 13:

Table 13: DSocialFactor2 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[9] $w_{l,i} f_{norm}(x_{l,i,j})$
Damage aggregate	0.1	0.1	0.02
Amount of aid being sent	0.1	0.1	0.02
Fraction of working communications	0.1	0.1	0.02
Response performance	0.1	0.1	0.02
Other Factors	0.9	0.9	0.18
Parameter Value for:	DSocialFactor2 ($d_{l,i}$):		0.26

D EnvirFactor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the environmental development of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements, but are applied instead to the environmental component of the community development.

Equations in Model

[9] $w_{l,i,j} = w_{l,i} = 0.2$

Within the model, the value for this parameter is 0.5. The calculation for this parameter is as shown in Table 14 using these values in Equation 96:

Table 14: D Envirfactor1 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[10] $w_{l,i}f_{norm}(x_{l,i,j})$
Implement Capability	0.5	0.5	0.125
Implement Priority	0..5	0.5	0.125
Nearness to event	0.1	0.1	0.025
Other Factors	0.9	0.9	0.225
Parameter Value for:	D EnvirFactor1 ($d_{l,i}$):		0.5

D EnvirFactor2 *Description*This parameter is a scaling factor which affects the aid flow into the environmental development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements, but are applied instead to the environmental component of the community development.

Equations in Model

Within the model, the value for this parameter is 0.26. The calculation for this parameter is as shown in Table 15 using the following values in Equation 96:

Table 15: D EnvirFactor2 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[11] $w_{l,i}f_{norm}(x_{l,i,j})$
Damage aggregate	0.1	0.1	0.02
Amount of aid being sent	0.1	0.1	0.02
Fraction of working communications	0.1	0.1	0.02
Response performance	0.1	0.1	0.02
Other Factors	0.9	0.9	0.18
Parameter Value for:	D EnvirFactor2 ($d_{l,i}$):		0.26

D PhysicalFactor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the physical development of the

[10] $w_{l,i,j} = w_{l,i} = 0.25$
[11] $w_{l,i,j} = w_{l,i} = 0.2$

community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements, but are applied instead to the physical component of the community development.

Equations in Model Within the model, the value for this parameter is 0.5. The calculation for this parameter is shown in Table 16 using the following values in Equation 96:

Table 16: D PhysicalFactor1 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[12] $w_{l,i}f_{norm}(x_{l,i,j})$
Implement Capability	0.5	0.5	0.125
Implement Priority	0.5	0.5	0.125
Nearness to event	0.1	0.1	0.025
Other Factors	0.9	0.9	0.225
Parameter Value for:	DPhysicalFactor1($d_{l,i}$):		0.5

D PhysicalFactor2 *Description*This parameter is a scaling factor which affects the aid flow into the physical development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements, but are applied instead to the physical component of the community development.

Equations in Model Within the model, the value for this parameter is 0.26. The calculation for this parameter is shown in Table 17 using the following values in Equation 96:

D EconFactor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the economic development of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements, but are applied instead to the economic component of the community development.

Equations in Model

[12] $w_{l,i,j} = w_{l,i} = 0.25$
[13] $w_{l,i,j} = w_{l,i} = 0.2$

Table 17: D PhysicalFactor2 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[13] $w_{l,i}f_{norm}(x_{l,i,j})$
Damage aggregate	0.1	0.1	0.02
Amount of aid being sent	0.1	0.1	0.02
Fraction of working communications	0.1	0.1	0.02
Response performance	0.1	0.1	0.02
Other Factors	0.9	0.9	0.18
Parameter Value for:	D PhysicalFactor2 ($d_{l,i}$):		0.26

Within the model, the value for this parameter is 0.5. The calculation for this parameter is as shown in Table 18 using the following values in Equation 96:

Table 18: D EconFacor1 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[14] $w_{l,i}f_{norm}(x_{l,i,j})$
Implement Capability	0.5	0.5	0.125
Implement Priority	0.5	0.5	0.125
Nearness to event	0.1	0.1	0.025
Other Factors	0.9	0.9	0.225
Parameter Value for:	D EconFactor1 ($d_{l,i}$):		0.5

D EconFactor2 *Description* This parameter is a scaling factor which affects the aid flow into the economic development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements, but are applied instead to the economic component of the community development.

Equations in Model Within the model, the value for this parameter is 0.26. The calculation for this parameter is as shown in Table 19 using the following values in Equation 96:

[14] $w_{l,i,j} = w_{l,i} = 0.25$
[15] $w_{l,i,j} = w_{l,i} = 0.2$

Table 19: D EconFactor2 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[15] $w_{l,i}f_{norm}(x_{l,i,j})$
Damage aggregate	0.1	0.1	0.02
Amount of aid being sent	0.1	0.1	0.02
Fraction of working communications	0.1	0.1	0.02
Response performance	0.1	0.1	0.02
Other Factors	0.9	0.9	0.18
Parameter Value for:	D EconFactor2 ($d_{l,i}$):		0.26

D Social2Factor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the social development of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements.

Values

The value of this parameter is the same as the value of D SocialFactor1 and is calculated in the same way.

D Social2Factor2 *Description* This parameter is a scaling factor which affects the aid flow into the social development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements.

Values

The value of this parameter is the same as the value of D SocialFactor2 and is calculated in the same way.

D Envir2Factor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the environmental development of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements, but are applied instead to the environmental component of the community development.

Values

The value of this parameter is the same as the value of D EnvirFactor1 and is calculated in the same way.

D Envir2Factor2 *Description*This parameter is a scaling factor which affects the aid flow into the environmental development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements, but are applied instead to the environmental component of the community development.

Values

The value of this parameter is the same as the value of D EnvirFactor2 and is calculated in the same way.

D Physical2Factor1 *Description* This parameter is a scaling factor which affects the rate of implementation of development improvements for the physical development of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements, but are applied instead to the physical component of the community development.

Values

The value of this parameter is the same as the value of D PhysicalFactor1 and is calculated in the same way.

D Physical2Factor2 *Description*This parameter is a scaling factor which affects the aid flow into the physical development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements, but are applied instead to the physical component of the community development.

Values

The value of this parameter is the same as the value of D PhysicalFactor2 and is calculated in the same way.

D Econ2Factor1 *Description* This parameter is a scaling factor which affects the rate of implementation of improvements for the economic development of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor1 data elements, but are applied instead to the economic component of the community development.

Values

The value of this parameter is the same as the value of D EconFactor1 and is calculated in the same way.

D Econ2Factor2 *Description* This parameter is a scaling factor which affects the aid flow into the economic development parameter of the community. The related data elements and the effect of the relationships are the same as the D SocialFactor2 data elements, but are applied instead to the economic component of the community development.

Values

The value of this parameter is the same as the value of D EconFactor2 and is calculated in the same way.

DevelFundingBudget *Description* This parameter describes the funding situation of the community. It is the fraction of the Devel Funding stock which is implemented in the community. The fraction is used to help provide the initial stock level for the Development Funding as a part of the internal community budget for development.

Equations in Model The parameter used in the model has a selected value of 0.333.

Further research is needed to understand the financial aspect of communities in order to provide a better means of calculating this value and to give meaning to the parameter.

DevelProgramsBudget *Description* This parameter describes the budgeting for programs whose implementation will increase the development level of the community. It is the fraction of the Devel Programs stock which is implemented in the community. The fraction is used to help provide the initial stock level for the Development Funding as a part of the internal community budget for development.

Equations in Model The parameter used in the model has a selected value of 0.333.

Further research is needed to understand the financial aspect of communities in order to provide a better means of calculating this value and to give meaning to the parameter.

DF Adjustment *Description* This parameter is a scaling factor for the flow of development funding resources into the different components of the community. This parameter is not further decomposed but could be defined as containing factors which might reduce the speed of community development funds being utilized.

Values

The value for the parameter may be between 0 and 1, and lower values in this range mean that the resources are more slowly implemented into the community than if the value were at the higher end of the range. This is not necessarily detrimental to the community but means that the community may take longer to rebuild.

Equations in Model

In the model the value is selected as 0.2.

Further research is needed to understand the financial aspect of communities in order to provide a better means of calculating this value.

DP Adjustment *Description* This parameter is a scaling factor for the flow of development program implementation into the different components of the community. This parameter is not further decomposed but could be defined as containing factors which might reduce the speed of community programs or projects being implemented.

Values

The value for the parameter may be between 0 and 1, and lower values in this range mean that the resources are more slowly implemented into the community than if the value were at the higher end of the range.

Equations in Model

In the model the value is selected as 0.2.

Further research is needed to understand the financial aspect of communities in order to provide a better means of calculating this value.

InitialFundingTotal *Description* This parameter describes the total initial funding available to the community.

Values The value for the parameter should be selected based on available data if possible. For this research the values shown in Table 7.3.3.2 were used: *Equations in Model* In the

Table 20: Funding Value Options

Funding Available:	Insufficient	Sufficient	Surplus
Parameter Value:	< 1	1	> 1

model the value is selected as 1.

PreparednessTrainingAdjust *Description* This parameter is a factor which scales the rate of implementation of the preparedness training resources. It is based on the initial Collaboration level in the community.

An increase in the collaboration level in the community will enable collaborators to be trained and train others from the same standards if a common training resource has been developed through collaboration exercises within the community.

Values The value is normalized between 0 and 1000 since during the model simulations the Training level may have a value in the range of that magnitude.

Equations in Model

In this model, the initial Collaboration level is 2.737. The normalized value is 0.00274 for this parameter.

Further research is needed to understand the financial aspect of communities in order to provide a better means of calculating this value.

PreparednessProgramAdjust *Description* This parameter is a factor which scales the rate of implementation of the preparedness programs in the community. It is based on the initial Collaboration level in the community.

Values The value is normalized between 0 and 1000 since during the model simulations the Training level may have a value in the range of that magnitude.

Equations in Model

In this model, the initial Collaboration level is 2.737. The normalized value is 0.00274 for this parameter.

Further research is needed to understand the financial aspect of communities in order to provide a better means of calculating this value.

InternalFundingBudget *Description* This parameter describes the flow of the internal funding into the preparedness aspect of the community.

Values The value for the parameter should be selected based on available data if possible. For this research the values shown in Table 7.3.3.2 were used.

Equations in Model In this model the value for this parameter is 1.

ifwarn *Description* This parameter enables the user to select whether or not there is a warning time which occurs prior to the disaster event. Depending on the type of disaster which is being tested, there may be little to no warning time, or a longer warning time during which community preparedness activities may be initiated to help mitigate some of the disaster effects or increase the response capabilities. The community forecasting capability will be a key factor in determining the existence of and amount of warning time. As forecasting capabilities develop for different disasters, the preparedness activity implementation may change as well.

Values The value for this parameter are as follows:

Setting:	Warning	No Warning
Value:	1	0

Equations in Model In this model the value for this parameter is 1. In the case of an earthquake, this may occur in the form of some smaller earthquakes which occur before the large earthquake, or it may be a very short warning time just before the large earthquake occurs. There is a possibility of a no warning earthquake, which may be more likely in some cases.

warning *Description* This parameter is the number of time units which occur before the disaster event during which the community becomes aware of the disaster and begins to acquire or activate response resources.

Values The value may be a whole number greater than 0.

Equations in Model

In the model, the warning time is set to 10. While for earthquakes there is a low possibility of this occurring, an example event may be a smaller earthquake occurring which prompted geologists to assess the ground and determine, as a result, that another larger earthquake was about to occur. Forecasting capabilities for hurricanes and other storms may provide a longer warning time, while earthquake forecasting may provide a short or non-existent warning time.

disasterstart *Description* This parameter is the start time of the disaster event.

Values The value may be any whole number greater than 0 within the time range of the simulation.

Equations in Model Within the model this parameter is set to 100.

timeoption *Description* This parameter is the amount of time after the initial disaster event before the aftershock will occur if that option has been selected.

Values This value may be any whole number greater than 0 but before the simulation ends.

Equations in Model Within the model this parameter is not applicable since the aftershock was not utilized.

chooseaftershock *Description* This parameter is the user selection of whether or not a second lower severity disaster event will occur (the aftershock).

Values The value for this parameter is set to 1 if there is a second disaster event, and 0 if there is to be only the initial disaster event.

Equations in Model Within the model this parameter is set to 0.

Severity *Description*

The Severity factor increases (or decreases) the effect of the initial disaster event and the aftershock if it is utilized.

An option for the calculation of this value may be to utilize the Disaster Severity Scale, which is described in Appendix B.2.2.6.

Values This value for this parameter is a number between 0 and 1. The higher values indicate a greater severity disaster, and the lower values indicate a lower severity disaster.

Equation in Model For this research, the parameter has a value of 0.7, which indicates a significant severity event, but not an event which has caused total devastation.

Fraction *Description* This parameter is a factor which adjusts the extent to which the community development is affected by the disaster. It is decomposed to several different data elements:

- Population density - an increase in this data element increases the disaster effect on the community. A higher population density requires different evacuation procedures and if greater infrastructure damage occurs, more people may be trapped among rubble after the disaster, and more survivors will require shelter space during the response phase and even into the restoration phase.

- Urban infrastructure density - an increase in this data element increases the disaster effect on the community. A higher urban infrastructure density means that there is a greater amount of infrastructure at risk to be damaged, destroyed, or rendered non-functional if a disaster event occurs in the urban area. Because this includes transportation and communication infrastructure in addition to buildings, an increase in this parameter will increase the effects on the community response and restoration. These two phases require some functionality of the transportation and communication infrastructure.

- Preparedness - an increase in this data element, which is also another parameter in the model, helps to decrease the disaster effect on the community. If the community has implemented measures to help mitigate some of the disaster effects as well as

Table 21: Fraction Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[16] $w_{l,i}f_{norm}(x_{l,i,j})$
Population Density	1189	0.982	0.196
Urban Infrastructure Density[17]	481	0.936	0.187
Preparedness	5	0.05	0.01
Distance from Location	0.23	0.0005	9e-05
Severity	0.1	0.9	0.18
Parameter Value for:		Fraction ($d_{l,i}$):	0.574

helped to prepare individuals and families for sustained survival after the disaster, there will be a lower requirement for immediate response resources. This will enable the community to better respond to the disaster as well as begin the restoration phase earlier.

- Severity - an increase in this data element, which is another parameter specified in the model, will increase the disaster effect on the community. It is defined by an increase in the disaster characteristics.

Values The values for this parameter range from 0 to 1.

Equations in Model Within the model the parameter value is 0.57366. The calculation for this parameter is as shown in Table 21 using these values in Equation 96:

Aid Param1 *Description* This parameter is a factor in the fraction of aid being sent to the community which is actually added to the Aid stock parameter. Its value comes from the aggregation of several different data elements:

- Social Development - an increase in this parameter increases the amount of aid which the community is able to receive. Currently existing social situations with higher development levels are at a lower risk to economic and health troubles and will be able to recover more quickly from a disaster. [79]

[17] $w_{l,i,j} = w_{l,i} = 0.2$

[17] Number of buildings per square mile

- Preparedness - an increase in this parameter increases the amount of aid which the community is able to receive from the aid being sent. A greater level of preparedness means that more activities and projects will have been implemented which increase the population capability to sustain and begin restoring after a disaster.

- Transportation System Damages - an increase in this parameter decreases the amount of aid which the community is able to receive. Aid resources must physically be transported to accessible locations within the community for distribution if there are no available resources in the community. Remote villages are more vulnerable to transportation system damages since often times there are few routes available for transporting aid into the community.

Values The values for this parameter range from 0 to 1.

Equations in Model

Within the model the parameter value is 0.22184. The calculation for this parameter is as shown in Table 22 using these values in Equation 96:

Table 22: Aid Param1 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[18] $w_{l,i}f_{norm}(x_{l,i,j})$
Social Development	0.165	0.165	0.055
Preparedness	5	0.001	0.0002
Transportation system damages	0.5	0.5	0.167
Parameter Value for:		Aid Param1 ($d_{l,i}$):	0.222

AidDelayAdjust *Description* This parameter is a factor which scales the aid delay parameter. It is set to be dependent on the preparedness of the community but other factors may need to be included.

Values The values for this parameter range from 0 to 1. For values near 0, the delay is low, but for values near 1, the aid delay amount increases.

[18] $w_{l,i,j} = w_{l,i} = 0.3333$

Table 23: AidDelayAdjust Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[19] $w_{l,i}f_{norm}(x_{l,i,j})$
Preparedness	5	0.001	0.0003
Parameter Value for:		Aid Param1 ($d_{l,i}$):	0.0003

Equations in Model Within the model the parameter value is 0.00025. The calculation for this parameter is as shown in Table 23 using these values in Equation 96:

Prep Param1 *Description* This parameter describes the fraction of preparedness activities which contribute to the aid being received by the community after the disaster. The data elements aggregated to provide a value for this parameter include:

- Preparedness Programming - an increase in this parameter will increase the Prep Param1 parameter and also the amount of aid which the community receives after the disaster. This data element rates whether or not the preparedness programs are effective at enabling a community to properly prepare for a disaster.

- Probability of another disaster occurring - an increase in this parameter will increase the fraction of preparedness activities which will contribute toward the aid being received after the disaster. If the probability of another disaster is high, communities will be more likely to implement preparedness activities.

- Recentness of last disaster - an increase in this parameter will increase the PrepParam1 value but only to a degree. A very recent disaster with significant effect on the community requires time for restoration, and during that time the preparedness activity implementation will begin to increase.

- Stability - an increase in this parameter will increase the Prep Param1 value. Greater stability within the community means fewer political, social, and economic issues which may compound difficulty when aid is received into the community.

[19] $w_{l,i,j} = w_{l,i} = 0.5$

Values The values for Prep Param1 range from 0 to 1.

Equations in Model Within the model the parameter value is 0.3123. The calculation for this parameter is as shown in Table refprepparam1values using these values in Equation 96:

Table 24: Prep Param1 Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[20] $w_{l,i}f_{norm}(x_{l,i,j})$
Population Density	1189	0.982	0.196
Urban Infrastructure Density [21]	481	0.936	0.187
Preparedness	5	0.05	0.01
Distance from Location	0.23	0.0005	9e-05
Severity	0.1	0.9	0.18
Parameter Value for:		Fraction ($d_{l,i}$):	0.574

Adjust MC *Description* This parameter is a scaling factor for the Media Coverage parameter. It allows other factors which might affect the amount of Media Coverage after a disaster.

*Values*The range of values for this parameter is from 0 to 1.

Equations in Model Within the model, this parameter is not further decomposed, and its value is 1.

Adjust CS *Description* This parameter is a scaling factor for the Sympathy parameter. It includes the factor of other parameters on the rate of increase of sympathy by potential aid senders who were exposed to media coverage of the disaster.

Values The range of values for this parameter is from 0 to 1.

Equations in Model Within the model, this parameter is not further decomposed, and its value is 1.

[21] $w_{l,i,j} = w_{l,i} = 0.2$
[21] Buildings per square mile

Initial Aid *Description*This parameter represents the amount of aid that a community is already receiving when the disaster event occurs. It is decomposed to the following parameters:

- Currently receiving aid from prior disaster - if the answer is yes, then the value of the initial aid is increased.
- Recentness of last disaster - for a more recent disaster there will be more aid still being received than if the disaster of the same severity occurred farther in the past.
- Development level - (initial value) as this parameter increases, the amount of aid coming into the community will be greater because the community will also be able to implement the received aid.

Values The values for this parameter are whole numbers greater than 0.

Equations in Model Within the model the parameter value is 5.36. The calculation for this parameter is as shown in Table 25 using these values in Equation 96:

Table 25: Initial Aid Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[22] $w_{l,i}f_{norm}(x_{l,i,j})$
Currently Receiving aid for previous disaster?	1	1	0.33
Recentness of last disaster	0	0	0
Development	60.81	0.608	0.2027
Parameter Value for:		Initial Aid ($d_{l,i}$):	5.36

World State *Description*

For the rate at which people become interested in providing aid and act on that interest, the model bases the equation on the world state 'W' which reflects the giving capability of potential aid providing nations, organizations, and individuals.

Components

The components of the World State are the following:

[22] $w_{l,i,j} = w_{l,i} = 0.333$

- Stability of global economy
- Number of ongoing wars in developed nations
- Number of social crises in developed nations
- Number of current disasters in developed nations
- Number of developing disasters in developed nations
- Number of ongoing wars in developing nations
- Number of social crises in developing nations
- Number of current disasters in developing nations
- Number of developing disasters in developing nations

These components affect the capability of other nations to provide aid which is considered as external aid that the community receives.

*Values*Each component has a value which goes from 0 to 1. No ongoing crises, wars, or disasters mean that component will have a value of 1. As different crises, wars, or disasters become present in developed or developing nations the component values decrease toward zero. Their weighted sum aggregate has a value from zero to 100. Low-0: Nations are less able to provide aid due to internal nation issues. High-100: Nations are able to provide aid because fewer crises, wars, and disasters are affecting them.

Equations in Model

WorldState reflects the capability of responding nations to provide external aid. If more likely contributors are experiencing difficult financial or political circumstances, the value may be lower, for example. [65]

Within the model, the value is calculated with the parameter values shown in Table 26: The total sum of the weighted normalized values is multiplied by 100 so that the state of the world is the same magnitude as the development levels.

Table 26: WorldState Values

Parameter		Value	Weighted
Stability		0.4	0.0444
Developed Nations			
	Ongoing War	0.7	0.0778
	Social Crises	0.4	0.0444
	Current Disasters	0.2	0.0222
	Developing Disasters	0.2	0.0222
Developing Nations			
	Ongoing War	0.6	0.0667
	Social Crises	0.5	0.0556
	Current Disasters	0.6	0.0667
	Developing Disasters	0.7	0.0778
		Total WorldState =	47.78

AidUnofficialFraction *Description*

This parameter describes the fraction of the aid being input to the community which is unofficial aid.

Within the VENSIM model, this parameter scales the total aid flow coming into the Unofficial Aid stock.

Values This parameter, along with the other aid fraction parameters, is a fractional value which sums to one with the rest of the parameters.

Equations in Model

Within the model, this parameter value is 0.06.

AidResponseFraction *Description*

This parameter describes the fraction of the aid being input to the community which is response aid.

Within the VENSIM model, this parameter scales the total aid flow coming into the Response Aid stock.

Values This parameter, along with the other aid fraction parameters, is a fractional value which sums to one with the rest of the parameters.

Equations in Model

Within the model, this parameter value is 0.20.

AidRestoreFraction *Description*

This parameter describes the fraction of the aid being input to the community which is restoration aid.

Within the VENSIM model, this parameter scales the total aid flow coming into the Restoration Aid stock.

Values This parameter, along with the other aid fraction parameters, is a fractional value which sums to one with the rest of the parameters.

Equations in Model

Within the model, this parameter value is 0.44.

AidExternalFraction *Description*

This parameter describes the fraction of the aid being input to the community which is external aid.

Within the VENSIM model, this parameter scales the total aid flow coming into the External Aid stock.

Values

This parameter, along with the other aid fraction parameters, is a fractional value which sums to one with the rest of the parameters.

Equations in Model

Within the model, this parameter value is 0.318.

Adjustment flowExt *Description*

This parameter is a scaling factor for the aid flow rate from the external aid stock to the total Aid parameter Aid Sum.

It is based on the following parameters:

- ratio of provided vs. needed food
- ratio of provided vs. needed drinking water
- ratio of provided vs. needed community sanitation

- ratio of provided vs. needed shelter
- ratio of provided vs. needed aid
- amount of partially provided vs. needed aid
- amount of survivors who did not receive aid but required it
- fraction of missing found alive
- amount of debris which needs to be removed ($m^3 \div km^2$ of land)
- community debris removal rate capability ($m^3 \div$ month)
- projected time to remove debris (months)
- time needed to remove and process bodies (weeks)
- ratio of available vs. needed capability for body removal and processing
- ratio of available vs. needed counseling services
- average amount of time for family reconnection (wks)
- average amount of time for family relocation (wks)
- average amount of time for family reassimilation (months)
- projected time to repair transportation infrastructure to 75% functional (weeks)
- projected time needed to repair buildings to 50% final (months)
- projected time needed to repair utilities to 50% (wks)

This parameter value is calculated by data elements which are based on the response and restoration performance. The other types of aid do not include both types of aid, but use the same parameters.

Values The parameter has a value from 0 to 1. Lower values mean that less external aid is being sent to the Aid Sum stock, and higher values mean that more external aid is being sent to the Aid Sum stock.

Equations in Model Within the model, the parameter value is 0.308. The value is calculated using the Table 27 values in Equation 96:

Table 27: Adjustment flowExt Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[23] $w_{l,i} f_{norm}(x_{l,i,j})$
Food (provided vs. needed)	0.5	0.5	0.025
Water (provided vs. needed)	0.5	0.5	0.025
Sanitation (provided vs. needed)	0.4	0.4	0.02
Shelter (provided vs. needed)	0.4	0.4	0.02
Aid (provided vs. needed)	0.6	0.6	0.03
Partial Aid (provided vs. needed)	0.3	0.3	0.015
No Aid (provided vs. needed)	0.1	0.1	0.005
Fraction of missing found alive	0.4	0.4	0.02
Amount of debris (m^3 / km^2 of land)	60,000	0.149	0.0075
Debris removal rate (m^3 / month)	200,000	0.1319	0.0066
Debris removal time (months, projected)	2	0.0025	0.0001
Body removal time (weeks)	6	0.5556	0.0278
Body removal capability (weeks, available vs. needed)	0.5	0.5	0.025
Counseling services (available vs. needed)	0.8	0.8	0.04
Family reconnection time (weeks)	1	0	0
Family relocation time (weeks)	3	0.1818	0.0091
Family reassimilation time (months)	5	0.3636	0.0182
Transportation repair (weeks, to 75%)	2	0.0417	0.0021
Building repair (months, to 50%)	5	0.1304	0.0065
Utility repair (weeks, to 50%)	2	0.1111	0.0056
Parameter Value for:	Adjustment flowExt ($d_{l,i}$):		0.308

Adjustment flowUn *Description* This parameter is a scaling factor for the aid flow rate from the unofficial aid stock to the total Aid parameter Aid Sum.

It is based on the following parameters:

- ratio of provided vs. needed food
- ratio of provided vs. needed drinking water
- ratio of provided vs. needed community sanitation

[23] $w_{l,i,j} = w_{l,i} = 0.05$

- ratio of provided vs. needed shelter
- ratio of provided vs. needed aid
- amount of partially provided vs. needed aid
- amount of survivors who did not receive aid but required it
- fraction of missing found alive

Values

The parameter has a value from 0 to 1. Lower values mean that less unofficial aid is being sent to the Aid Sum stock, and higher values mean that more unofficial aid is being sent to the Aid Sum stock.

Equations in Model

Within the model, the parameter value is 0.4. The value is calculated using the Table 28 values in Equation 96:

Table 28: Adjustment flowUn Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[24] $w_{l,i}f_{norm}(x_{l,i,j})$
Food (provided vs. needed)	0.5	0.5	0.0625
Water (provided vs. needed)	0.5	0.5	0.0625
Sanitation (provided vs. needed)	0.4	0.4	0.05
Shelter (provided vs. needed)	0.4	0.4	0.05
Aid (provided vs. needed)	0.6	0.6	0.075
Partial Aid (provided vs. needed)	0.3	0.3	0.0375
No Aid (provided vs. needed)	0.1	0.1	0.0125
Fraction of missing found alive	0.4	0.4	0.05
Parameter Value for:	Adjustment flowUn ($d_{l,i}$):		0.4

Adjustment flowRes *Description*

This parameter is a scaling factor for the aid flow rate from the response aid stock to the total Aid parameter Aid Sum.

[24] $w_{l,i,j} = w_{l,i} = 0.125$

It is based on the following parameters:

- ratio of provided vs. needed food
- ratio of provided vs. needed drinking water
- ratio of provided vs. needed community sanitation
- ratio of provided vs. needed shelter
- ratio of provided vs. needed aid
- amount of partially provided vs. needed aid
- amount of survivors who did not receive aid but required it
- fraction of missing found alive

Values

The parameter has a value from 0 to 1. Lower values mean that less unofficial aid is being sent to the Aid Sum stock, and higher values mean that more unofficial aid is being sent to the Aid Sum stock.

Equations in Model

Within the model, the parameter value is 0.4. The value is calculated using the Table 29 values in Equation 96:

Adjustment flowRest *Description*

This parameter is a scaling factor for the aid flow rate from the restoration aid stock to the total Aid parameter Aid Sum.

It is based on the following parameters:

- amount of debris which needs to be removed ($m^3 \div km^2$ of land)
- community debris removal rate capability ($m^3 \div$ month)

[25] $w_{l,i,j} = w_{l,i} = 0.125$

Table 29: Adjustment flowRes Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[25] $w_{l,i}f_{norm}(x_{l,i,j})$
Food (provided vs. needed)	0.5	0.5	0.0625
Water (provided vs. needed)	0.5	0.5	0.0625
Sanitation (provided vs. needed)	0.4	0.4	0.05
Shelter (provided vs. needed)	0.4	0.4	0.05
Aid (provided vs. needed)	0.6	0.6	0.075
Partial Aid (provided vs. needed)	0.3	0.3	0.0375
No Aid (provided vs. needed)	0.1	0.1	0.0125
Fraction of missing found alive	0.4	0.4	0.05
Parameter Value for:	Adjustment flowRes ($d_{l,i}$):		0.4

- projected time to remove debris (months)
- time needed to remove and process bodies (weeks)
- ratio of available vs. needed capability for body removal and processing
- ratio of available vs. needed counseling services
- average amount of time for family reconnection (wks)
- average amount of time for family relocation (wks)
- average amount of time for family reassimilation (months)
- projected time to repair transportation infrastructure to 75% functional (weeks)
- projected time needed to repair buildings to 50% final (months)
- projected time needed to repair utilities to 50% (wks)

Values

The parameter has a value from 0 to 1. Lower values mean that less restoration aid is being sent to the Aid Sum stock, and higher values mean that more restoration aid is being sent to the Aid Sum stock.

Equations in Model

Table 30: Adjustment flowRest Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[26] $w_{l,i}f_{norm}(x_{l,i,j})$
Amount of debris ($m^3 \div km^2$ of land)	60,000	0.149	0.0125
Debris removal rate ($m^3 \div$ month)	200,000	0.1319	0.011
Debris removal time (months, projected)	2	0.0025	0.0002
Body removal time (weeks)	6	0.5556	0.0463
Body removal capability (weeks, available vs. needed)	0.5	0.5	0.0417
Counseling services (available vs. needed)	0.8	0.8	0.0667
Family reconnection time (weeks)	1	0	0
Family relocation time (weeks)	3	0.1818	0.0152
Family reassimilation time (months)	5	0.3636	0.0303
Transportation repair (weeks, to 75%)	2	0.0417	0.0035
Building repair (months, to 50%)	5	0.1304	0.0109
Utility repair (weeks, to 50%)	2	0.1111	0.0093
Parameter Value for:	Adjustment flowRest ($d_{l,i}$):		0.247

Within the model, the parameter value is 0.247. The value is calculated using the Table 30 values in Equation 96:

Adjust Preparedness *Description* This parameter scales the sum of the different preparedness aspect flows into the preparedness stock. The parameter is based on the following elements:

- Development - this parameter is previously defined, and an increase in the Development level will enable more of the preparedness components to contribute to the preparedness stock level.
- Stability - this parameter is previously defined, and an increase in the community stability will enable more of the preparedness components to contribute to the preparedness stock level.
- Recentness of last disaster - this parameter is previously defined. A recent disaster increases the priority for communities to increase their preparedness.

[26] $w_{l,i,j} = w_{l,i} = 0.0833$

Values

The value will range from 0 to 1. A 0 means no recent disaster has occurred, and a value closer to 1 means that a disaster has recently occurred.

Equations in Model

Within the model, the parameter value is 0.3241. The value is calculated using the Table 31 values in Equation 96:

Table 31: Adjust Preparedness Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[27] $w_{l,i}f_{norm}(x_{l,i,j})$
Development	60.81	0.608	0.2027
Stability	0.4736	0.364	0.1214
Recentness of last disaster	0	0	0
Parameter Value for:	Adjust Preparedness ($d_{l,i}$):		0.3214

TrainingInit *Description* This parameter is the initial value of the Training parameter. This is based on the following parameters:

- Budget Status - this parameter is the budget status of the Preparedness Training, which is either insufficient(< 1), sufficient(1), or a surplus (> 1).
- Recentness of last disaster - this parameter is previously defined. A recent disaster increases the priority for communities to increase their preparedness.
- Probability of another disaster occurring - a lower probability of a disaster occurring will reduce the urgency the community may have for implementing preparedness training, and a higher probability of a disaster occurrence may increase the urgency for implementing preparedness training.

Values The value in the model is a number greater than zero.

Equations in Model

[27] $w_{l,i,j} = w_{l,i} = 0.3333$

Within the model, the parameter value is 3.33667. The value is calculated using the Table 32 values in Equation 96 and the final sum of the weighted values is multiplied by ten because the stock level of the training is measured in values greater than zero but not restricted to values less than 1:

Table 32: TrainingInit Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[28] $w_{l,i}f_{norm}(x_{l,i,j})$
Budget Status	1	0.333	0.333
Recentness of last disaster	0	0	0
Probability of another disaster occurrence	0.001	0.001	0.0003
Parameter Value for:		Training Init ($d_{l,i}$):	3.33367

Prep ProgramsInit *Description*

This parameter is the initial value of the Preparedness programs parameter. This is based on the following parameters:

- Budget Status - this parameter is the budget status of the Preparedness Training, which is either insufficient(< 1), sufficient(1), or a surplus (> 1).
- Recentness of last disaster - this parameter is previously defined. A recent disaster increases the priority for communities to increase their preparedness.
- Probability of another disaster occurring - a lower probability of a disaster occurring will reduce the urgency the community may have for implementing preparedness training, and a higher probability of a disaster occurrence may increase the urgency for implementing preparedness training.

Equations in Model

Within the model, the parameter value is 3.33667. The value is calculated using the Table 33 values in Equation 96 and the final sum of the weighted values is multiplied by

[28] $w_{l,i,j} = w_{l,i} = 0.3333$

ten because the stock level of the training is measured in values greater than zero but not restricted to values less than 1:

Table 33: Prep ProgramsInit Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[29] $w_{l,i}f_{norm}(x_{l,i,j})$
Budget Status	1	0.333	0.333
Recentness of last disaster	0	0	0
Probability of another disaster occurrence	0.001	0.001	0.0003
Parameter Value for:	Prep ProgramsInit ($d_{l,i}$):		3.33367

ProcurementInit *Description* This parameter is the initial value for the Procurement level and includes the following parameters:

- Budget Status - this parameter is the budget status of the Preparedness Training, which is either insufficient(< 1), sufficient(1), or a surplus (> 1).
- Recentness of last disaster - this parameter is previously defined. A recent disaster increases the priority for communities to increase their preparedness.
- Probability of another disaster occurring - a lower probability of a disaster occurring will reduce the urgency the community may have for implementing preparedness training, and a higher probability of a disaster occurrence may increase the urgency for implementing preparedness training.
- Warning - this parameter is a value of zero if there was no warning, and as the amount of warning time increases, the value of the parameter will increase.

Values The parameter value is a number greater than zero and its value increases to represent an increase amount of procurement.

Equations in Model

[29] $w_{l,i,j} = w_{l,i} = 0.3333$

Within the model, the parameter value is 2.5275. The value is calculated using the Table 34 values in Equation 96 and the final sum of the weighted values is multiplied by ten because the stock level of the procurement is measured in values greater than zero but not restricted to values less than 1:

Table 34: ProcurementInit Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[30] $w_{l,i}f_{norm}(x_{l,i,j})$
Budget Status	1	1	0.25
Recentness of last disaster	0	0	0
Probability of another disaster occurrence	0.001	0.001	0.0003
Warning	0.01	0.01	0.0025
Parameter Value for:	ProcurementInit ($d_{l,i}$):		2.5275

PrepositionInit *Description* This parameter is the initial value for the Prepositioning parameter. It is based on the following parameters:

- Budget Status - this parameter is the budget status of the Preparedness Training, which is either insufficient(< 1), sufficient(1), or a surplus (> 1).
- Recentness of last disaster - this parameter is previously defined. A recent disaster increases the priority for communities to increase their preparedness.
- Probability of another disaster occurring - a lower probability of a disaster occurring will reduce the urgency the community may have for implementing preparedness training, and a higher probability of a disaster occurrence may increase the urgency for implementing preparedness training.
- Warning - this parameter is a value of zero if there was no warning, and as the amount of warning time increases, the value of the parameter will increase.

Values The parameter value is a number greater than zero and its value increases to represent an increase amount of prepositioning.

[30] $w_{l,i,j} = w_{l,i} = 0.25$

Table 35: PrepositionInit Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[31] $w_{l,i} f_{norm}(x_{l,i,j})$
Budget Status	1	1	0.25
Recentness of last disaster	0	0	0
Probability of another disaster occurrence	0.001	0.001	0.0003
Warning	0.01	0.01	0.0025
Parameter Value for:	PrepositionInit ($d_{l,i}$):		2.5275

Equations in Model

Within the model, the parameter value is 2.5275. The value is calculated using the Table 35 values in Equation 96 and the final sum of the weighted values is multiplied by ten because the stock level of the prepositioning is measured in values greater than zero but not restricted to values less than 1:

CollabInit *Description*

This parameter is the initial value for the Collaboration parameter. It is based on the following parameters:

- Budget Status - this parameter is the budget status of the Preparedness Training, which is either insufficient(< 1), sufficient(1), or a surplus (> 1).
- Recentness of last disaster - this parameter is previously defined. A recent disaster increases the priority for communities to increase their preparedness.
- Probability of another disaster occurring - a lower probability of a disaster occurring will reduce the urgency the community may have for implementing preparedness training, and a higher probability of a disaster occurrence may increase the urgency for implementing preparedness training.
- Warning - this parameter is a value of zero if there was no warning, and as the amount of warning time increases, the value of the parameter will increase.

[31] $w_{l,i,j} = w_{l,i} = 0.25$

Values The parameter value is a number greater than zero and its value increases to represent an increase amount of prepositioning.

Equations in Model

Within the model, the parameter value is 2.5275. The value is calculated using the Table 36 in Equation 96 and the final sum of the weighted values is multiplied by ten because the stock level of the collaboration is measured in values greater than zero but not restricted to values less than 1:

Table 36: CollabInit Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[32] $w_{l,i} f_{norm}(x_{l,i,j})$
Budget Status	1	1	0.25
Recentness of last disaster	0	0	0
Probability of another disaster occurrence	0.001	0.001	0.0003
Warning	0.01	0.01	0.0025
Parameter Value for:		CollabInit ($d_{l,i}$):	2.5275

Adjust Pro *Description* This parameter is a factor which scales the amount of procurement which takes place after the disaster event. It is based on some collaboration parameters, which were selected because after a disaster event, effective procurement (acquiring the needed supplies and resources) can be done with communication, organization and training, procuring the actual resources, and prepositioning them or sending them to the community. The selected parameters for calculating this value were:

- Organization - training - an increase in the training of personnel for the procurement aspect of the response enables greater knowledge and preparedness of the community by enabling an increase in the level of procurement.

- Communication - an increase in the communication among personnel enables an increase in the level of procurement since now different personnel from other regions of the community may have different perceptions about the procurement needs of the

[32] $w_{l,i,j} = w_{l,i} = 0.25$

community.

- Procurement -
- Prepositioning

Values Within the model the values range from 0 to 1.

Equations in Model Within the model, the parameter value is 0.525. The value is calculated using the Table 37 values in Equation 96:

Table 37: Adjust Pro Values

Data Element $x_{l,i,j}$	Value	Norm. Val. $f_{norm}(x_{l,i,j})$	Weighted Norm.[33] $w_{l,i}f_{norm}(x_{l,i,j})$
Organization and training	0.7	0.7	0.175
Communication	0.5	0.5	0.125
Procurement	0.5	0.5	0.125
Prepositioning	0.4	0.4	0.1
Parameter Value for:		Adjust Pro ($d_{l,i}$):	0.525

Wt Train Proc *Description* This parameter scales the strength of the effect of training on the procurement parameter. Each of the programs and training flow from their respective stocks to the procurement stock may be scaled using these parameters.

Values The value is selected by the user and may be a value between zero and one. If the training has a stronger effect on the amount of procurement which is done, then the value should be closer to one. If the training has a weaker effect on the procurement, then the value should be closer to zero.

Equations in Model Within the model this parameter has a value of 0.5.

Wt ProgProc *Description* This parameter scales the strength of the effect of programs on the procurement parameter. Each of the programs and training flow from their respective stocks to the procurement stock may be scaled using these parameters.

Values

[33] $w_{l,i,j} = w_{l,i} = 0.25$

The value is selected by the user and may be a value between zero and one. If the programs have a stronger effect on the amount of procurement which is done, then the value should be closer to one. If the programs have a weaker effect on the procurement, then the value should be closer to zero.

Equations in Model Within the model this parameter has a value of 0.2.

Wt TrainPrep *Description* This parameter scales the strength of the effect of training on the prepositioning parameter. The parameter may increase or decrease the flow of the training resources into the prepositioning stock.

Values

The value is selected by the user and may be a value between zero and one. If training has a stronger effect on the amount of prepositioning which is done, then the value should be closer to one. If the training has a weaker effect on the prepositioning, then the value should be closer to zero.

Equations in Model Within the model this parameter has a value of 0.5.

Wt ProgPrep *Description*This parameter scales the strength of the effect of programs on the prepositioning parameter. The parameter may increase or decrease the flow of the program resources into the prepositioning stock.

Values The value is selected by the user and may be a value between zero and one. If programs have a stronger effect on the amount of prepositioning which is done, then the value should be closer to one. If the programs have a weaker effect on the prepositioning, then the value should be closer to zero.

Equations in Model Within the model this parameter has a value of 0.2.

Wt TrainColl *Description*This parameter scales the strength of the effect of training on the collaboration parameter. The parameter may increase or decrease the flow of the training resources into the collaboration stock.

Values The value is selected by the user and may be a value between zero and one. If training has a stronger effect on the amount of collaboration which is done, then the value should be closer to one. If the training has a weaker effect on the collaboration, then the value should be closer to zero.

Equations in Model

Within the model this parameter has a value of 0.5.

Wt ProgColl *Description*This parameter scales the strength of the effect of programs on the collaboration parameter. The parameter may increase or decrease the flow of the program resources into the collaboration stock.

Values The value is selected by the user and may be a value between zero and one. If programs have a stronger effect on the amount of collaboration which is done, then the value should be closer to one. If the programs have a weaker effect on the collaboration, then the value should be closer to zero.

Equations in Model Within the model this parameter has a value of 0.2.

storetime1 *Description* This parameter records the first time value used to calculate system level metric, Restoration time. The time is defined as the time when the disaster occurs until the Development level has increased past its pre-disaster value and reached a preset goal value.

Values The value of the parameter is zero until the Development value decreases to a difference greater than a certain threshold from the initial Development value.

Equations in Model Within the VENSIM model, the equation is as follows:

$$storetime1 = \begin{cases} Time & \text{if } DevelThrottle - Development > 1 \\ & \text{and if } storetime1 = 0 \\ 0 & \text{otherwise} \end{cases} \tag{97}$$

storetime2 *Description* This parameter records the second time value used to calculate system level metric, Restoration Time.

Values The value of the parameter is zero until the difference between DevelThrottle and Development values is less than a certain threshold (for this research the threshold was

1). At that time, the Time parameter value becomes the storetime2 value. hold was 1). At that time, the Time parameter value becomes the storetime2 value.

Equations in Model Within the VENSIM model, the equation is as follows:

$$storetime2 = \begin{cases} Time & \text{if } DevelThrottle - Development < 1 \\ & \text{and if } storetime1 > 0 \\ & \text{and if } storetime2 = 0 \\ 0 & \text{otherwise} \end{cases} \tag{98}$$

storetime3 *Description* This parameter records the first time value used to calculate system level metric, Restoration time.

Values The value of the parameter is zero until the Development value decreases to a difference greater than a certain threshold from the initial Development value.

Equations in Model Within the VENSIM model, the equation is as follows:

$$storetime3 = \begin{cases} Time & \text{if } DevelThrottleIdeal - Development2 > 1 \\ & \text{and if } storetime3 = 0 \\ 0 & \text{otherwise} \end{cases} \tag{99}$$

storetime4 *Description*This parameter records the second time value used to calculate system level metric, Restoration Time. The time is defined as the time when the disaster occurs until the Development level has increased past its pre-disaster value and reached a preset goal value.

This parameter has the same function as storetime2 but is able to calculate an alternate Restoration time for the same community within the same simulation.

*Values*The value of the parameter is zero until the difference between DevelThrottle and Development values is less than a certain threshold (for this research the threshold was 1). At that time, the Time parameter value becomes the storetime2 value.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$storetime4 = \begin{cases} Time & \text{if } DevelThrottleIdeal - Development2 < 1 \\ & \text{and if } storetime3 > 0 \\ & \text{and if } storetime4 = 0 \\ 0 & \text{otherwise} \end{cases} \tag{100}$$

InitialStability *Description* This parameter provides the initial value for the Stability parameter.

Values The values for this parameter are determined by the Development parameter and the Adjustment DSD parameter.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$InitialStability = Development \times AdjustmentDSD \tag{101}$$

fx onsys *Description* This parameter describes the effect of the disaster event on the system. It relays the disaster effect to the development level.

Values The value for the effect on the system is calculated by doing a lookup of the development level in an effect lookup graph.

Equations in Model Within the VENSIM model, the equation is:

$$fxonsys = effectlookup(DevelThrottle) \tag{102}$$

effect lookup *Description*This parameter is the lookup graph for the parameter fx onsys. The effect of the disaster on the system changes depending on the Development level (DevelThrottle) of the community. Higher development levels correspond to a reduced disaster effect, while a lower development level will correspond to an increased disaster effect.

Values The values scale from 20 to 1. Low development levels correspond to the higher effect lookup values, and the higher development levels correspond to the lower effect lookup values.

Equations in Model

The lookup values in the VENSIM model are shown in the graph in Figure 45

ThrottleConstant *Description* This parameter is a scaling factor used in the calculation of the development components. It is a constant value set within the model and does not change throughout the simulations. It also is not a user input. In the development component calculations, ThrottleConstant scales the effect of the development component flow into the component stock.

Values The value should be between zero and 1.

Equations in Model Within the VENSIM model, the value for this parameter is 0.99.

Adjustment D *Description* This parameter is a scaling factor which applies to the disaster effect within the development component level. It is currently not a user input and does not change during the simulation.

Values The value for this parameter should be between 0 and 1. Values near 0 reduce the disaster effect, and values near 1 will be less reducing on the disaster effect.

Equations in Model

Within the VENSIM model the parameter value is 1.

aftershock *Description*

The aftershock is set to occur for the same duration as the initial earthquake, at a time after the initial earthquake which can be designated (in the timeoption variable) by the user.

Values

The aftershock is a pulse which lasts for 2 time units, and begins at a certain time after the disaster occurs.

Equation in Model

Within the VENSIM model, the aftershock earthquake is described as follows:

$$aftershock = PULSE(disasterstart + timeoption, 2) \tag{103}$$

aftershockoption *Description*

The aftershockoption allows the user to select whether or not an afershock occurs. If the chooseaftershock parameter is set to 1, then the value of the aftershock is described in the aftershock parameter.

*Values*The value is zero unless the aftershock is selected.

Equation in Model

The equation in the VENSIM model is as follows:

$$aftershockoption = IFTHENELSE(chooseaftershock = 1, aftershock, 0) \tag{104}$$

Adjust FD *Description* This parameter scales the effect of the disaster event on the amount of media coverage of the event. It may include the effect of factors which might reduce the media coverage of the event or prevent coverage from being received by viewers or consumers.

Values The value ranges between 0 and 1. It remains constant throughout the simulation and the value should be set during the system model development.

Equations in Model Within the VENSIM model, the value of this parameter is 1.

randomnormal *Description* This parameter supplies a random number to the media coverage of the event.

Values The values range from $e^{(-1)}$ to e, which are the minimum and maximum limits of the parameter.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$randomnormal = e^{N(0,1)} \tag{105}$$

Adjust flowCS *Description* This parameter scales the flow from the media coverage stock to the sympathy stock. Not all individuals exposed to media coverage of the disaster will feel compelled to contribute to the relief efforts.

Values The value of this parameter is between 0 and 1.

Equations in Model Within the model, this parameter has a value of 0.5. That is to say, half of those exposed to media coverage of the disaster will feel compelled to contribute to the relief efforts. While this parameter may be more complex, more research would be required for either a supplied data value or a further decomposition into other parameters which affect this one.

Adjustment FD *Description* This parameter adjusts the effect of the disaster event (Flow Disturbance parameter). It is a constant within the model.

Values The value of this parameter should be greater than zero and less than or equal to 1.

Equations in Model Within the VENSIM model this parameter value is 1.

DisasterEvent *Description*

The Disaster Event is the disaster occurrence. The event is not described by a particular type of disaster but instead affects the different components of the community.

Values

In this model, the disaster is represented by a 2 time-unit-long pulse of one unit in magnitude, which occurs at the disaster start time which the user may designate.

Equation in Model

Within the VENSIM model, the equation is as follows:

$$DisasterEvent = PULSE(disasterstart, 2) \tag{106}$$

quaketime *Description* This parameter measures the time of the earthquake occurrence. The current setup in the model uses the time at the end of the occurrence. This provides a start time for the post-disaster collaboration.

Values The values for this parameter come from the Time clock.

Equations in Model Within the model this parameter is defined by the following equation:

$$quaketime = quaketime2 \tag{107}$$

Where quaketime2 is the Time clock value at the end of the disaster occurrence.

quaketime1 *Description* This parameter measures the start of the disaster occurrence.

Values The values for this parameter come from the Time clock.

Equations in Model Within the VENSIM model, the parameter is defined as follows:

$$quaketime1 = \begin{cases} Time & \text{if } DsasterEvent > 0 \\ & \text{and if } quaketime1 = 0 \\ 0 & \text{otherwise} \end{cases} \tag{108}$$

quaketime2 *Description* This parameter measures the end of the disaster occurrence.

Values The values for this parameter come from the Time clock.

Equations in Model

Within the VENSIM model, the parameter is defined as follows:

$$quaketime2 = \begin{cases} Time & \text{if } DsasterEvent > 0 \\ & \text{and if } quaketime1 > 0 \\ & \text{and if } quaketime2 = 0 \\ 0 & \text{otherwise} \end{cases} \tag{109}$$

PrepTrainingBudget *Description* This parameter scales the amount of resources flowing into the Training stock from the InternalFundingBudget.

Values The value of this parameter should be between 0 and 1.

Equations in Model

Within the VENSIM model the parameter value is 0.1.

Adjust TrainB *Description* This parameter is a factor which also scales the amount of resource input to the Training from the InternalFundingBudget.

Values The value should be between 0 and 1.

Equations in Model The current value in the model is 1.

Adjust IF *Description* This parameter is a factor adjusting the amount of resource flowing from the Internal Funding.

Values This parameter should be a value from 0 to 1.

Equations in Model Within the model, this parameter has a value of 1.

PrepProgramBudget *Description* This parameter is a factor adjusting the amount of resource flowing from the InternalFundingBudget.

Values This parameter should be a value from 0 to 1.

Equations in Model Within the model, this parameter has a value of 1.

Adjust PrepP *Description* This parameter is a factor adjusting the amount of resource flowing from the InternalFundingBudget to the PrepPrograms.

Values The value should be between 0 and 1.

Equations in Model Within the VENSIM model this parameter has a value of 1.

ProcureBefore *Description* This parameter describes the amount of procurement which takes place before the disaster occurrence. The value changes after the disaster occurrence as the amount of relief and restoration resources are procured.

Values The value of this parameter should be a number greater than 0.

Equations in Model Within the model this parameter value is 3, indicating some initial amount of relief procurement.

Procure After *Description* This parameter describes the amount of procurement which takes place after the disaster occurrence. This value is dependent on the amount of collaboration which occurs, since collaboration after a disaster enables responders to know what resources are needed for the community so that they can be procured and distributed.

Values The value of this parameter is a number greater than 0.

Equations in Model Within the model, this parameter value is calculated using the following:

$$ProcureAfter = Collaboration \times AdjustPro \tag{110}$$

ProcureValue *Description* This parameter selects either the pre-disaster procurement calculation or the post-disaster procurement calculation based on whether or not the disaster has happened.

Values The values come from Procure Before or Procure After depending on if the disaster has occurred or not.

Equations in Model

Within the model, this parameter is calculated as follows:

$$ProcureValue = \begin{cases} ProcureBefore & \text{if } Time < disasterstart \\ ProcureAfter & \text{if } Time \geq disasterstart \end{cases} \tag{111}$$

Adjust Pre *Description* This parameter is a scaling factor for the rate of implementation of the prepositioning.

Values The range of values for this parameter is from 0 to 1.

Equations in Model Within the model, this parameter is not further decomposed, and its value is 1.

Adjust FCP *Description* This parameter is a scaling factor for the rate of implementation of the Collaboration as a component of the Preparedness stock.

Values The range of values for this parameter is from 0 to 1.

Equations in Model Within the model, this parameter is not further decomposed, and its value is 1.

Prep No Warn *Description* This parameter describes the amount of prepositioning done when there is no warning before the disaster. The disaster warning is specified as a number of days or time units prior to the disaster, but there is also a parameter which has a value of zero or 1, which specifies whether or not there is any warning.

Values This parameter should have a value greater than 0. If there is some amount of prepositioning which occurs in the community before a disaster occurrence, then the value should be greater than zero.

Equations in Model Within the model, this parameter has a value of 0.

Prep Warn *Description* This parameter gives the amount of prepositioning that occurs when there is a warning period before the disaster.

Values The value for this parameter comes from the parameter which describes the effect of prepositioning (Prepo Effects), but only during the selected warning period.

Equations in Model

Within the VENSIM model, the equation is as follows:

$$\text{Prep Warn} = \begin{cases} \text{PrepoEffects} & \text{if } TIME \geq \text{(disasterstart - warning)} \\ & \text{and if } TIME \leq \text{disasterstart} \\ 0 & \text{otherwise} \end{cases} \tag{112}$$

Prepo Effects *Description* This parameter describes the amount of prepositioning which would be implemented during a warning period before a disaster occurrence.

Values This value should be a number greater than zero if the community is capable of prepositioning resources during a disaster warning period.

Equations in Model Within the model this parameter is not further decomposed and has a value of 3.

Preposition Value *Description* This parameter selects between the prepositioning value depending on whether or not there is a warning before the disaster.

Values This value is either the value of the Prep No Warn parameter or the Prep Warn parameter.

Equations in Model

Within the VENSIM model the equation is as follows:

$$PrepositionValue = \begin{cases} PrepNoWarn & \text{if } warn = 0 \\ PrepWarn & \text{otherwise} \end{cases} \tag{113}$$

Collab Before *Description* This parameter describes the amount of collaboration which takes place prior to the disaster. This includes collaboration done before a warning period if it exists, as well as collaboration which takes place during the warning period.

Values The parameter value should be a number which is 0 or greater.

Equations in Model The value is a constant at 2 within the model.

Collab After *Description* This parameter describes the amount of collaboration which takes place after the disaster. The majority of the collaboration will be conducted in order to provide a timely response for the community and provide needed essential items such as food, water, and shelter to the right places at the right time.

Values This parameter will have a value of 0 or greater. Because the collaboration occurs during the response phase, the value after the disaster event is equal to the Response Aid. As the response phases out, the collaboration level caused by activities related to the response returns to zero. The actual collaboration value contains this effect as well as a constant level of collaboration present within the community.

Equations in Model Within the model, the value for Collab After is calculated as follows:

$$CollabAfter = f(ResponseAid, quaketime, 0) \tag{114}$$

where $f(ResponseAid, quaketime, 0)$ is a function which returns the value Response Aid as the value of the Collaboration after the disaster once the disaster has occurred at the time described in quaketime. Before this the value is 0.

Collab Value *Description* This parameter is the collective effect of the prior and post-disaster collaboration values from the Collab Before and Collab After parameters. It is the base value of the Collaboration parameter prior to the effects of other resources which either increase of decrease the level of the Collaboration stock.

Values The initial value is given by the CollabInit parameter, and will be a value greater than or equal to zero.

Equations in Model

Within the VENSIM model the equation is as follows:

$$CollabValue = CollabBefore + CollabAfter \tag{115}$$

Time *Description* This parameter is the time unit in the simulation. The model may be adjusted so that this parameter represents hours, days, weeks, or longer.

Values The values start at 0 and increase in whole units until the simulation stop time which is decided by the user.

Equations in Model Within the model the Time represents days.

The parameters used within the VENSIM model are shown in their visual relationships in Figure 46-49.

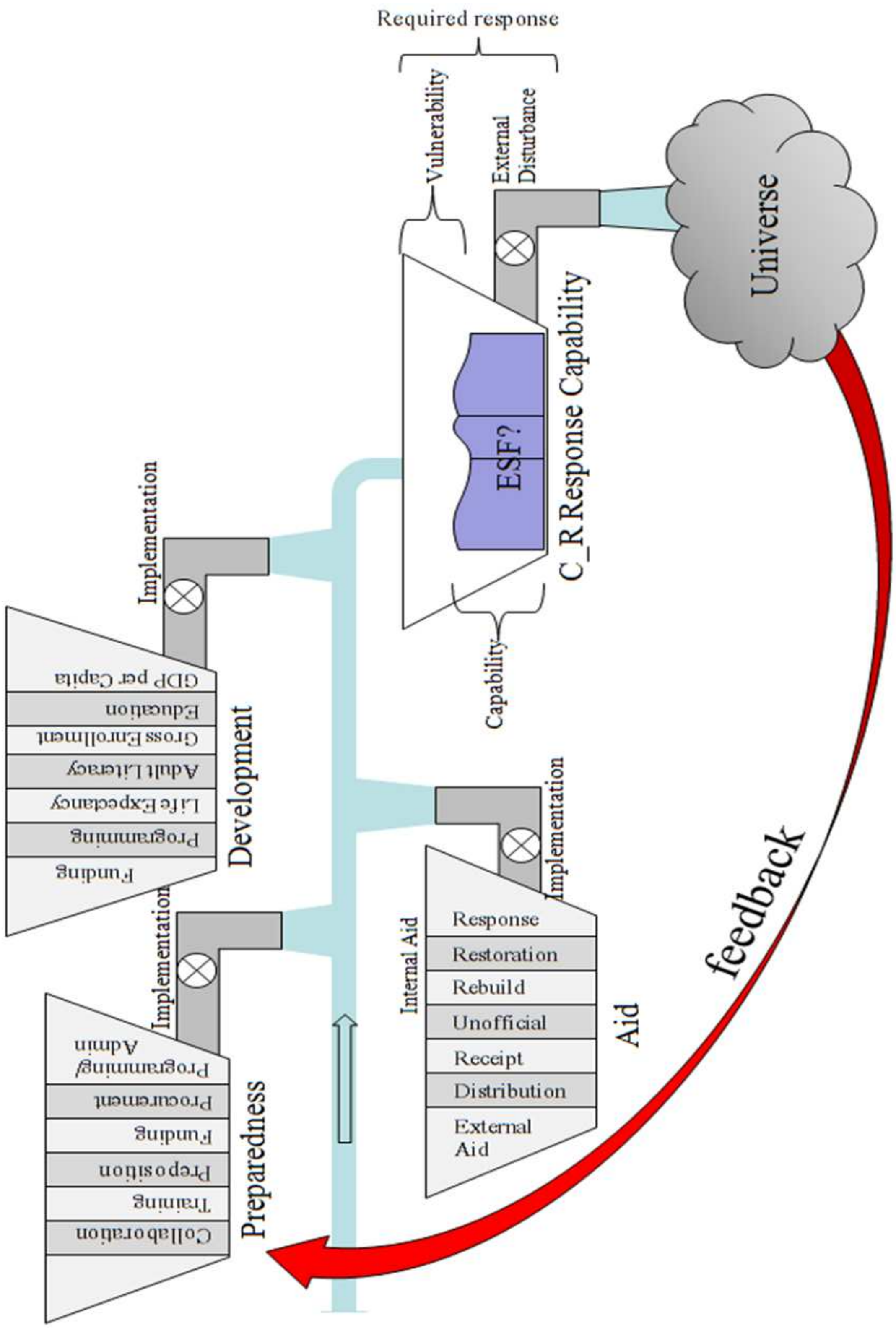


Figure 42: Response-Capability-Driven Flow Diagram

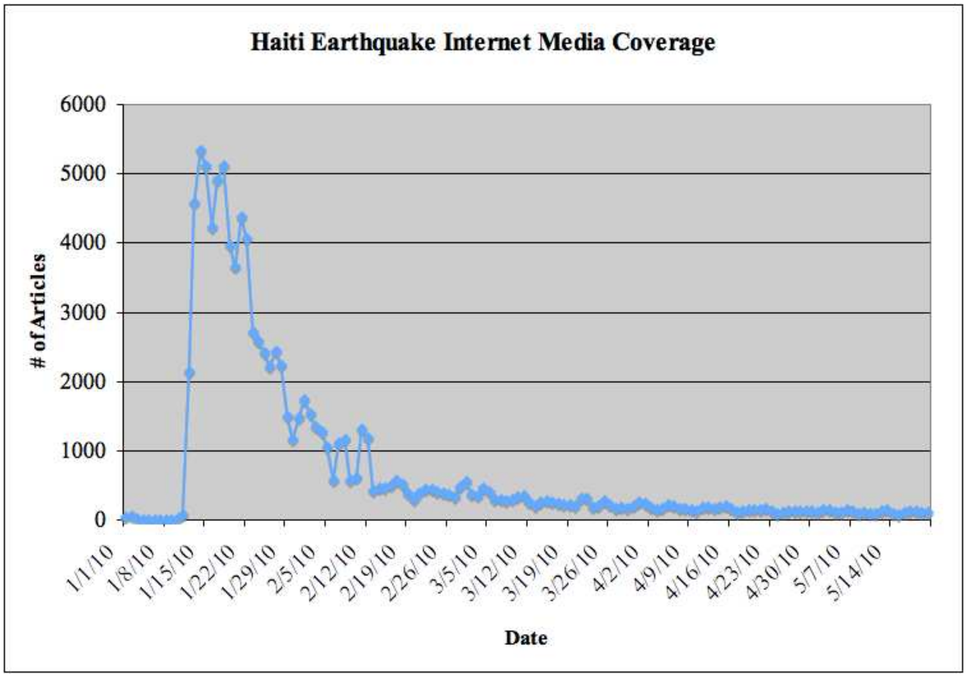


Figure 43: Haiti Earthquake Media Coverage

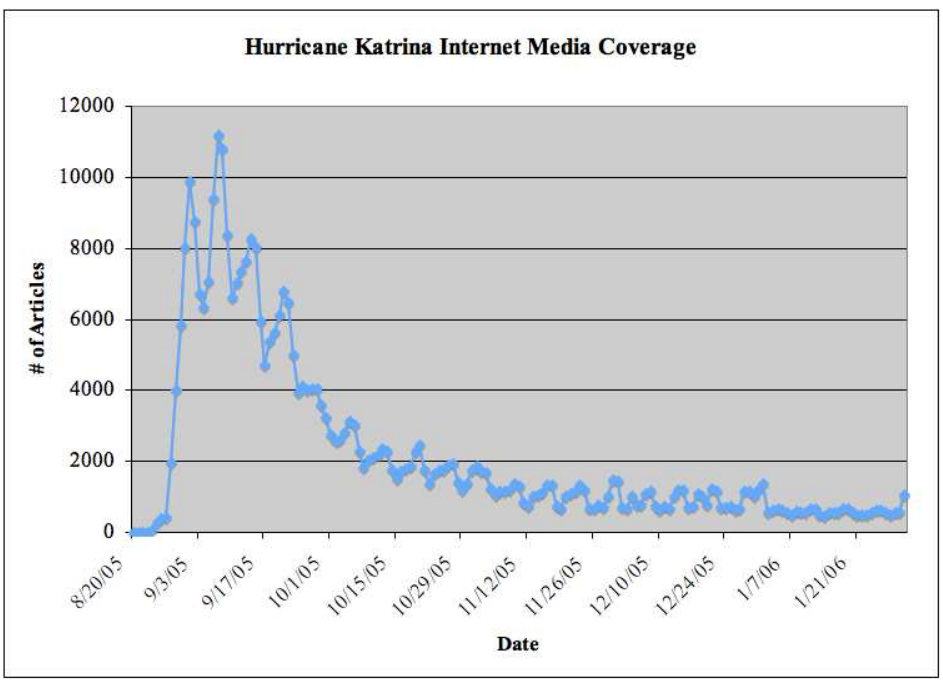


Figure 44: Hurricane Katrina Media Coverage

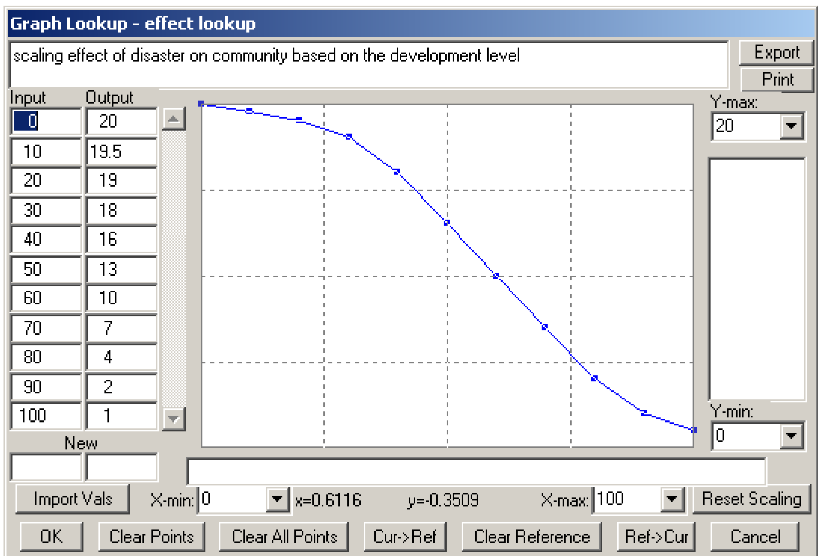


Figure 45: Effect Lookup for Disaster Effect on Community

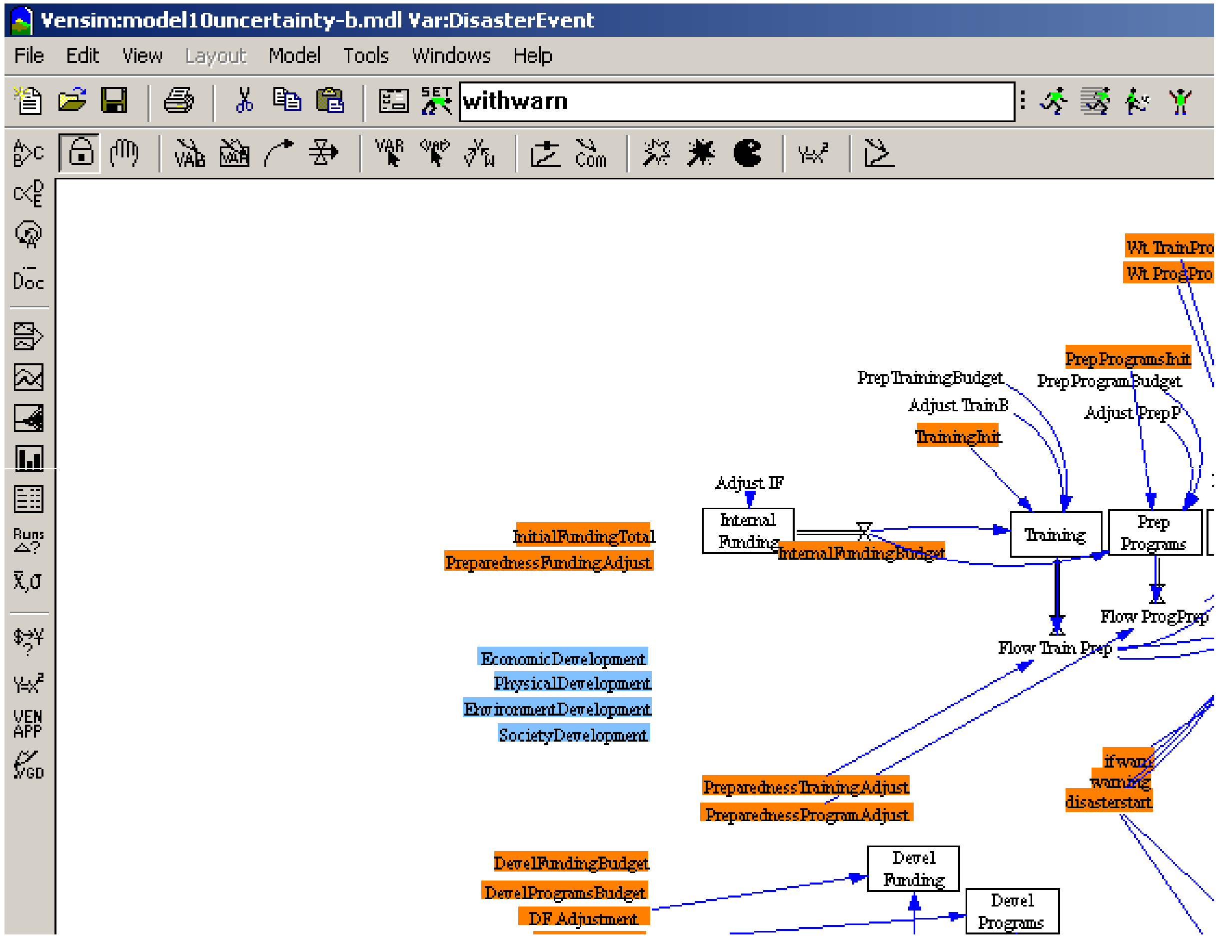


Figure 46: System Model Visual Diagram - TOP LEFT

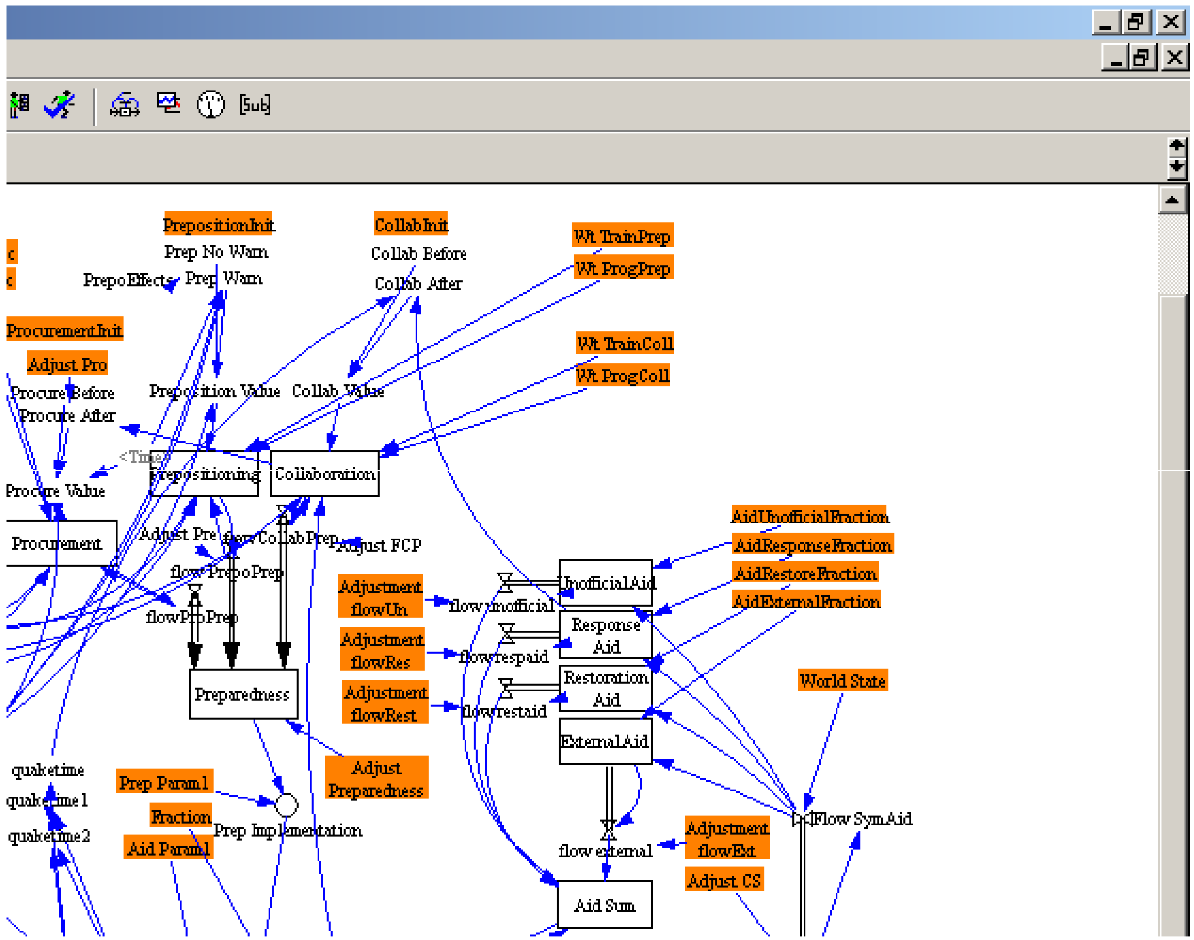


Figure 47: System Model Visual Diagram - TOP RIGHT

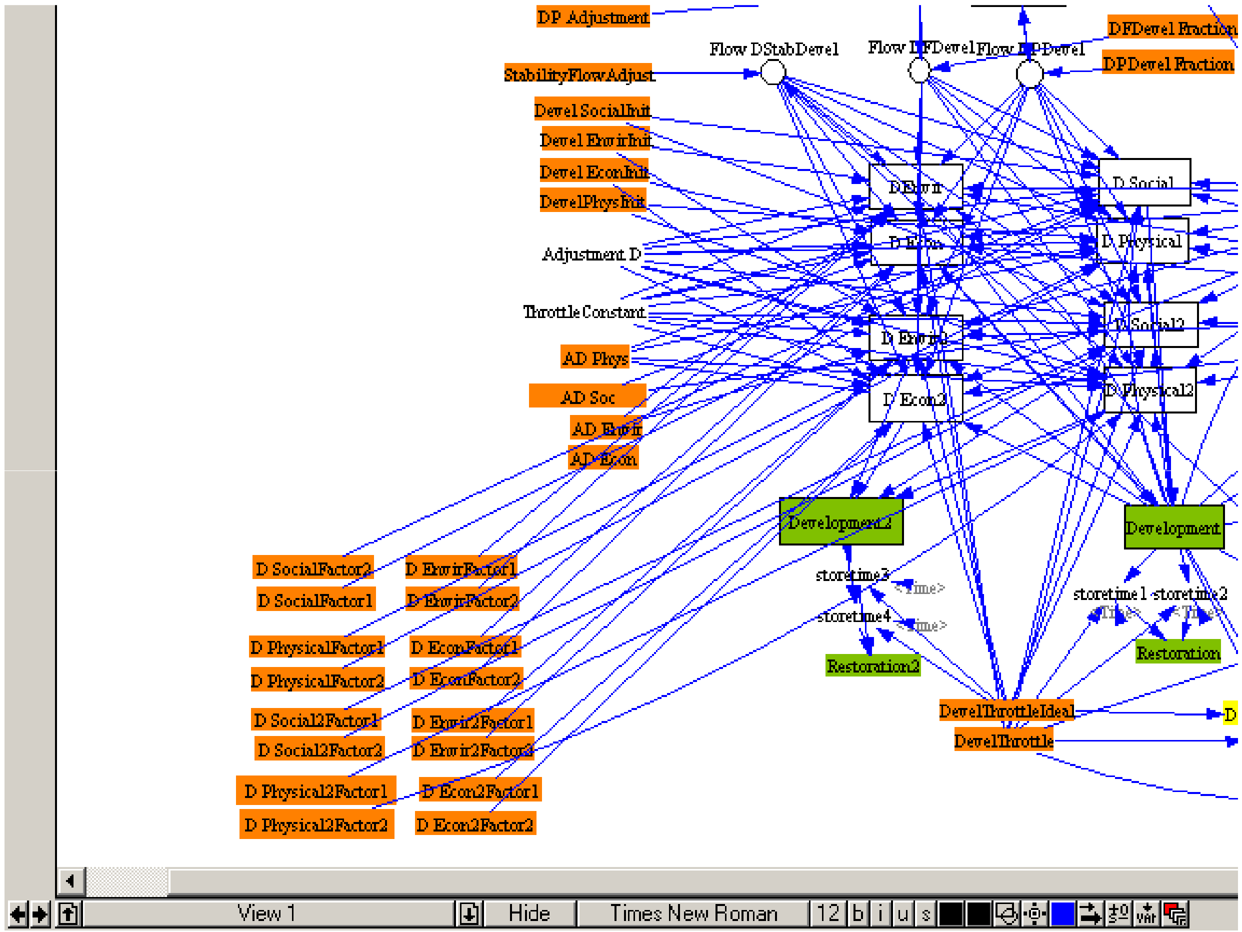


Figure 48: System Model Visual Diagram - BOTTOM LEFT

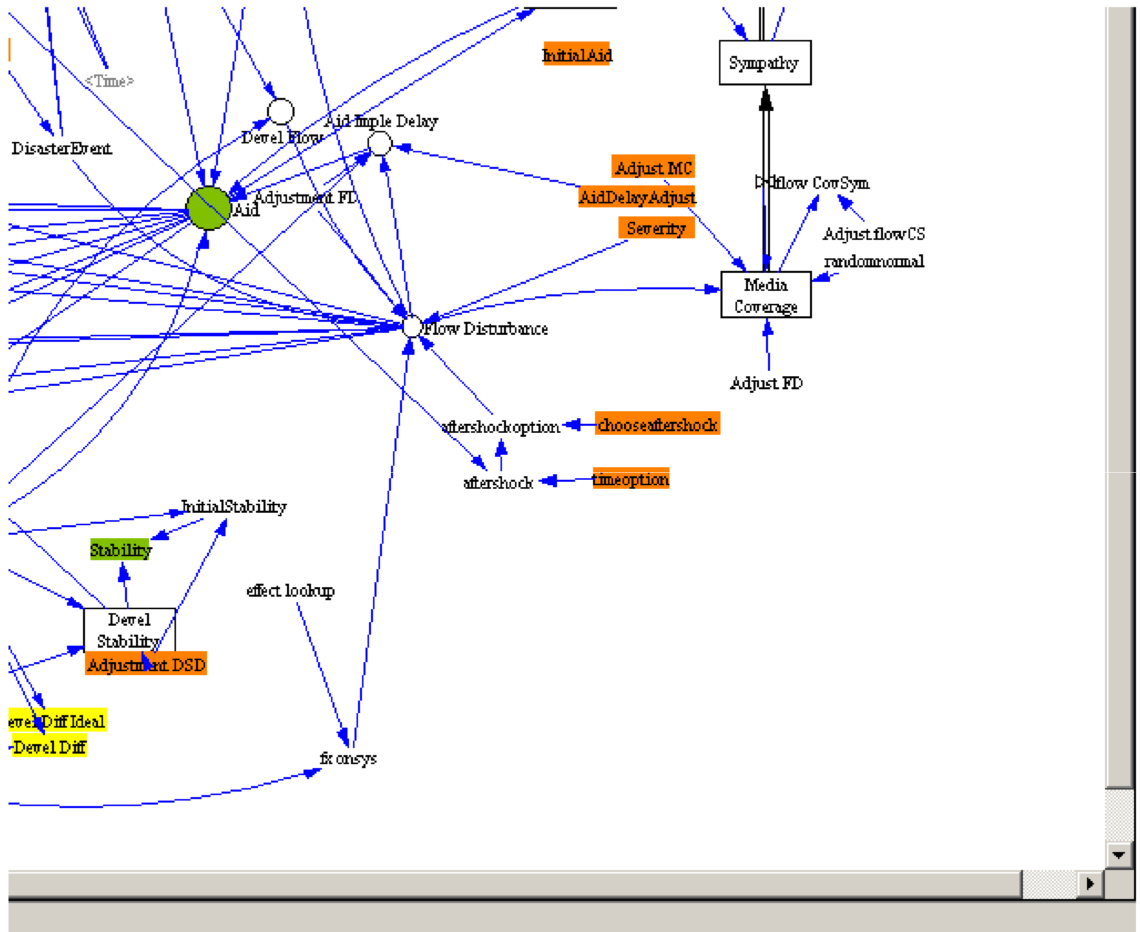


Figure 49: System Model Visual Diagram - BOTTOM RIGHT

Each of the input parameters for the VENSIM model may be decomposed to another level or have a group of data elements which provide the value for the parameter. The connections between the different data elements and the model parameters are shown in Figures 50-53.

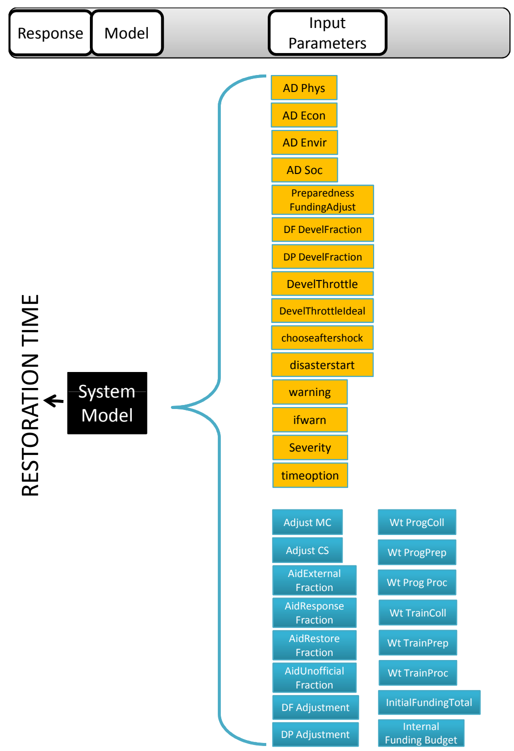


Figure 50: System Model Parameter decomposition and definition

7.4 Validation and Verification

7.4.1 Validation and Verification of SD Model

The development of the system dynamics model was done partially by quantifying some qualitative terms through the selection and implementation of different measures. However, the information generated by the system dynamics model simulations may not show the behavior of the true system. In order to be able to consider the generated information in the research assessment, validation and verification of the developed system dynamics model was needed.

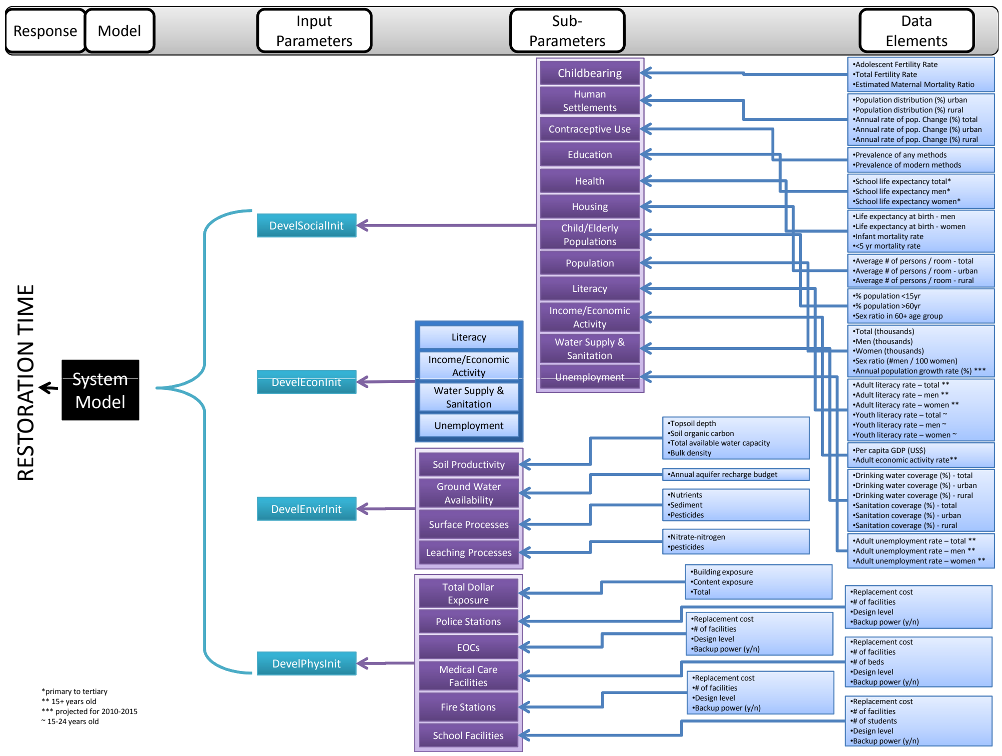


Figure 51: System Model Parameter decomposition and definition

7.4.1.1 Verification

Verification of the system would entail checking the functionality of the system. For the system dynamics model this included making sure that the dimensions and scale of the different parameters were reasonable. This check was still subjective since comparison with other models was not possible, but the selected software was able to conduct a units check on the parameters. Another verification check was for the model to be able to run simulations within the specified ranges. If the objective parameter values became too large in both positive and negative directions, the model ranges and parameter relationships were checked and adjusted. Another issue that came up was the convergence of the run within the selected run time. Some of the parameter combinations caused extremely high or extremely low objective parameter values and this was addressed in the model structure.

For the top level parameters, some general trends were expected based on the available literature and knowledge transferred through conferences and other expertise inputs.

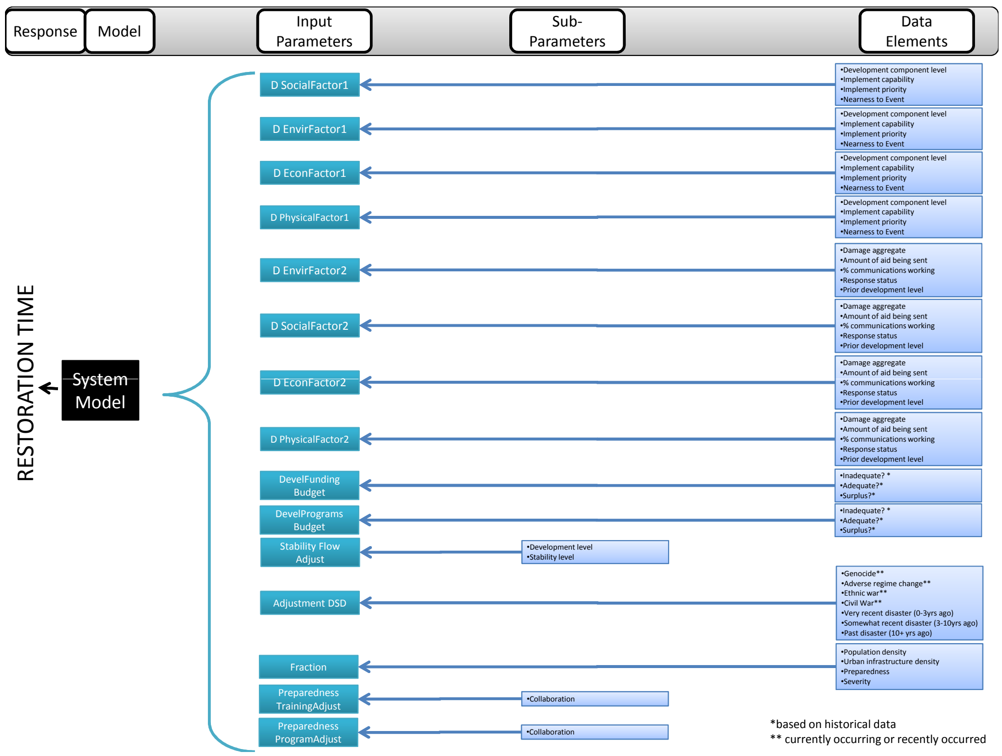


Figure 52: System Model Parameter decomposition and definition

Development Level The development level of the community, which was included as one of the higher level parameters within the developed system, is shown in Figure 54 over the time period for 3650 days, or approximately ten years. However, because the disaster is specified to occur when the Time value is 100 which is very early on in the simulation, it is difficult to see what the trend looks like as the disaster is happening and also immediately afterward. This is shown in Figure 55. The level drops as the disaster occurs, but as the aid is received and implemented (both external and internal) development level begins to increase again. The speed of the increase depends on the ability of the community to receive and implement aid, as well as some of the initial conditions. The second visible drop of development is the value of the parameter when the aftershock is included in the model. The value for the development level is initialized based on various data elements which capture the current state of development of the community in several different areas.

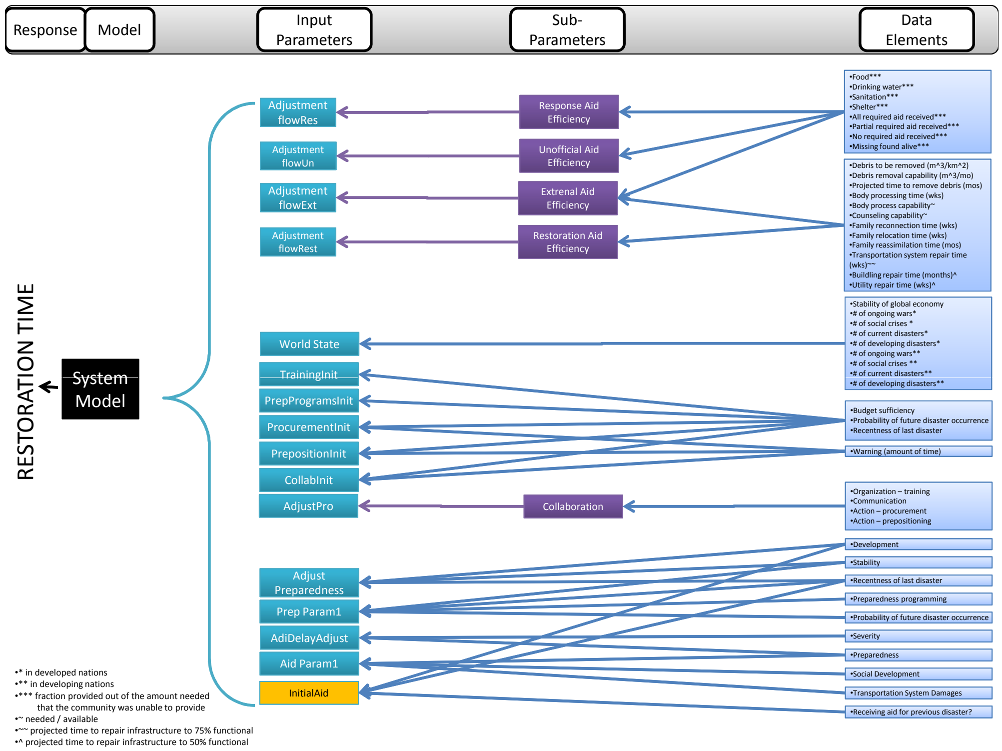


Figure 53: System Model Parameter decomposition and definition

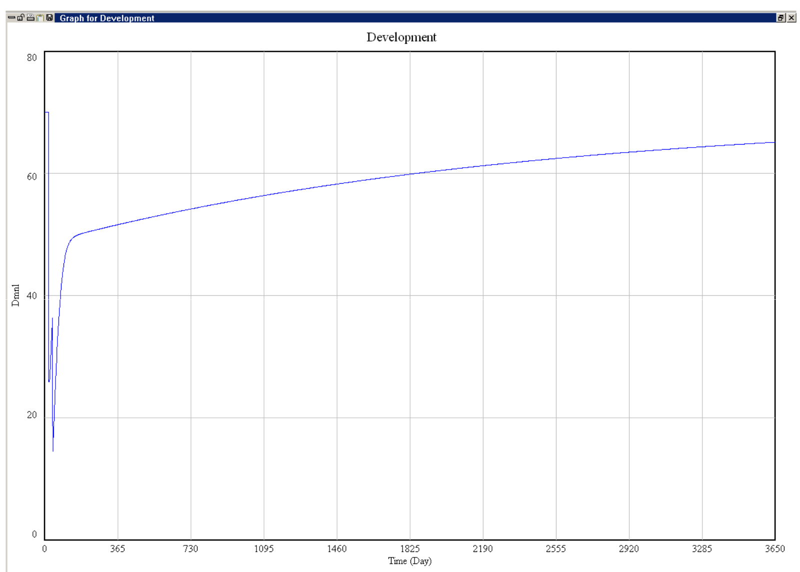


Figure 54: Trend of Development Level over ten years in SD Model

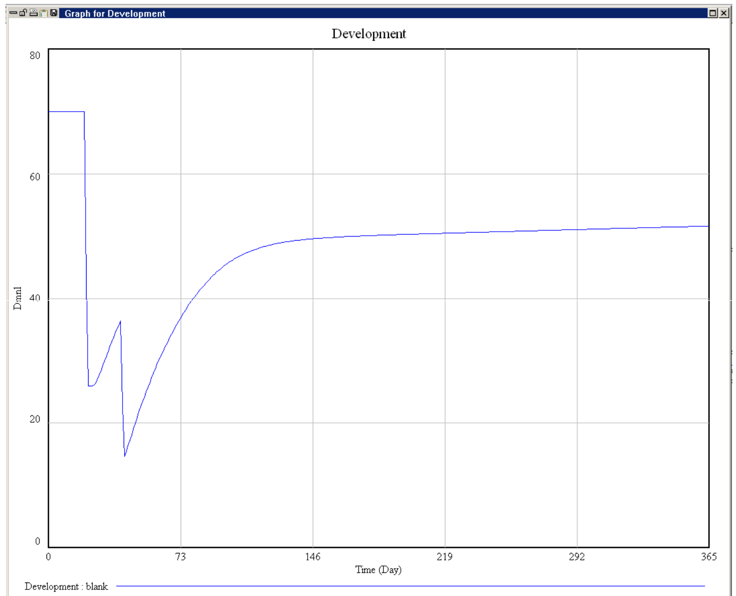


Figure 55: Trend of Development Level over time in SD Model

The earthquake event was selected without the aftershock for the methodology application. The Development trend for the methodology application is shown in Figure 56.

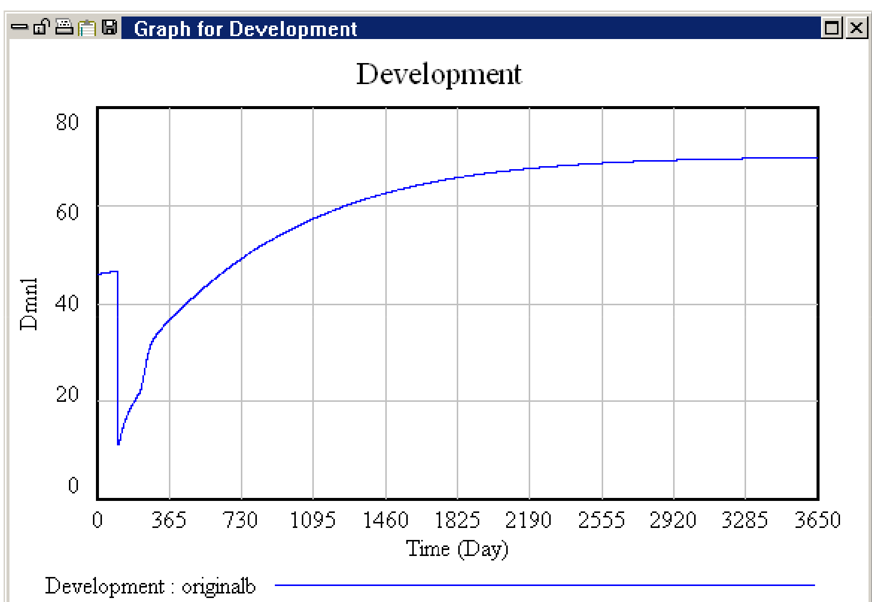


Figure 56: Trend of Development Level over time in SD Model (Application)

Media Response Figure 57 shows the model's amount of media coverage. The two spikes are the initial disaster and the secondary disaster occurrence. The magnitude of the first spike does not necessarily depend on the magnitude of the event. That relationship may be an item for further research. The developed model values over time follow a similar trend as the trend for the two disasters where data was collected regarding posted media coverage of the event.

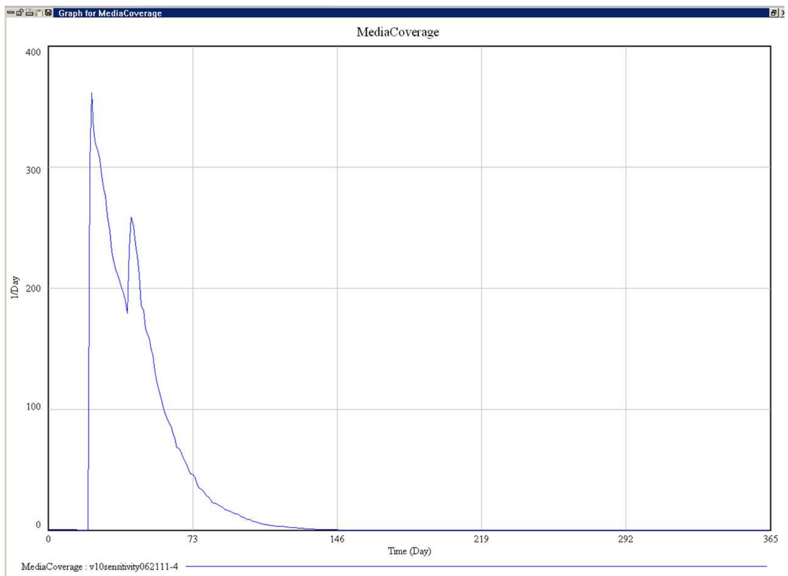


Figure 57: Trend of Media Coverage over time in SD Model

The trend for the model, which is the trend for the methodology application with the earthquake event and no aftershock, is shown in Figure 58. The amount of coverage spikes as the disaster occurs, then drops in the days following the disaster.

Disaster Disturbance To simulate the occurrence of a disaster, a timed pulse was added to the model. A second optional pulse was also enabled if an aftershock was to be included after the first earthquake. If representing other types of disasters, the aftershock might be a secondary event which occurs. Figure 59 shows the value of the pulse and included secondary pulse.

When using the pulse, since the severity and magnitude of the event will differ in measurement parameters among different disasters, a general severity range should be specified

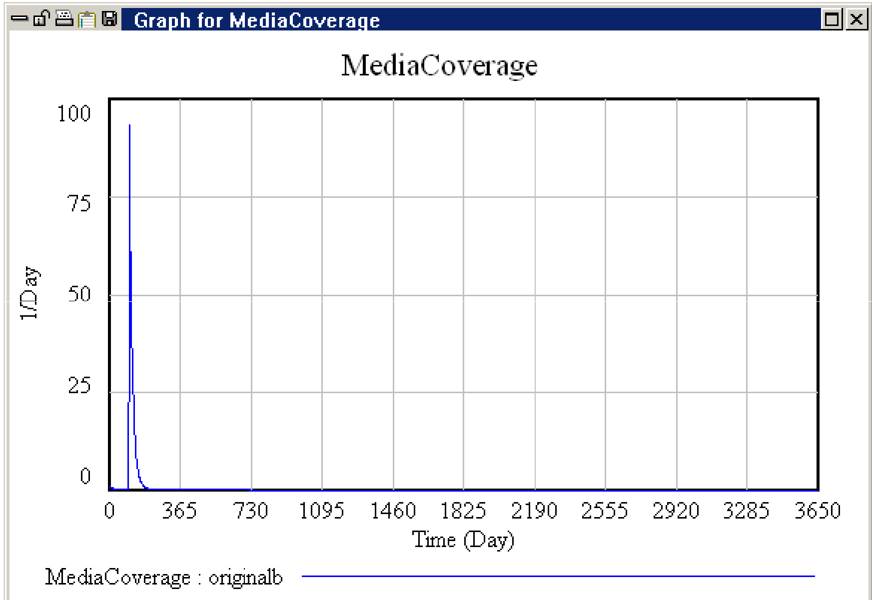


Figure 58: Trend of Media Coverage over time in SD Model

if possible. Historically, there had been several 8 MMS or greater earthquakes in the New Madrid Seismic Zone in the late 1800s. It is sometimes difficult to set parameter values representative of different severity events, since it should not be set to the maximum allowable for the system. If this is the case, an occurrence of a disaster with a greater magnitude may happen or a planning scenario may require it to be set above the maximum value in the model, and allowance for that would not have been included in the planning.

The trend for the model, which is the trend for the methodology application with the earthquake event and no aftershock, is shown in Figure 60.

Aid The amount of aid represented by the Aid parameter is the aid which is being received into the region and implemented. In the model, it is based on the media coverage of the event as well as the sympathy generated, global stability, and the internal stability of aiding or developed nations. The values over time can be seen in Figure 61, and the large spike of aid occurs just after the disaster occurs. The aid value does drop just before the spike, which means the values drop just as the disaster occurs. This is a drop in aid implementation,

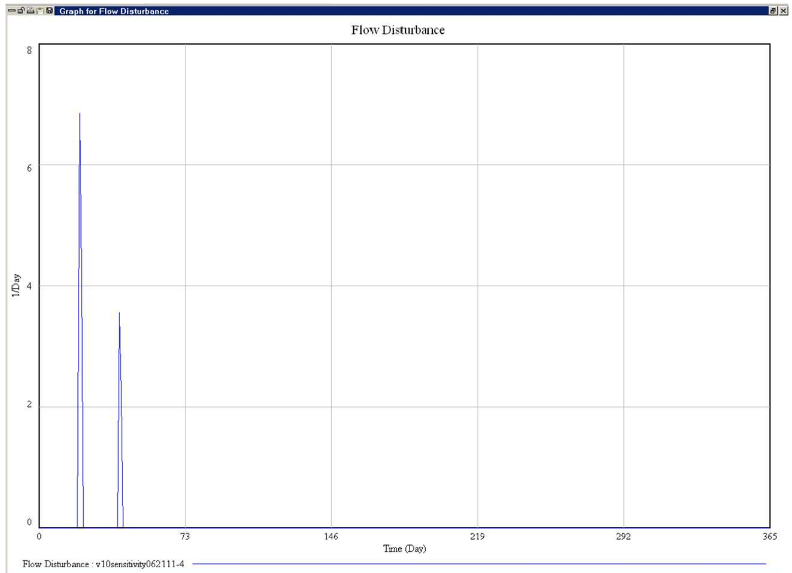


Figure 59: Trend of Disaster Event (Flow Disturbance) over time in SD Model

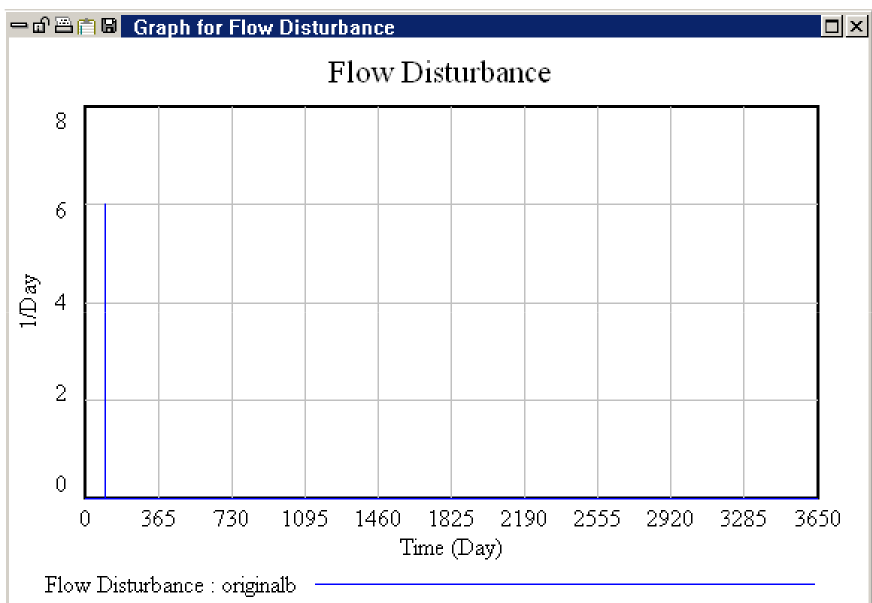


Figure 60: Trend of Disaster Event (Flow Disturbance) over time in SD Model for Methodology Application

from the amount of aid that a community may have already been receiving prior to the disaster. During the disaster occurrence the aid is assumed to be indispensable and unable to be implemented.

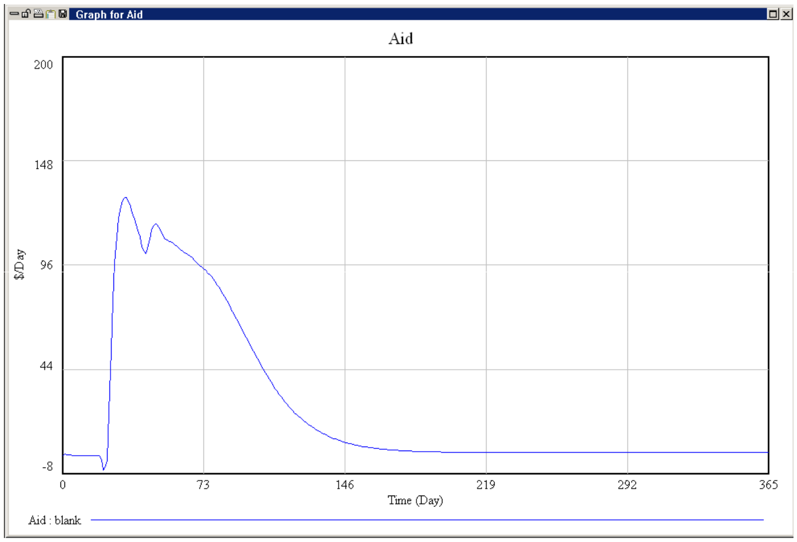


Figure 61: Trend of Aid Level over time in SD Model

The trend for the model, which is the trend for the methodology application with the earthquake event and no aftershock, is shown in Figure 62.

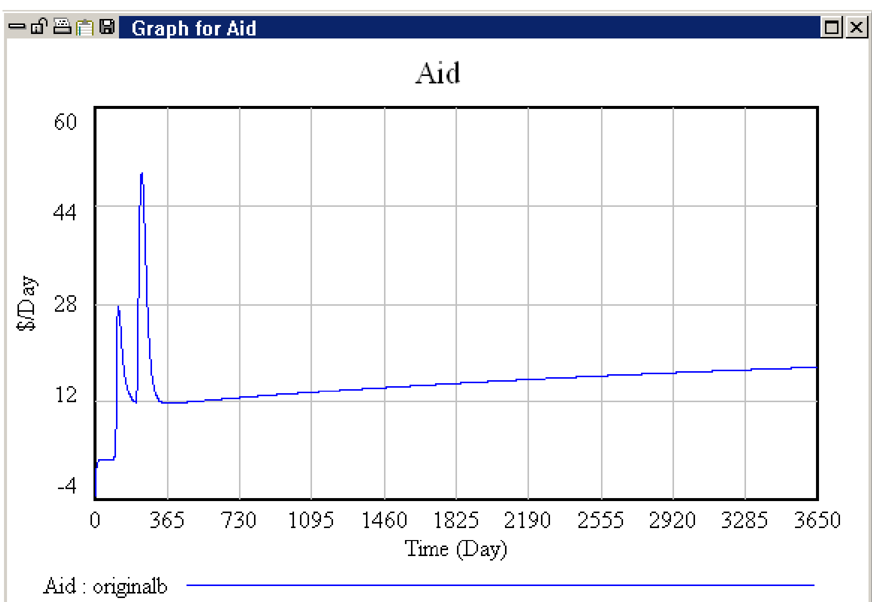


Figure 62: Trend of Aid over time in SD Model for Methodology Application

7.4.1.2 Validation

Difficulty in conducting validation within the field because much of the parameter values would depend on available data. The validation of the system would entail making sure that the model behaved like a physical system (or community) would as it went through the restoration process. However, because there are currently no systems which currently conduct simulations over the time and measures used in this research, and because time cannot be compressed in order for different parameters to be adjusted on a physical community, the value trends of the different parameters must be validated through other methods.

Validation of models with non-traditional uncertainty is discussed by Stults in his Ph.D. dissertation [147]. Some of the possible validation methods are:

- Comparing to physical test data (case studies)
- Using highest available fidelity data
- Quantify uncertainty via probabilistic approach
- Include parameter and model uncertainty via evidence theory approach

The developed model contained both parameter uncertainty and model uncertainty. Parameter uncertainty was included due to not knowing the value of some parameters in the model. Model uncertainty was included due to not having some physical data or available fidelity data with which to calibrate and validate the model.

The Parameter uncertainty was reduced by gathering as much accurate data values as possible. This was a lengthy process due to the number of different data values needed and also the dispersed nature of the different values. If the data was unavailable, it was either omitted or an estimate was made. The assumption is that community experts, once involved with such a project, will have the resources to procure those values.

The parameter trends can be seen through observation of past disasters and available literature. However, the literature and historical disasters address trends for a vast group of different types of communities and disasters, in all many different time periods and circumstances. The general behavior of the trend may be seen, but specific scaling and values may not be available for the community of interest.

The uncertainty in the developed model relationships was qualitatively addressed by basing relationship development on available literature, but there were still relationships within the model which had factors that needed calibration and numerical validation to show that the trends and behavior shown by the simulations were reasonable for the selected community.

If year-data is available for parameters in the model, that can be used to calculate surveyable parameters in the model. This will not work well if the model is more complex and contains more data elements than are available as year-data.

A relative comparison validation may be done with the objective parameters. Currently one objective parameter was selected for the model development, but other possible objective parameters which would enable comparative validation may be defined. This would enable assessing available data and changes in the data to selected tuning parameters. The tuning parameters are values that describe the behavior of model parameters through the simulation.

Other objective parameters may include simulation trend characteristics, such as the effect of disaster on development level by measuring the drop in development level before and after the disaster, or the change in the development trend as the response aid begins to turn to restoration aid and the rate of improvement in the development level decreases. Figure 63 shows examples of these measures. The inclusion of these objective parameters were not included in the system development but may easily be implemented in future system model development. This would enable the model trends to be compared to available data.

Simpson and Katirai mention qualitative validation as an option for multiple indicator validation, if the results of the model development are then continually validated through time testing of the model as different events occur. [140]

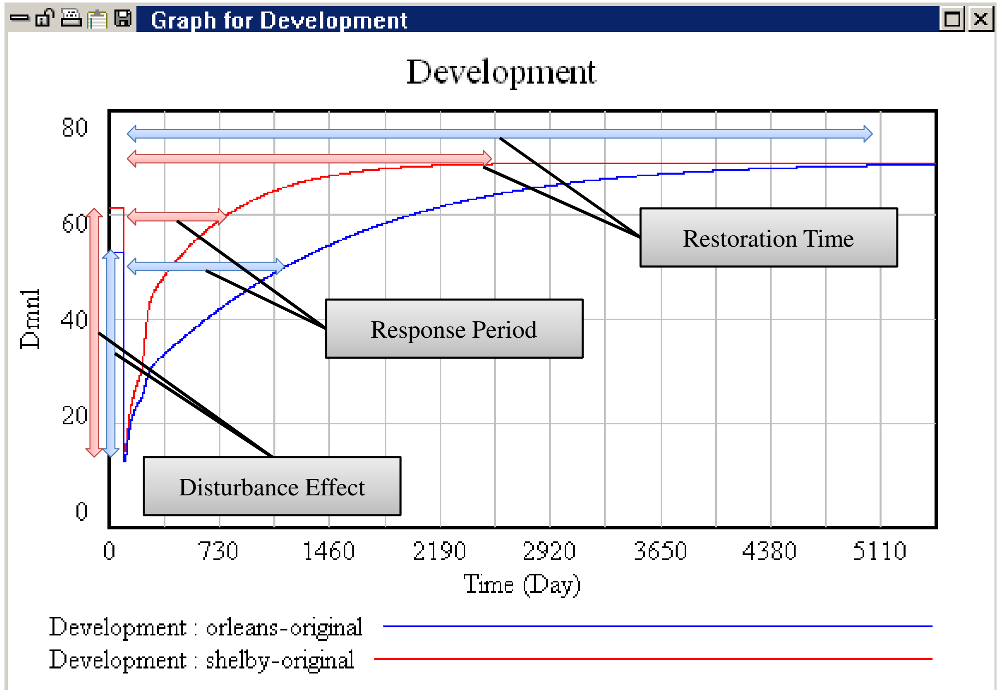


Figure 63: Sample Objective Parameters which Enable Comparison

7.5 Uncertainty and Variability

There are several aspects of uncertainty which are incorporated in the model. Much of the uncertainty comes from lack of prior knowledge about the behavior of community systems with different levels of preparedness, simply due to the fact that there have not been great efforts to measure or document the amount of preparedness existing and preparedness activities which are conducted. There have also been no great efforts to show the relationships between the different elements of preparedness and how they influence the resulting resiliency of the community through a lower restoration time than projected, etc.

Additionally, several parameters and aspects also are subject to a level of variability as well. For non-homogeneous regions, the demographic and infrastructural variability changes the characteristics of an area sometimes even from block to block. This may not significantly affect the disaster response capability on the whole for the community, but may change things at the local level where the demographic characteristics are significantly varied from the community-level statistical value.

The variables were separated into unchanging variables, variables containing uncertainty, and variables containing variability. The unchanging variables remain constant through the development of the regression model, and the uncertainty- and variability- parameters are regressed over their allowed ranges.

7.5.0.3 Variability

Variability ranges within a demographic came from statistical findings. The selected parameters with variabilities are:

- Initial Social Development Level
- Initial Economic Development Level
- Initial Environmental Development Level
- Initial Physical Development Level
- Stability Factor - based on past disasters
- (user input) Fraction of Aid Implementation to Social Development Level
- (user input) Fraction of Aid Implementation to Physical Development Level
- (user input) Fraction of Aid Implementation to Economic Development Level
- (user input) Fraction of Aid Implementation to Environmental Development Level
- (user input) Disaster Severity
- Initial Development Goal

The variability comes from the different statistical data sub-parameters which aggregate to provide values for each of those parameters. These are discussed in the Model Definition chapter.

7.5.1 Uncertainty

The uncertainty parameters were selected by the user but can be modified based on additional expert recommendations, updated data or more available parameters. The selected parameters with uncertainties are (variable name):

1. Ability of Social Development aid to be implemented by community
2. Ability of Economic Development aid to be implemented by community
3. Ability of Environmental Development aid to be implemented by community
4. Ability of Physical Development aid to be implemented by community
5. Fraction of development that is affected by the disaster
6. Initial amounts of preparedness training
7. Initial amounts of preparedness programs
8. Initial amounts of response supply procurement
9. Initial amounts of inter and intra-organization and community collaboration
10. Amount of collaboration which enables procurement after the disaster occurs.
11. Fraction of preparedness sum which contributes to the overall preparedness
12. The amount of overall preparedness measures which actually are implemented and affect the community after a disaster happens
13. Additional delays to aid distribution from community lack or preparedness / disaster severity
14. Fraction of distributed aid to donated aid or offered aid
15. Amount of aid a community may already be receiving at time= 0 if prior disasters have occurred and restoration has not completed
16. Fraction of received aid which is from official external sources
17. Fraction of received aid which is from unofficial external sources
18. Fraction of official aid (not including external) which is implemented during the response phase
19. Fraction of official aid (not including external) which is implemented during the restoration phase

20. Fraction of external official aid flow which is effectively utilized
21. Fraction of external unofficial aid which is effectively utilized
22. Fraction of internal official aid which is effectively utilized
23. Fraction of internal official aid which is effectively utilized

Without an understanding of the system behavior over the range of the variability and uncertainty defined above, or a capability of system exploration, response planning development would be much more difficult.

The developed system dynamics model was connected through some visual basic scripts to Microsoft Excel but in order to enable planners to explore more options, collecting that information would be too time consuming without added computation power. For a full exploration of the system, with ranges in each of the variables, the time required for complete exploration of different combinations of different values for each of the variables would be too great for the existing and available computational power.

Chapter 7 contains the discussion on which method was used to enable the provision of information about the behavior of the system.

7.5.2 Model Limitations

For some combinations of variables the restoration time is higher than the time limit set for the system dynamics model. This time limit was set so that all the system exploration simulations would be complete in a finite amount of time reasonable for the research. For low Development (DevelThrottle), and high severity situations, the case runs out of time and returns a zero for the restoration time.

Also for low initial development (DevelThrottle) and higher Severity, the Restoration time tends to be lower than it is in most of the other situations are. However, a lower developed community should have a higher restoration time. The validity of this model is lessened in the cases where the initial development level, represented in the system dynamics model by DevelThrottle, is extremely low. The inclusion of hypothetical or parametrized real communities will enable more reasonable values of the development level if based on data from the communities themselves, which was selected to be aggregated for the initial value.

The model is set up so that each community will rebuild itself and continue on to achieve a higher development level. While that achievement may take longer for some communities, for most of the runs the community was able to achieve this higher development level.

7.5.2.1 Initial Development Level or Goal (DevelThrottle)

Changing the DevelThrottle to more extreme values causes case failure with a low WorldState value. The DevelThrottle represents the level of development that the community is aiming to achieve, even from before the inclusion of development causes extreme changes in the restoration time, which is caused by a combined effect with high severity values for the disaster and lower world states. This makes developing the neural network more difficult, as the standard deviation from the neural network was too large for the defined ranges.

7.5.2.2 World State level

World State level at values toward the low end of the range couple with the DevelThrottle values in causing failed runs. For simulation purposes, keeping the World State level constant in the development of the neural network model reduces the number of cases which fail in the system dynamics model.

The response and restoration period does span several years, and in that time, other disasters may happen globally or there may be political situation changes. In order to enable the model development, the following assumptions are made:

a) the world state does not change during the time when aid is being distributed, or if the world state does change it will not significantly affect the external aid being received

b) the change of world state does not affect restoration time after the external aid is sent and received (this is reflected in the model)

CHAPTER VIII

ESCAAPE STEP 4: EXPLORATION

8.1 Sensitivity Analysis

In order to develop the system understanding and also provide data for neural network regression, a different range of values were enabled for sensitivity testing on parameters. Initially every input parameter was given a range, but in the screening results some of the parameters were not significant contributors to the restoration time. Additionally, having so many parameters with test ranges meant that the needed number of simulations would be higher. Having so many parameter values meant that more simulation was needed in order to provide enough information for the neural network and the program capabilities limit the number of runs which are allowable in the time which was available.

Some limitations also come from the design of the model. In designing, each relationship was developed as accurately as possible based on reasoning elements and available knowledge from literature, but developing such a model would greatly benefit from expert input at the development stages so that relationships could be more accurately developed.

Within the field and similar fields, many innovations have been done in the way of agent-based modeling of some of the response phase activities in a community. Integration of one of these such models might provide more insight into the immediately post-disaster phase, and enable some of those relationships within the system dynamics or higher level models to be understood more and refined.

While the actual sensitivity analysis itself was done rather smoothly, several issues came up before the right settings for the sensitivities was decided. Initially, the data elements for the variables had different uncertainties and variabilities associated with them depending on community and its demographic data. If variables were tested at a more extreme range of inputs, the developed SD model would be failed and would have no return at particular combinations of values. Also initially, the experiment simulated run time was much lower and many cases were needing longer than that for the community to be able to complete its restoration. The simulated run time was extended so that the number of un-restored community scenarios were left.

The initial ranges and variables were then set to the range of data elements if they were set to all high or all low. Over these ranges the model was more well-behaved and there were less than ten percent failed cases out of the whole experiment set, which ended up being 1,024 runs.

The settings for each run were generated from inside the system dynamics program (VENSIM). Each of the ranges were used as a uniform distribution. The results did not save the data from each time period but just the initial input values and final output values.

The total simulation "time", which had a unit of days, was increased from ten years, or 3650 days, to forty years, or 14,600 days. The number of days was kept rounded for simplicity. Initially too many cases were not being completed in their restoration to the ideal level because the simulation time was too short.

Figure 64 shows the parameter effect strength for the model parameters. The table of the sensitivity analysis data is included in Appendix C.7. The screening test revealed several single effect variables which were influential in the model, but it was difficult to tell how much the two-factor effects made up the influence. The nonlinearity of the relationships may exist and since many terms are interdependent, there are many higher order effects that must be tested. However, with so many variables it is impossible to test for orders higher than three parameters within a reasonable amount of time. Then a test was run for the system in a full-factorial setting (all of the factors multiplied together).

For the full-factorial test each variable was set to a low, medium, and high values. However, to run a 3-level full effect sensitivity run would take $1,879,048,192$ simulations, which at 211 runs per minute turns out to be a little over sixteen years to complete on one computer.[1] Additionally, using a three level test on variables in this case would not provide a good understanding of a complex and interdependent response system. The uniform variable with set ranges would be a better choice. (A future revision enabled a full-factorial

[1]Estimated age of computer: Six years

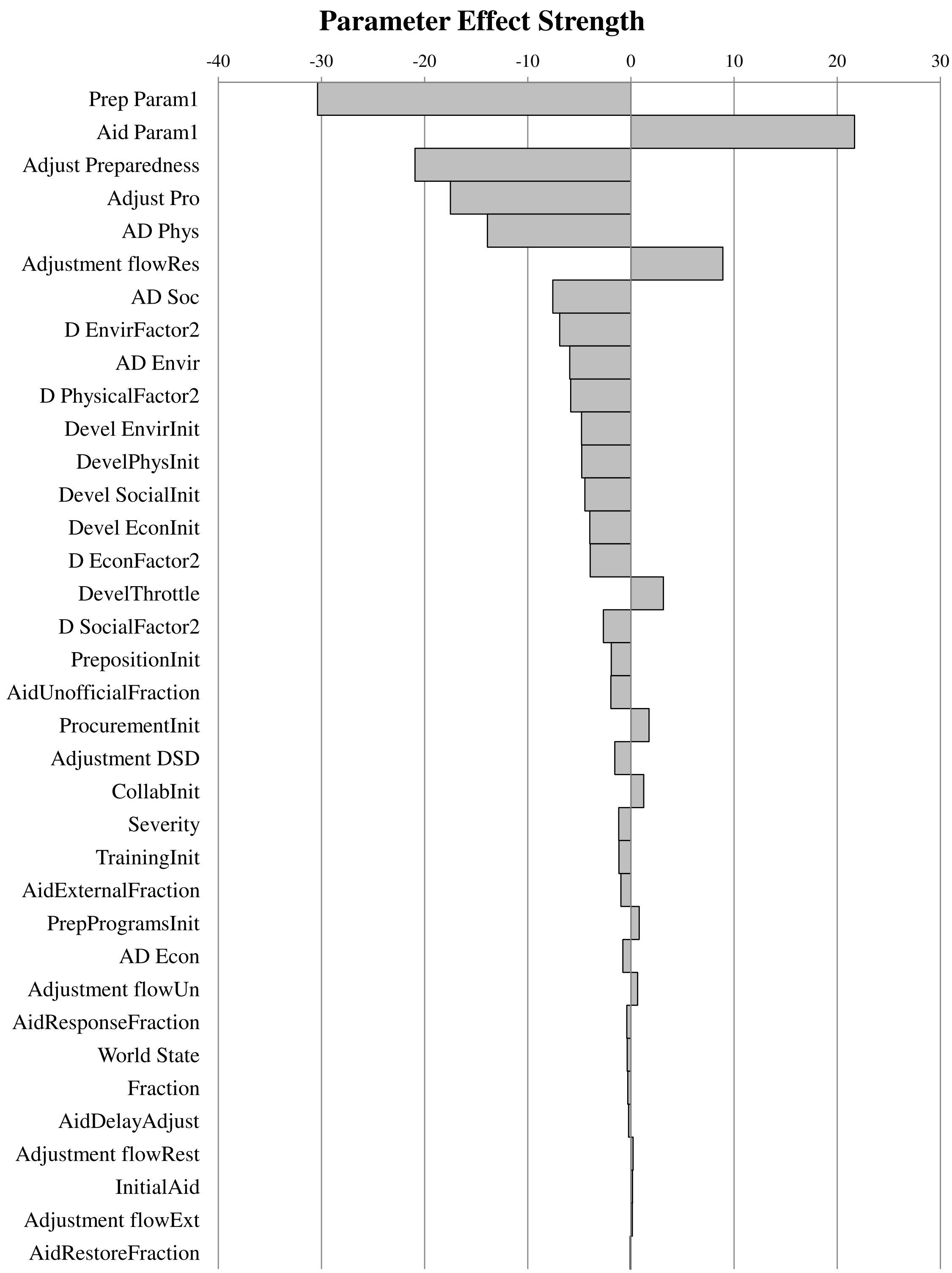


Figure 64: Effect Sensitivity for System Model Parameters

three level test to be run with fewer variables, and indeed the results were inconclusive.)

The possibility of using available cluster or supercomputer computational power existed but may not be available in all situations, so an alternate method was chosen to continue system exploration and develop the system understanding.

Based on the screening test, twenty-two different variables were significant in their effects on the response, which is Restoration Time. These twenty-two variables were:

1. Adjust Preparedness
2. Adjust Pro
3. Adjustment flowRes
4. Adjustment flowUn
5. Aid Param1
6. Aid DelayAdjust
7. AidResponseFraction
8. CollabInit
9. D EconFactor2
10. D EnvirFactor2
11. D PhysicalFactor2
12. D SocialFactor2
13. Devel EconInit
14. Devel EnvirInit
15. Devel SocialInit
16. DevelPhysInit
17. Fraction
18. InitialAid
19. Prep Param1
20. PrepositionInit
21. PrepProgramsInit
22. TrainingInit

An additional fourteen variables were also added. The components of the system subject to nonuniformity may be separated into two categories: ones that are non-uniform due to uncertainty from unknown behaviors and relationships or outcomes from situations, and ones that are non-uniform due to variability within the community demographics.

Table 38: Original grouping of variability sources

Sources of Variability

variable name	lower bound	upper bound
Adjustment DSD	0.257	1
DevelEconInit	0	0.25
DevelEnvirInit	0	0.25
DevelSocialInit	0	0.25
DevelPhysInit	0	0.25
WorldState	0	100

Table 39: Original grouping of uncertainty sources

Sources of Uncertainty

variable name	lower bound	upper bound	variable name	lower bound	upper bound
Adjust preparedness	0.126	1	D EconFactor2	0.26	0.9
Adjust Pro	0.1	1	D EnvirFactor2	0.26	0.9
Adjustment flowExt	0.0187	0.87	D PhysicalFactor2	0.26	0.9
Adjustment flowRes	0	0.8125	D SocialFactor2	0.26	0.9
Adjustment flowRest	0.0311	0.9083	Fraction	0.574	0.980
Adjustment flowUn	0	0.813	InitialAid	1	7.667
AidDelayAdjust	0	0.5	Prep Param1	0.0445	0.7442
AidExternalFraction	0	0.4	PrepositionInit	2.528	10
AidParam1	0.0667	0.6000	PrepProgramsInit	3.334	10
AidResponseFraction	0.1	0.5	ProcurementInit	2.528	10
AidRestoreFraction	0.1	0.5	AD Econ	0.05	1
AidUnofficialFraction	0	0.1	AD Envir	0.05	1
CollabInit	2.528	7.503	AD Phys	0.05	1
			AD Soc	0.05	1
			DevelThrottle	10	100
			Severity	0.2	1

Further system exploration showed that the system dynamics model in VENSIM was generating a significant amount of failed cases for combinations of low DevelThrottle, low WorldState, and high Severity.

Assumptions regarding these three variables were made in order to reduce the number of failed cases and enable greater amount of system exploration. First, the DevelThrottle, which is the "ideal goal" that the restoration time is based on, is assumed to be constant. Since there is no metric for levels of development, and additionally no standard has been set, the current value in the model (70 from a range of 0 to 100) is assumed to be the standard and Restoration Times are based on a community starting from not the standard and returning to the standard after the disaster and rebuilding phase has occurred.

Second, Worldstate, the variable which reflects the global stability at the time, was also assumed to be constant. For this experiment setup it was assumed to be 70, but can also be based on the data parameter values selected to comprise its value. It has a value of 47.8 if that option is selected.

Third, Severity, represents the disaster which occurs during the simulation. It is important to understand the behavior of a community and its response cycle for different severities of disaster. However, the value used, 0.7 in its assumed constancy, is meant to represent a severity level which for many communities would overwhelm the initial response resources and require external aid for that phase and the rebuilding and restoration phase. During the assessment some of the community descriptive parameters corresponded with restoration times of less than one year.

8.1.1 Simulation

Each of the developed parameters were grouped within their overarching aspects. The effect on restoration time was tested in one test, by random uniform distribution over each variable in a Latin Hypercube design of experiments. The Latin Hypercube is a good experiment design for understanding a design space. There were also tests done to develop the single and mixed effects of the variables.

Because selecting a community to examine gives the researcher a good starting place for selecting data values and ranges, instead of generalizing across all variables, several variables were set at constants or narrowed ranges in order to represent a specific community. This also reduces the amount of time spent on testing different parameter changes within a community.

The knowledge being offered through this research is not in the field of humanitarian logistics as far as community development and policy is concerned. The methodology being offered is for the purposes of enabling leaders and planners to further their endeavors in selecting effective development and possibly policy decisions which will enhance the restoration process for communities after disasters. For that reason, the selection of a specific community enables the proposed methodology to be illustrated for a specific example, instead of doing a very generalized example for a non-existent community.

8.2 Single Effects

Single effects were tested at 20 levels within the allowed range. All of the tests beyond the initial system space filling Latin Hypercube Design of Experiments were done with the same normalization settings. The untested variables were all held at the Shelby County data set value while the tested variable was tested over its allowed range.

8.2.0.1 AD Econ

The AD Econ parameter in the system model represents one of the factors which affects how much aid is implemented into the economic development aspect of the community. Figure 65 shows the single effect that the parameter has on the total restoration time. Although there is a slight change in the Restoration time based on the value of AD Econ, this factor by itself does not have a significant effect on the restoration time.

8.2.0.2 AD Envir

The AD Envir parameter in the system model represents one of the factors which affects how much aid is implemented into the environmental development aspect of the community. Figure 66 shows the single effect that the parameter has on the total restoration time. From the low to the high value the graph shows a slight effect, greater than that of AD Econ in the same scale display, where a greater allowance of aid will, according to the developed system

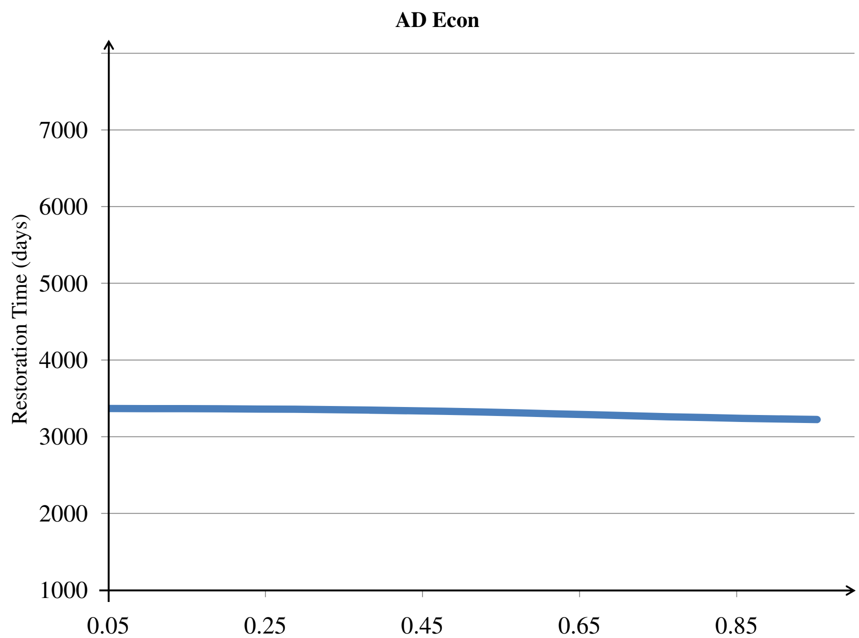


Figure 65: ADEcon single effect on Restoration time

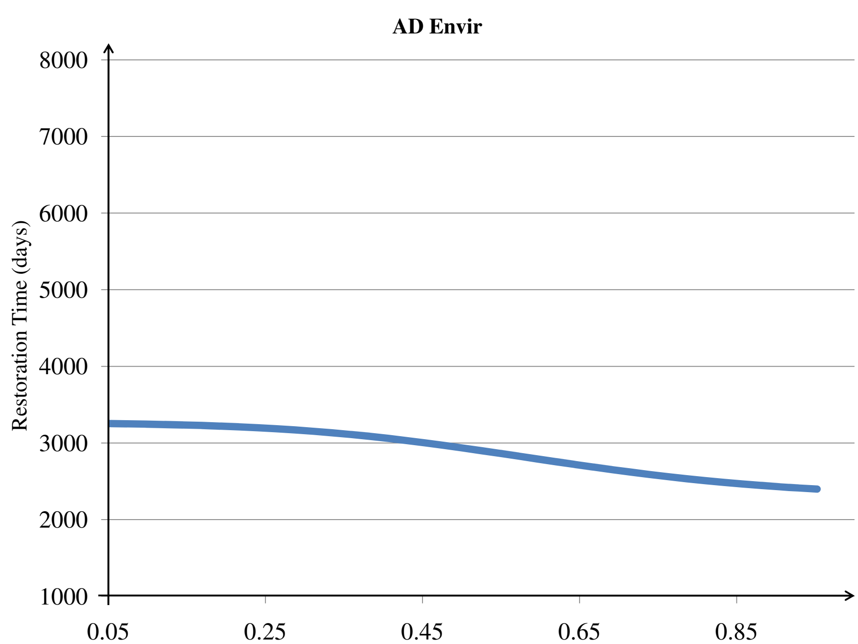


Figure 66: ADEnvir single effect on Restoration time

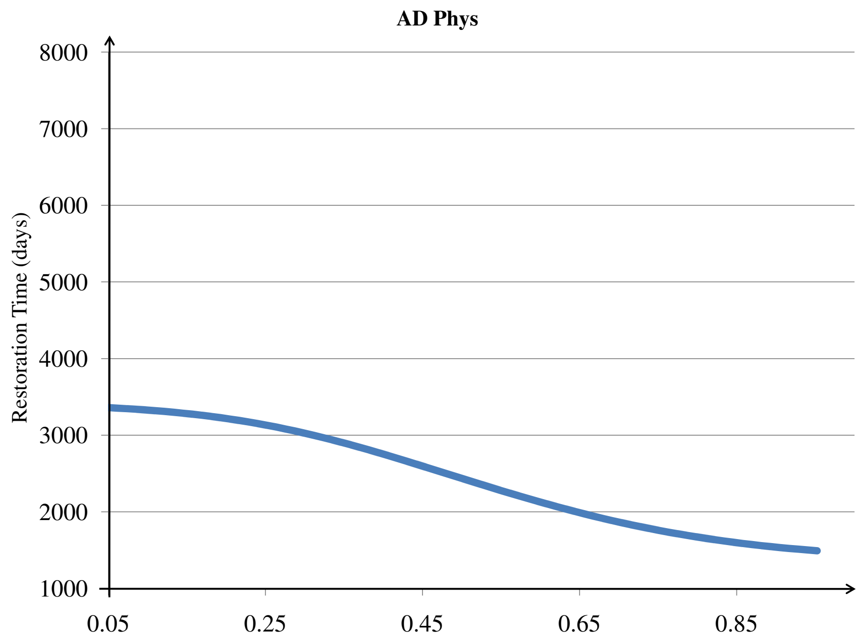


Figure 67: ADPhys single effect on Restoration time

model, decrease the amount of time (days) that the complete restoration would require.

Being able to more quickly and effectively implement aiding resources into the environmental aspect of the community might include activities such as, during immediate response, having a speedy system set up in which sandbags could be laid down quickly to protect an area prone to flooding (or other anti-flood technologies), so that other response and restoration resources can continue to function at the normal pace in that area and restore the community more quickly. The aid referred to always includes both internal and external aid, which may also be both officially sanctioned and unofficially donated or distributed resources.

8.2.0.3 AD Phys

The AD Phys parameter in the system model represents one of the factors which affects how much aid is implemented into the physical development aspect of the community. Figure 67 shows the single effect that the parameter has on the total restoration time. Similar to the

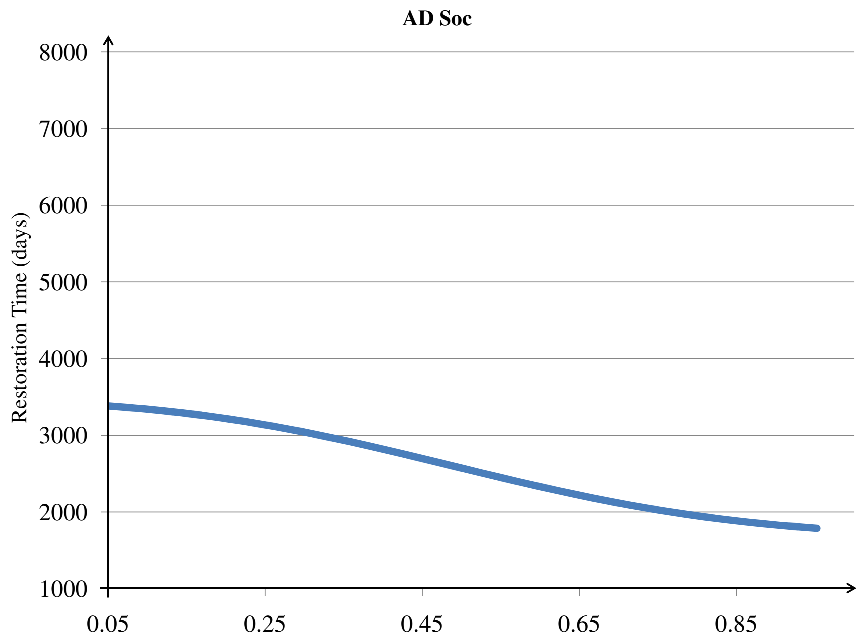


Figure 68: ADSoc single effect on Restoration time

environmental aid implementation capability there is a slight effect, although the AD Phys effect on Restoration Time is greater than AD Envir. The effect still holds a somewhat reversed 'S' shaped curve. The values for this set of 'AD' prefixed parameters are set by the user. With time, more information may be added to the model to refine the relationship.

8.2.0.4 AD Soc

The AD Soc parameter in the system model represents one of the factors which affects how much aid is implemented into the social development aspect of the community. Figure 68 shows the single effect that the parameter has on the total restoration time. The effect is very similar to that of AD Phys but at the upper limit does not have as much of an effect as AD Phys. Again, better knowledge about how aid is implemented into the social development aspect of a community would improve the developed model relationships as well as the behavior of the system (Restoration time) when the value of AD Soc changes.

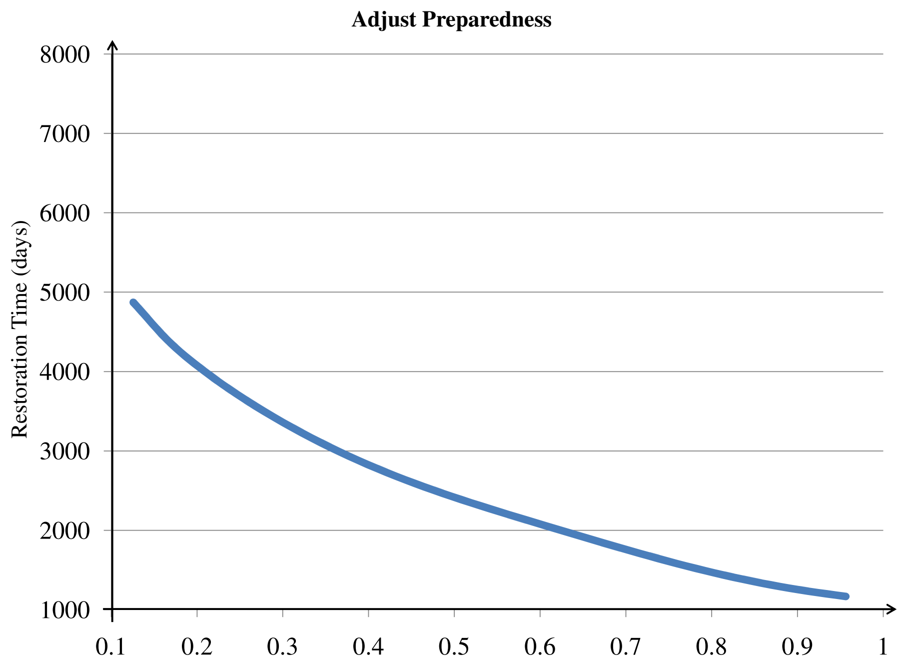


Figure 69: AdjustPreparedness single effect on Restoration time

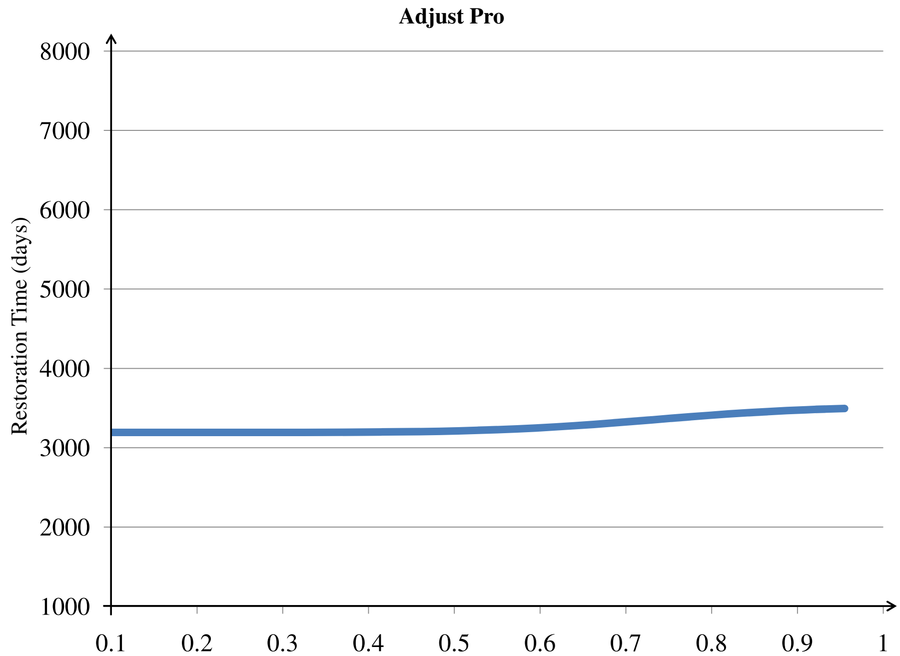


Figure 70: AdjustPro single effect on Restoration time

8.2.0.5 Adjust Preparedness

The Adjust Preparedness parameter in the system model represents how much of the preparedness components contribute to the overall preparedness level for a community. Figure 69 shows the single effect that the parameter has on the total restoration time. This chart shows that as the value of Adjust Preparedness goes to one, the Restoration time is reduced. The relationship does not seem to be completely linear from this chart but seems to follow more of an inverse x curve.

8.2.0.6 Adjust Pro

The Adjust Pro parameter in the system model represents a fraction of the collaboration that occurs after a disaster occurs, which represents how much of the collaboration may contribute toward how much post-disaster resources are procured. Because this relationship is not entirely understood, it was assumed that the collaboration between responding organizations are all helping to increase the amount of resources procured for the disaster

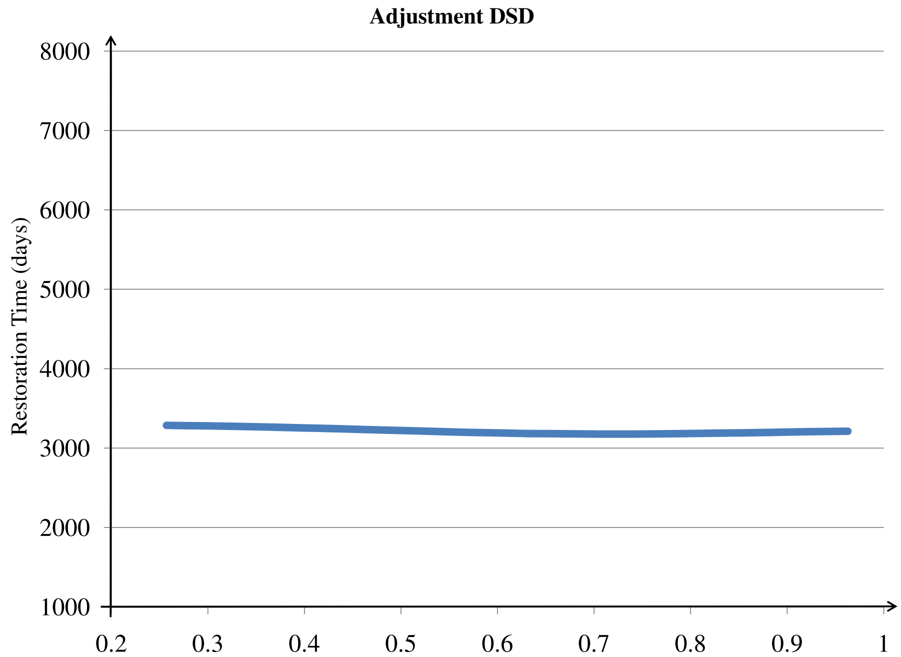


Figure 71: AdjustmentDSD single effect on Restoration time

from the preparedness perspective.

Figure 70 shows the single effect that the parameter has on the total restoration time. For the values in the upper range of Adjust Pro, the Restoration time actually seems to increase. The change is slight and may not be significant, or may be due to the model development (which may be improved if better information is implemented into the model). The change may also be due to higher amounts of collaborative procurement actually hindering the effectiveness of the resource procurement process.

8.2.0.7 Adjustment DSD

The Adjustment DSD parameter in the system model is a control parameter which adjusts the stability effect of the development level. The stability effect uses the development level compared against a standard or goal development level so that the direction of improvement is always back towards the standard (goal). This parameter is a component of the four different development aspects in the model and is influential in the growth (or decline)

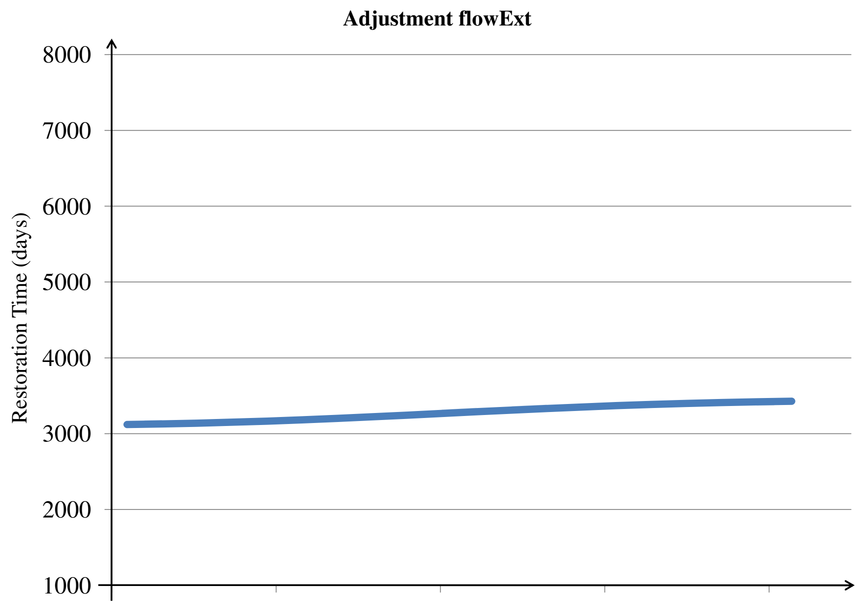


Figure 72: AdjustmentflowExt single effect on Restoration time

rates of the different developmental aspects.

Figure 71 shows the single effect that the parameter has on the total restoration time. From the way the model is currently built, Adjustment DSD does not have a significant amount of influence on the Restoration Time output.

8.2.0.8 Adjustment flowExt

The Adjustment flowExt parameter in the system model represents the fraction of external aid which is actually received into the community needing or requesting aid. Figure 72 shows the single effect that the parameter has on the total restoration time. For the higher bounds of the parameter the restoration time actually increases but the effect is very slight. There may be a resource cost associated with receiving larger amounts of aid but it is not significant.

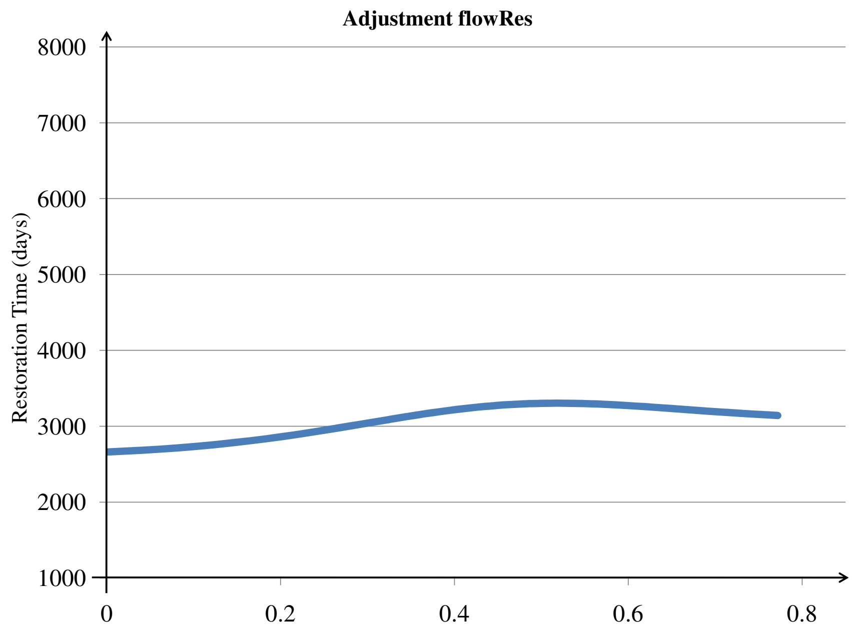


Figure 73: AdjustmentflowRes single effect on Restoration time

8.2.0.9 Adjustment flowRes

The Adjustment flowRes parameter in the system model represents the fraction of response aid which is actually received into the community needing or requesting aid. Figure 73 shows the single effect that the parameter has on the total restoration time. The general overall trend is an increase in response time, although the behavior for this variable seems to not follow the idea that more aid coming from external sources would have a decreasing effect on the restoration time. From a logical point of view if the community cannot handle that amount of aid coming from external sources it may increase the restoration time.

8.2.0.10 Adjustment flowRest

The Adjustment flowRest parameter in the system model represents the fraction of aid that has come from official channels within the national restoration process. For a general purpose it represents the restoration aid coming from the next highest governing body or the highest governing body over the area which also includes other areas. This aid comes

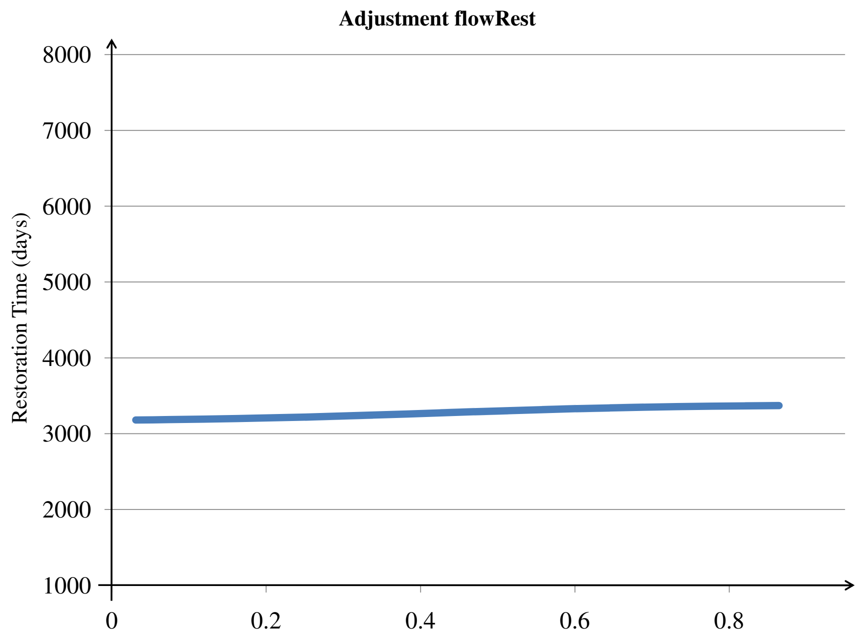


Figure 74: AdjustmentflowRest single effect on Restoration time

through official receiving and distribution channels. Figure 74 shows the single effect that the parameter has on the total restoration time. Figure 74 shows that only a slight increase in the Restoration Time comes as the percentage of aid increases. Again this may be due to the model development, and may perhaps even be considered not terribly significant. The relationship could be improved if more information or expertise were available. It may also reflect what was stated earlier, that if a community is unable to handle receiving high amounts of aid, this may increase the restoration time if too much aid is pushed into the area at once.

8.2.0.11 Adjustment flowUn

The Adjustment flowUn parameter in the system model represents the fraction of the unofficial aid which is received by the receiving community. Unofficial Aid includes donated resources which do not go through official receiving and distribution channels. Often the amount of aid which is brought into an area in this way is mostly undocumented and the

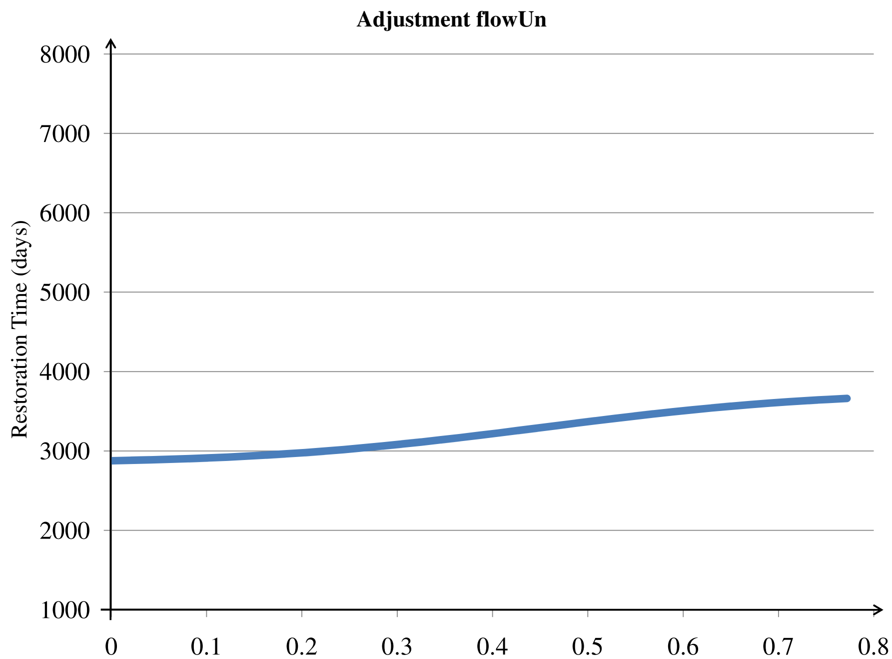


Figure 75: AdjustmentflowUn single effect on Restoration time

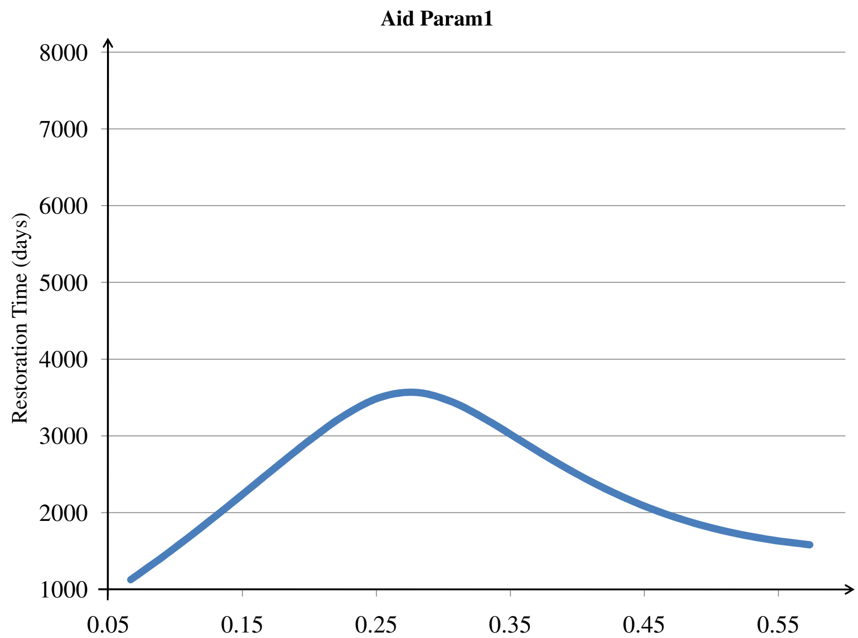


Figure 76: AidParam1 single effect on Restoration time

number must be estimated. Particularly for island nations where governments may be distrusting of any international aid organizations and non local governments to bring in aid, unofficial aid comprises a larger part of the total aid to areas in need after a disaster in those cases.

Figure 75 shows the single effect that the parameter has on the total restoration time. Adjustment flowUn has a slight but not insignificant effect on the Restoration time. The higher values of the parameter also seem to increase the restoration time by just under one thousand days from the low to high boundaries of the parameter. An increase in the restoration time with the increase in the parameter may be representative of the increase resources needed to organize and disperse unofficial aid, or it could be a cause from unofficial aid which is detrimental to the overall restoration because it is unplanned for and cannot be particularly predicted.

8.2.0.12 Aid Param1

The Aid Param1 parameter in the system model represents the fraction of the aid which actually is sent to the area and implemented. The Aid Param1 deals with the official and unofficial aid, but this term does not include other aid types which are implemented, such as aid set up during the preparedness phase and a term which includes the development level. The development term assumes that the development level also helps in a community being able to receive and implement aid. Figure 76 shows the single effect that the parameter has on the total restoration time. For the lower half of the range increasing the fraction of sent aid actually increases the restoration time but when Aid Param1 is greater than 0.27, the effect of the parameter reduces the Restoration time. This may be due to the cost associated with developing the response infrastructure. If those things have been done, the restoration process will go more smoothly and this is shown by the decrease in restoration time for values above the 0.27 threshold.hold.

8.2.0.13 AidDelayAdjust

The AidDelayAdjust parameter in the system model represents the delay associated with implementing aid after a disaster occurs. In the model it is a scale that affects how much of a delay would occur with aid delivery, based on the severity of the disaster. Figure 77 shows the single effect that the parameter has on the total restoration time. There is not a strong relationship with the single AidDelayAdjust factor but for a higher factor value, the restoration time increases. A mixed effect with Severity would have a more significant impact on the restoration time, if Severity were to be included in the surrogate model development for system exploration. A higher delay factor would increase delay of aid to the community, which may worsen some of the initial effects of the disaster, increasing the restoration time.

8.2.0.14 AidExternalFraction

The AidExternalFraction parameter in the system model represents the fraction of the aid which is being sent to the community that comes from entities external to the governance

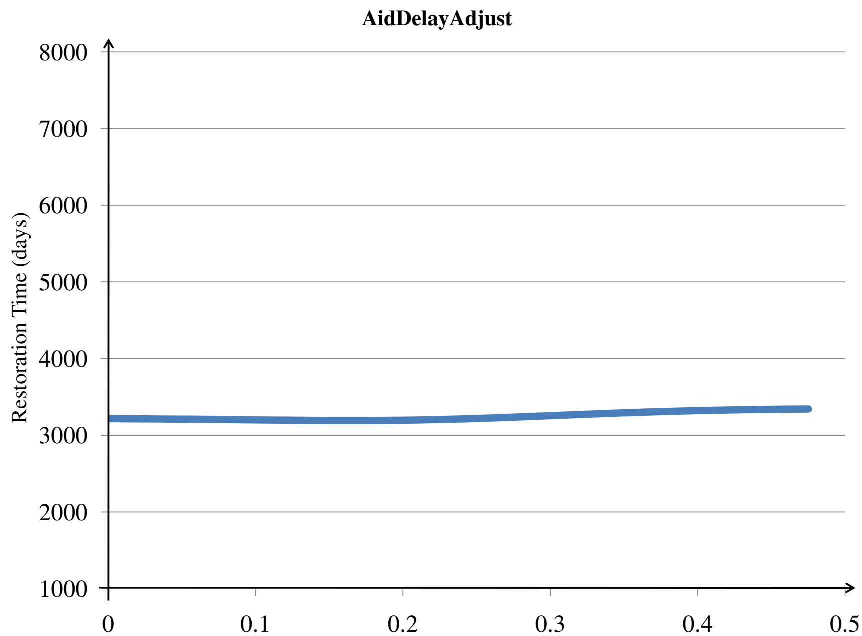


Figure 77: AidDelayAdjust single effect on Restoration time

of the community of interest. These entities may include governments, inter-governmental organizations, international aid organizations, and other non-profit organizations. These groups are assumed to have coordinated with the community's authorities and aid coming from them is considered to have come through official channels (Official Aid). Figure 78 shows the single effect that the parameter has on the total restoration time. The effect shows that for a greater fraction of aid coming from outside sources, a community will have a longer restoration time. The effect is very slight. This may mean that more precise data is needed to better define this relationship. It may also mean that a greater fraction of external aid may occur from the external groups to help a community which is less capable of restoration and more devastated by a disaster occurrence. If that is the case there will be a longer restoration time.

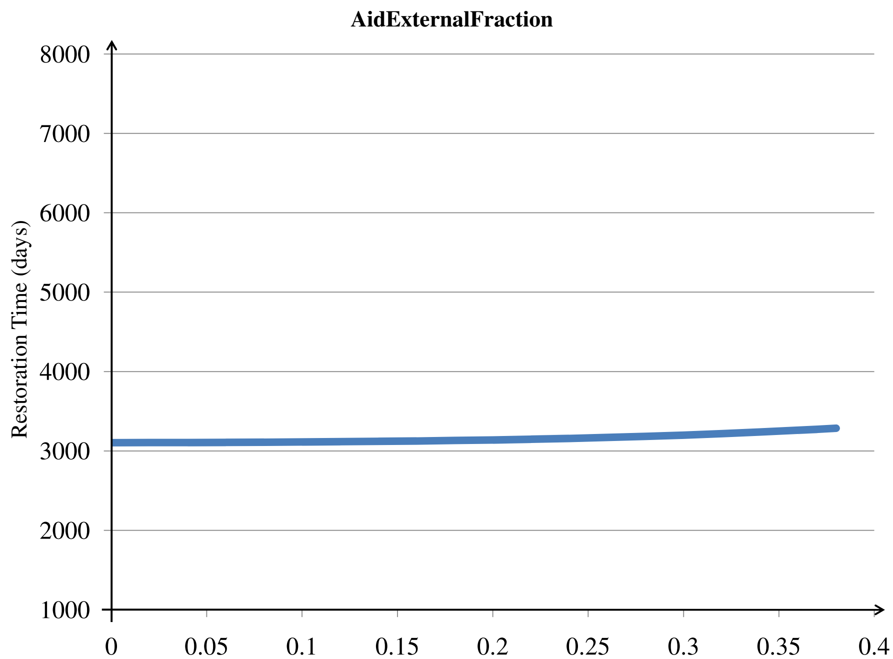


Figure 78: AidExternalFraction single effect on Restoration time

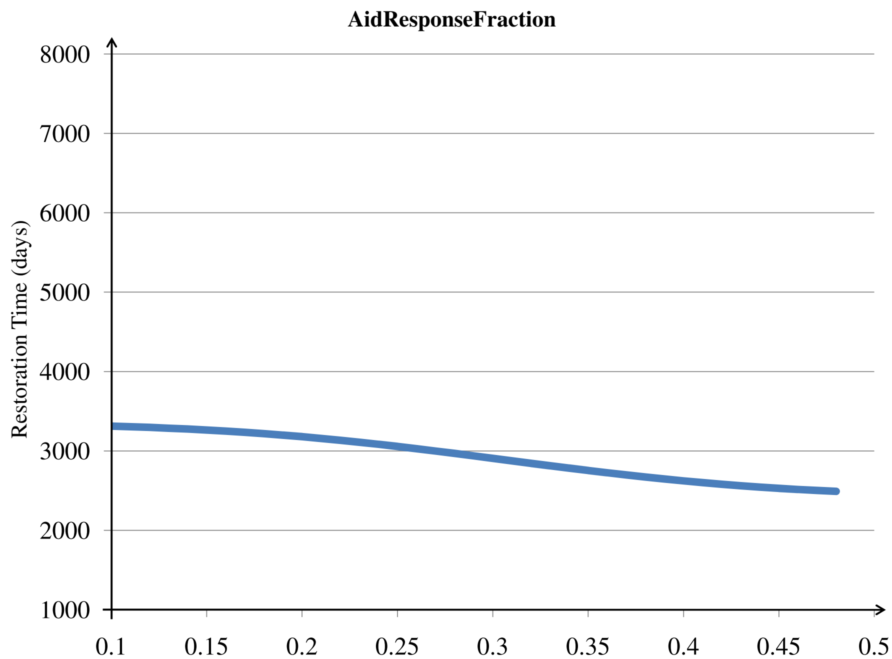


Figure 79: AidResponseFraction single effect on Restoration time

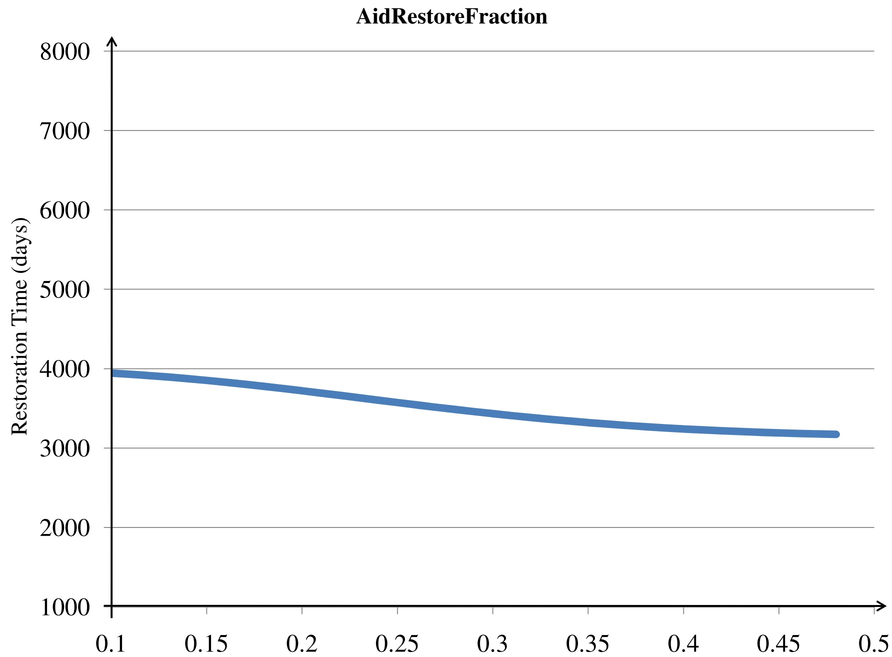


Figure 80: AidRestoreFraction single effect on Restoration time

8.2.0.15 AidResponseFraction

The AidResponseFraction parameter in the system model represents the fraction of aid being sent to the community which is used during the response phase and comes from official channels (Official Aid). This aid includes aid coming from the government under which the community of interest resides, and external sources which have sent aid officially and the aid has been officially received. This aid is implemented in the first few days to the first week or two after the disaster has occurred. In most circumstances this type of aid is primarily emergency and critical medical care, food, water, and shelter for displaced persons, and primary utility repair activities. Figure 79 shows the single effect that the parameter has on the total restoration time. As the amount of response increases, the restoration time decreases. The effect is not insignificant, but as with most of the variables, may be included with some other mixed effects.

8.2.0.16 AidRestoreFraction

The AidRestoreFraction parameter in the system model represents the fraction of aid being sent to the community which is used during the restoration phase and comes from official channels. This includes aid directed toward such activities such as rebuilding of transportation and urban infrastructure, longer term relocation or temporary housing solutions, environmental restoration activities, and economic restoration. Figure 80 shows the single effect that the parameter has on the total restoration time. The effect is not insignificant, and similar to the AidResponseFraction effect helps to decrease the restoration time as more restoration aid is sent to the community. The fraction includes all official aid which goes toward response, including external aid. However for the most part external aid is used mostly in response situations, and the community and its governing body takes responsibility for more during the restoration phase.

8.2.0.17 AidUnofficialFraction

The AidUnofficialFraction parameter in the system model represents the fraction of aid being sent to the community through unofficial means. These means may vary in different types of communities or regions depending on the response of the governing authorities in the area. Often unofficial aid consists of supplies packed by locals near the disaster area but unaffected and able to transport aid resources into the disaster area. For some areas the government may be wary of external aid but in desperate need of it. In those cases, local citizens turned to unofficial aid as a means of sending aid into the affected region. Typically, while it is not insignificant, it is either not as well recorded or does not make up a large percentage of the aid coming into an area. Figure 81 shows the single effect that the parameter has on the total restoration time. The effect seems to increase the restoration time with the increase of the amount of unofficial aid. This may be due to the relationship needing to be refined and better defined or it may mean that larger amounts of unofficial aid hinder the official aid distributor's ability to conduct the restoration of the region. Unofficial aid will primarily be delivered or sent during the response period and during the early parts of the restoration period. It may be that if unofficial aid is continually needed, or if larger

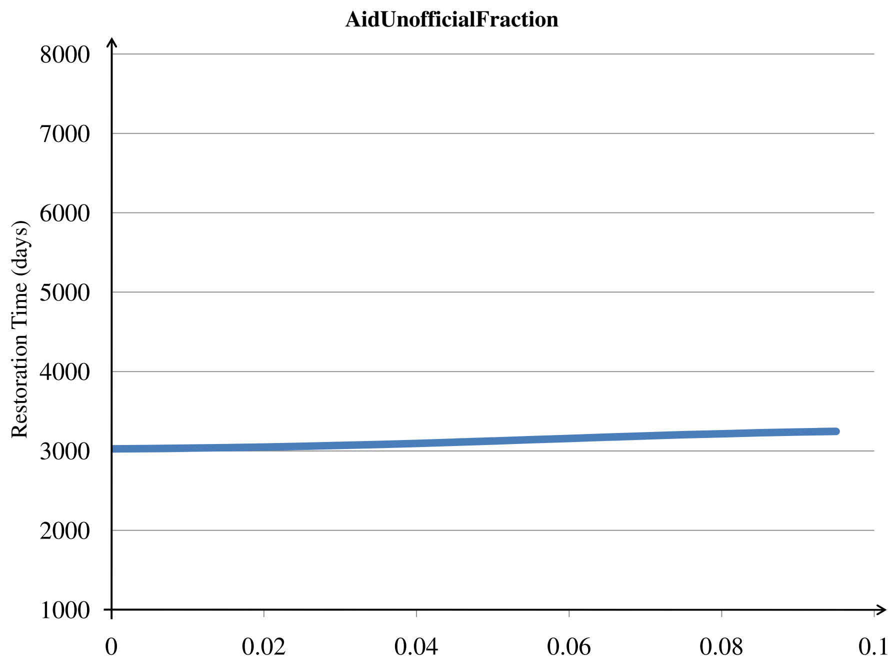


Figure 81: AidUnofficialFraction single effect on Restoration time

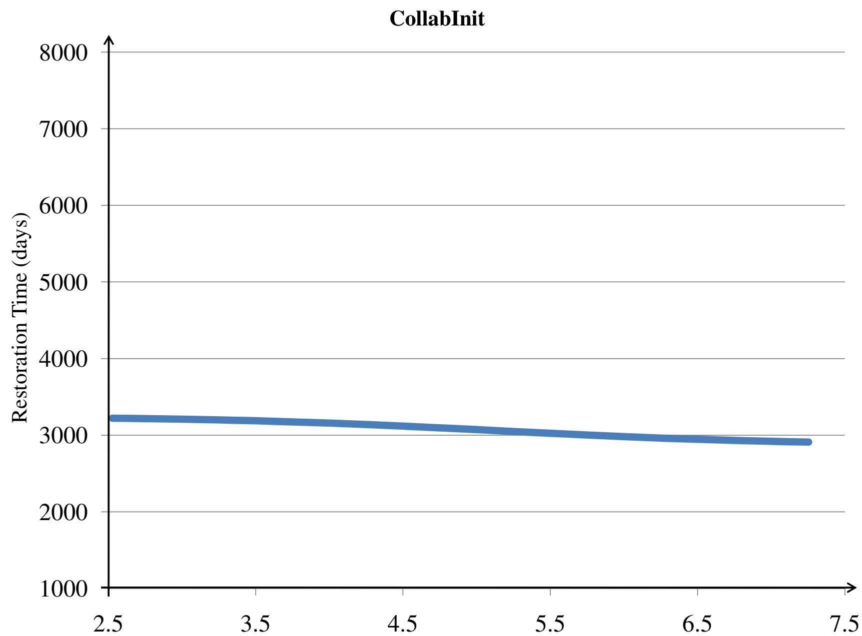


Figure 82: CollabInit single effect on Restoration time

amounts of it are needed, that the community is less able to provide help through official means, and in that case the restoration may take longer.

8.2.0.18 CollabInit

The CollabInit parameter in the system model represents the initial level of collaboration in the preparedness activities of a community before a disaster occurs or is imminent. Figure 82 shows the single effect that the parameter has on the total restoration time. While the effect of collaboration depends more on the amount of warning, if there is no warning, the initial collaboration level does give a slight decrease to the restoration time. Collaboration enables a smoother response implementation.

8.2.0.19 D EconFactor2

The D EconFactor2 parameter in the system model is the fractional value of the aid which affects the development of the community. Its value is based on some response metrics which are specific to the aid implementation process, such as communications, how well

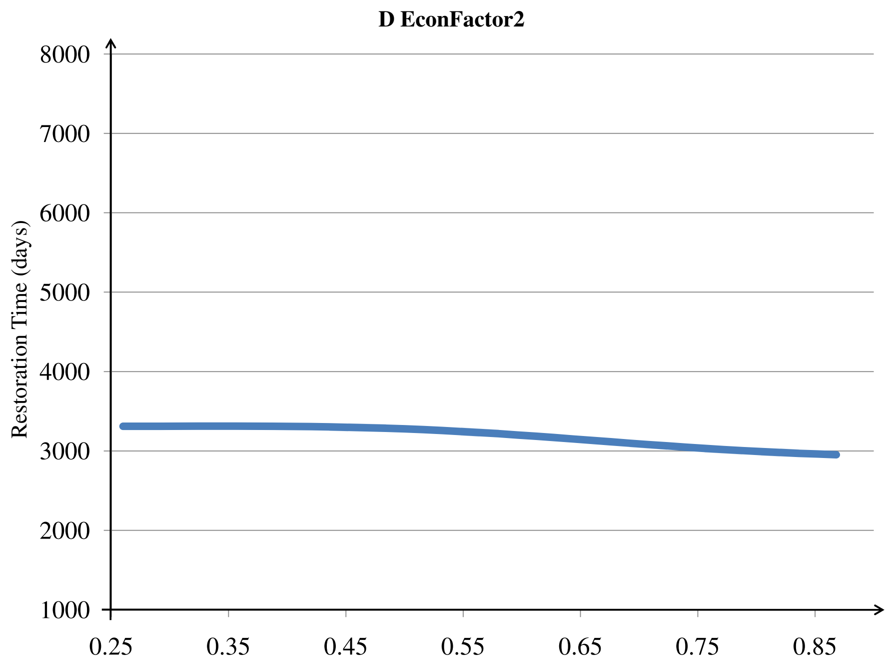


Figure 83: DEconFactor2 single effect on Restoration time

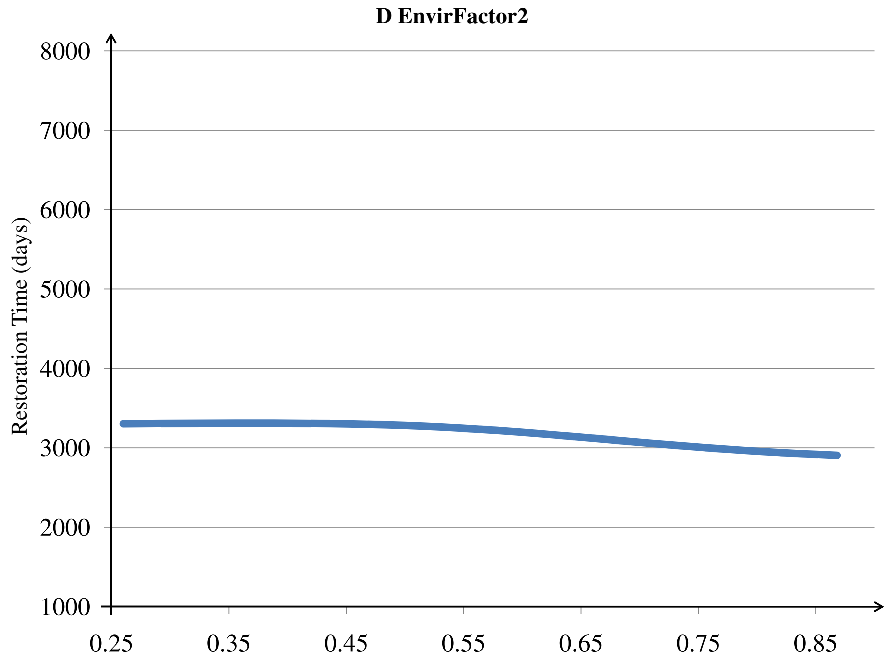


Figure 84: DEnvirFactor2 single effect on Restoration time

the current response is going, and how much aid was sent. The parameter works with the AD Econ parameter in determining the fraction of aid being implemented in the Economic Development of the community. Figure 83 shows the single effect that the parameter has on the total restoration time. There is a slight decrease in the restoration time as D Econfactor2 increases. The more aid is implemented, the faster a community will be able to reach their previous development levels through response and restoration after a disaster.

8.2.0.20 D EnvirFactor2

The D EnvirFactor2 parameter in the system model is the fractional value of the aid being received which affects the environmental development level of the community. Its value is based on some response metrics which are specific to the aid implementation process, such as communications, how well the current response is going, and how much aid was sent. The parameter works with the AD Envir parameter in determining the fraction of aid being implemented in the environmental component of the community. Figure 84 shows the single

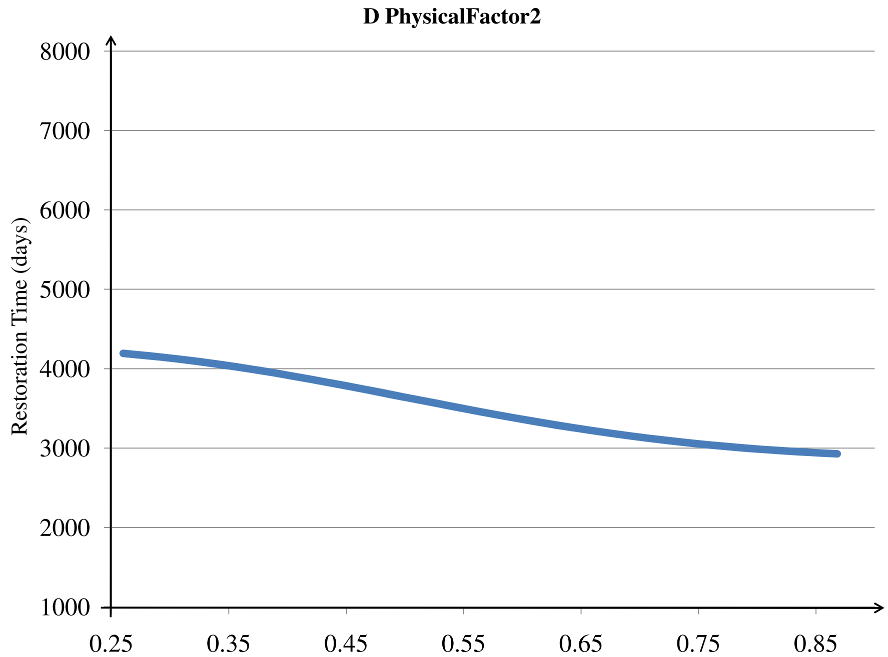


Figure 85: DPhysicalFactor2 single effect on Restoration time

effect that the parameter has on the total restoration time. Similar to D EconFactor2, the greater the value is, the more aid may be implemented into the community, which would serve to shorten the restoration time. While the effect is somewhat slight it is not insignificant, particularly if considering two-factor effects.

8.2.0.21 D PhysicalFactor2

The D PhysicalFactor2 parameter in the system model is the fractional value of the aid being received which affects the physical development level of the community. Its value is based on some response metrics which are specific to the aid implementation process, such as communications, how well the current response is going, and how much aid was sent. The parameter works with the AD Phys parameter in determining the fraction of aid which is implemented into the physical component of the community. Figure 85 shows the single effect that the parameter has on the total restoration time. Similar to D EconFactor2 and

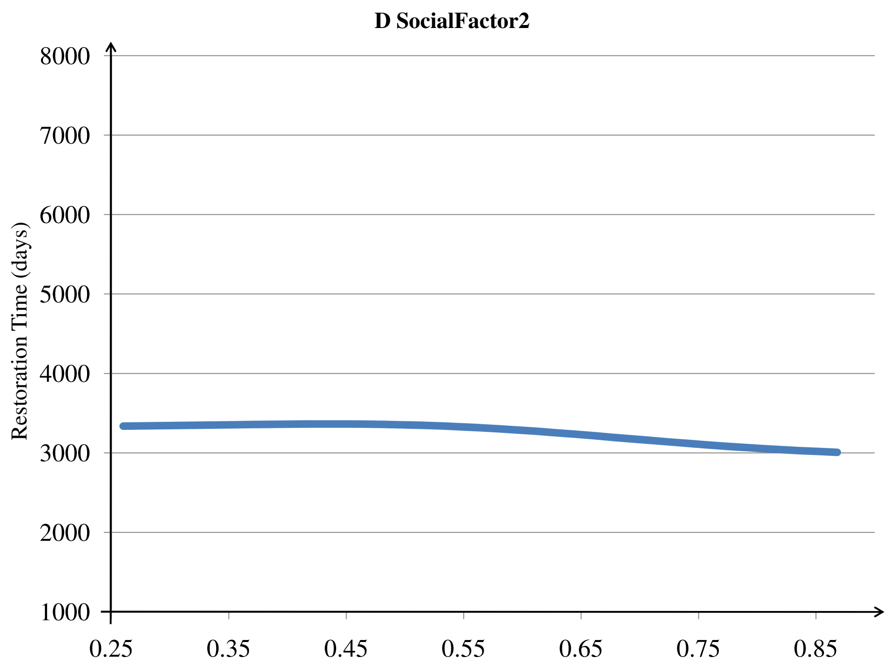


Figure 86: DSocialFactor2 single effect on Restoration time

D EnvirFactor2, a greater value for D PhysicalFactor2 will mean that more aid may be implemented into this aspect of the community, which will help to reduce the restoration time. The effect for D physicalFactor2 is stronger than for D EconFactor2 and D EnvirFactor2.

8.2.0.22 D SocialFactor2

The D SocialFactor2 parameter in the system model is the fractional value of the aid being received into the social aspect of the community. Its value is based on some response metrics which are specific to the aid implementation process, such as communications, how well the current response is going, and how much aid was sent. The parameter works with the AD Soc parameter in determining the fraction of aid which is implemented into the physical component of the community. Figure 86 shows the single effect that the parameter has on the total restoration time. The effect is similar to the previous three parameter behaviors but is a more slight effect than D PhysicalFactor2. For greater values, or more aid implementation, the restoration time is lower.

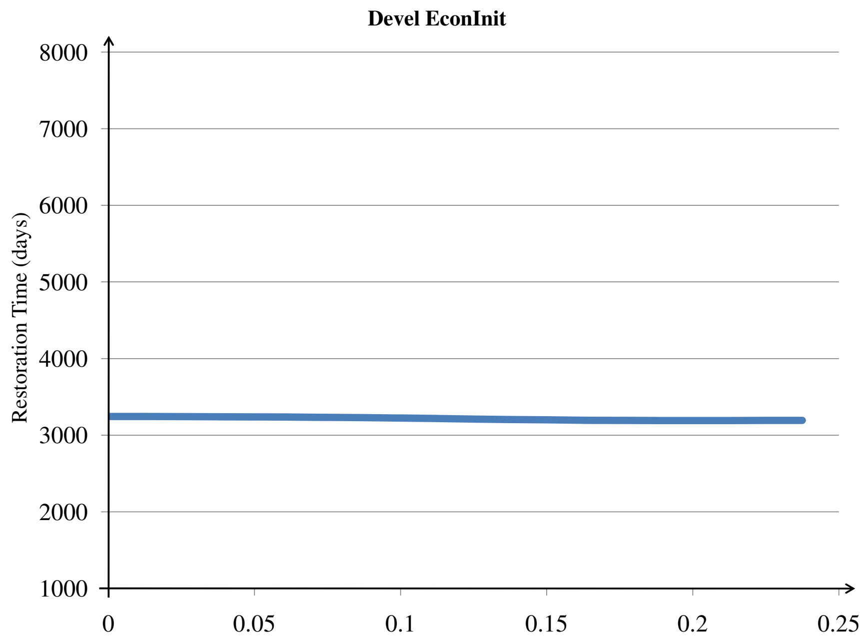


Figure 87: DevelEconInit single effect on Restoration time

8.2.0.23 Devel EconInit

The Devel EconInit parameter in the system model is the initial level of development present in the community, at the economic perspective, before the disaster occurs. It is based on an economic and human development indicator developed by the SOPAC unit of the United Nations and takes into account economic wealth as well as educational development and life expectancy. Figure 87 shows the single effect that the parameter has on the total restoration time. The value for Economic Development fluctuates as the disaster occurs, but the initial parameter value does not have a significant effect on the restoration time after the disaster.

8.2.0.24 Devel EnvirInit

The Devel EnvirInit parameter in the system model is the initial level of the environmental development in the community. The parameters chosen for the initial environmental development level had to do with the condition of the land in the community, but information for the selected community was unavailable. Because the information was unavailable for this

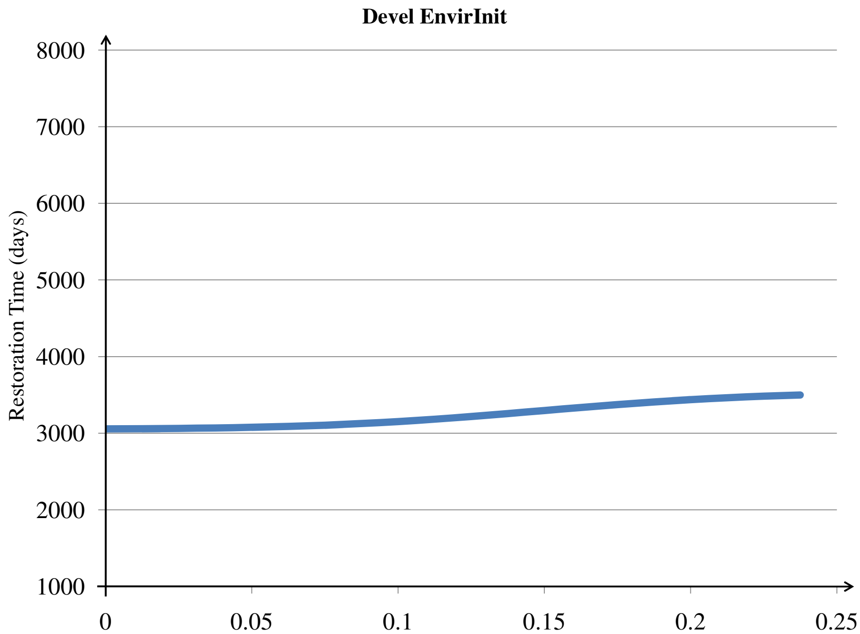


Figure 88: DevelEnvirInit single effect on Restoration time

parameter, it was an assumed default of 0.5. Adding some more measures and parameters is needed but was out of the scope for this research. The environmental vulnerability indicator developed by SOPAC [158] contains a number of environmental indicators. Although the study and development of the index was developed for small island developing nations (SIDS), some parameters may be applicable for a general environmental assessment index. Some of these values might be available for different areas in non SIDS regions but a more knowledgeable input would provide insight as to which measures may be more appropriate than others. Figure 88 shows the single effect that the parameter has on the total restoration time. The effect on restoration time is slight but the higher Devel EnvirInit value seems to cause an increase in the restoration time. The cost of implementing improvements would remove resources from directly aiding in restoration time and would thus lengthen the restoration time.

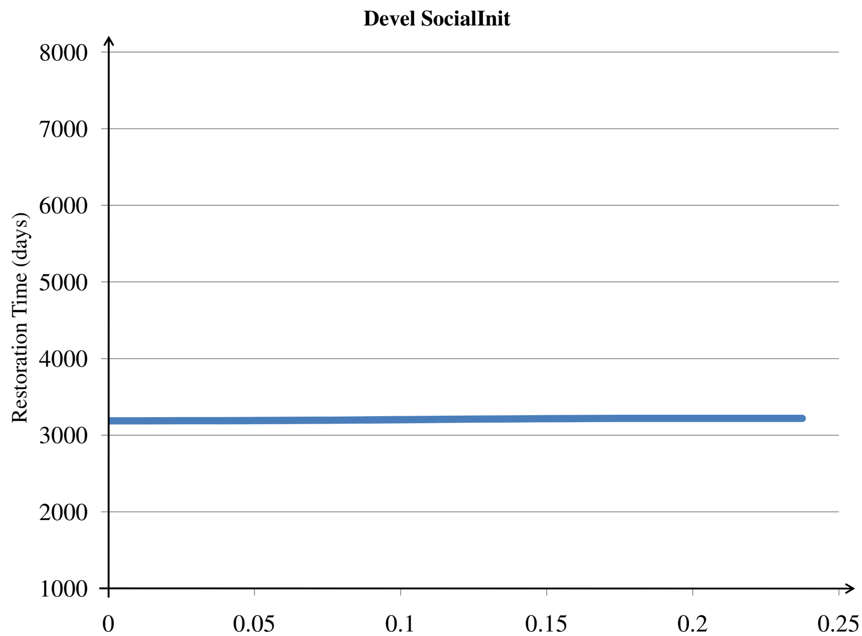


Figure 89: DevelSocialInit single effect on Restoration time

8.2.0.25 Devel SocialInit

The Devel SocialInit parameter in the system model represents the initial level of social development in the community. The parameter is based on some of the different aspects of social development, including children and families, education, housing, health, poverty, and other measures which affect social demographics in communities. Social Indicators from the United Nations Statistics Division were used. If values were not available for the specific region, the national estimates were used. Figure 89 shows the single effect that the parameter has on the total restoration time. The effect on restoration level, however, is negligible for the selected scenario developed in the model.

8.2.0.26 DevelPhysInit

The DevelPhysInit parameter in the system model represents the initial level of physical development in the community. The parameter is composed of measures which describe the infrastructural development of the community including the emergency response buildings

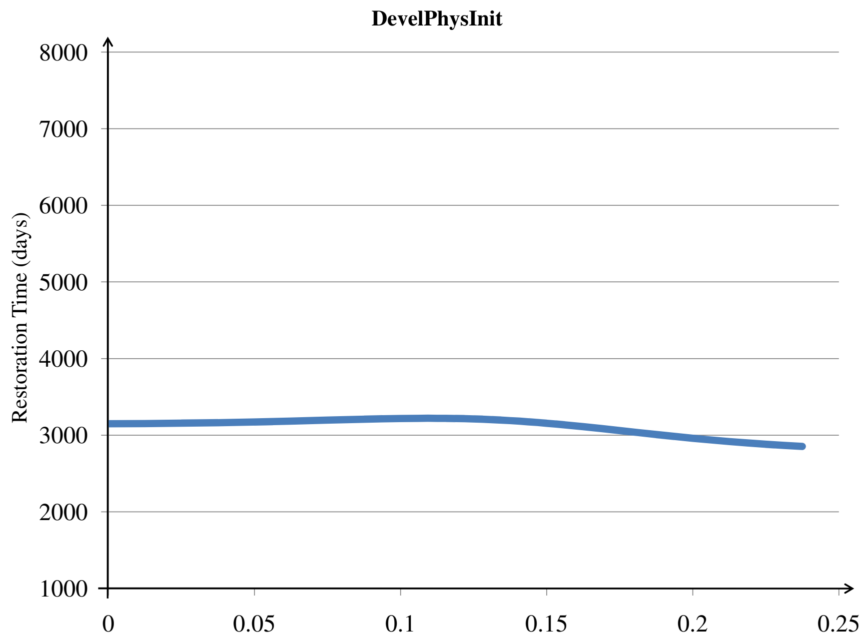


Figure 90: DevelPhysInit single effect on Restoration time

and conditions, as well as some of the other building exposure levels in terms of cost. Figure 90 shows the single effect that the parameter has on the total restoration time. There is a slight effect on the restoration time, and that is as the development level goes up the restoration time decreases for the upper range of the physical development.

8.2.0.27 Fraction

The Fraction parameter in the system model represents the portion of the measured development which changes the extent to which a disaster occurrence would affect the community. Figure 91 shows the single effect that the parameter has on the total restoration time. The effect on restoration time is insignificant.

8.2.0.28 InitialAid

The InitialAid parameter in the system model is the amount of aid which a community is currently receiving at the time of the disaster occurrence. It may mean that the community has not gone through full restoration from the previous disaster, or it may mean that there

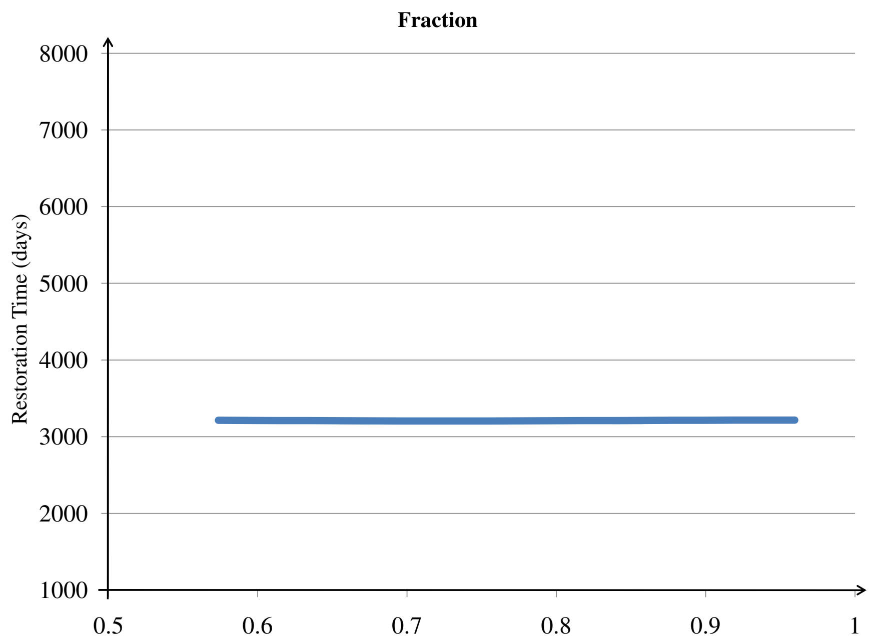


Figure 91: Fraction single effect on Restoration time

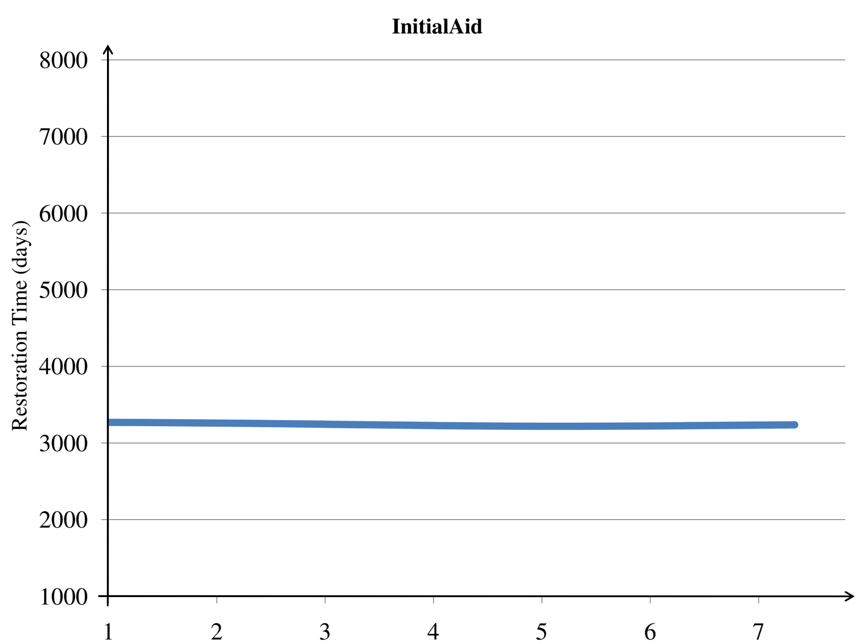


Figure 92: InitialAid single effect on Restoration time

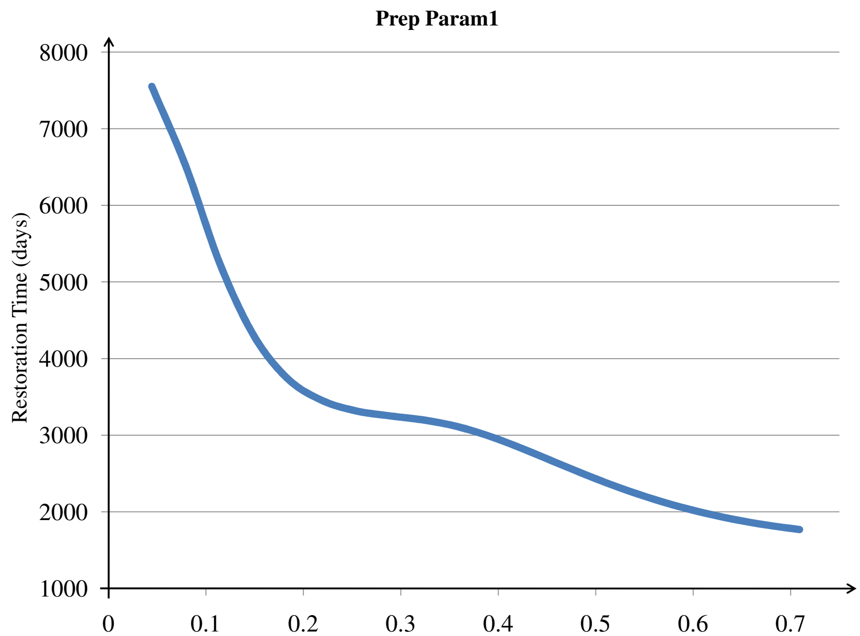


Figure 93: PrepParam1 single effect on Restoration time

is some issue within the community which requires external aid. Figure 92 shows the single effect that the parameter has on the total restoration time. The effect on restoration time is insignificant.

8.2.0.29 Prep Param1

The Prep Param1 parameter in the system model is the fractional amount of preparedness which contributes to the aid in the community after the disaster occurs. A portion of preparedness activities contribute to the response after the disaster, at which point it becomes a part of the aid for the community. Figure 93 shows the single effect that the parameter has on the total restoration time. This parameter causes a significant decrease in restoration time as the value increases. For higher amounts of preparedness resources which become response aid resources after the disaster, the restoration time is lowered.

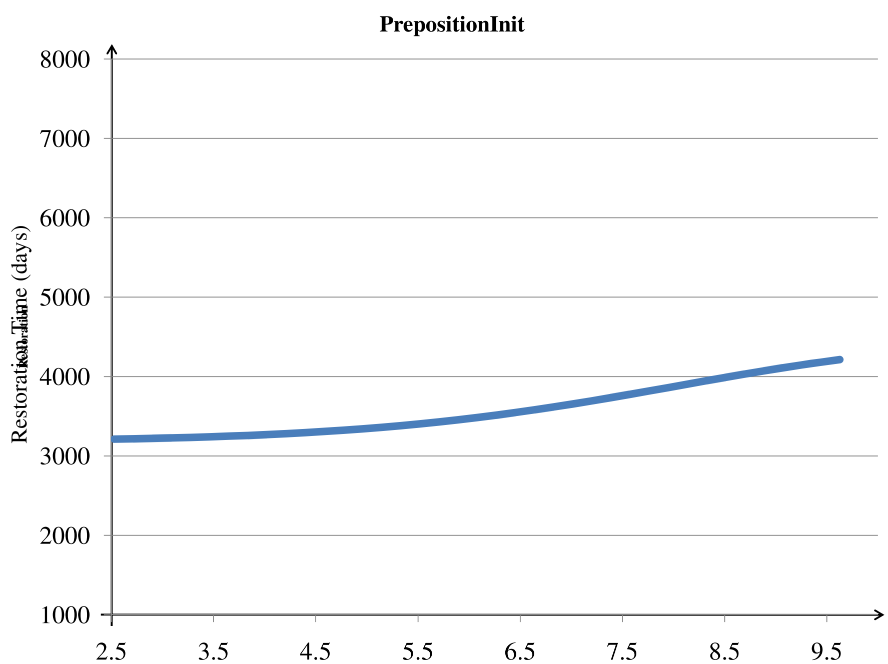


Figure 94: PrepositionInit single effect on Restoration time

8.2.0.30 PrepositionInit

The PrepositionInit parameter in the system model represents the initial amount of prepositioning done in preparedness for a disaster. The amount of prepositioning (of response resources such as food, water, shelter, and medical aid) done may change over the course of a "simulation" and depends on the perceived likelihood of another disaster occurring and how far in the future planners believe it will occur, as well as the amount of resources which are assignable to ensure that this activity is conducted. Figure 94 shows the single effect that the parameter has on the total restoration time. The higher amounts of prepositioning are shown to increase the restoration time for a particular community. This counter-intuitive, since as with general preparedness a community would decrease their restoration time, and therefore it is reasonable to conclude that the prepositioning relationships may have a need for a refined relationship within the model. It may also be explained by reasoning that too much prepositioning decreases the flexibility of responders to efficiently adjust to post-disaster conditions if the pre-positioning was incorrect in assumptions about the disaster.

8.2.0.31 PrepProgramsInit

The PrepProgramsInit parameter in the system model represents the initial amount of preparedness programs implemented to improve a community's disaster preparedness. These types of programs may include programs which help raise awareness of the need for disaster preparedness among community residents or programs which help individuals, families, and businesses develop contingency plans and begin to stockpile emergency resources. Figure 95 shows the single effect that the parameter has on the total restoration time. The effect on restoration time is slight but decreases the restoration time. This is a reasonable effect because having a prepared community does aid in organizing the response and restoration after a disaster. A more prepared community may even be able to mitigate some of the disaster effects before the response begins.

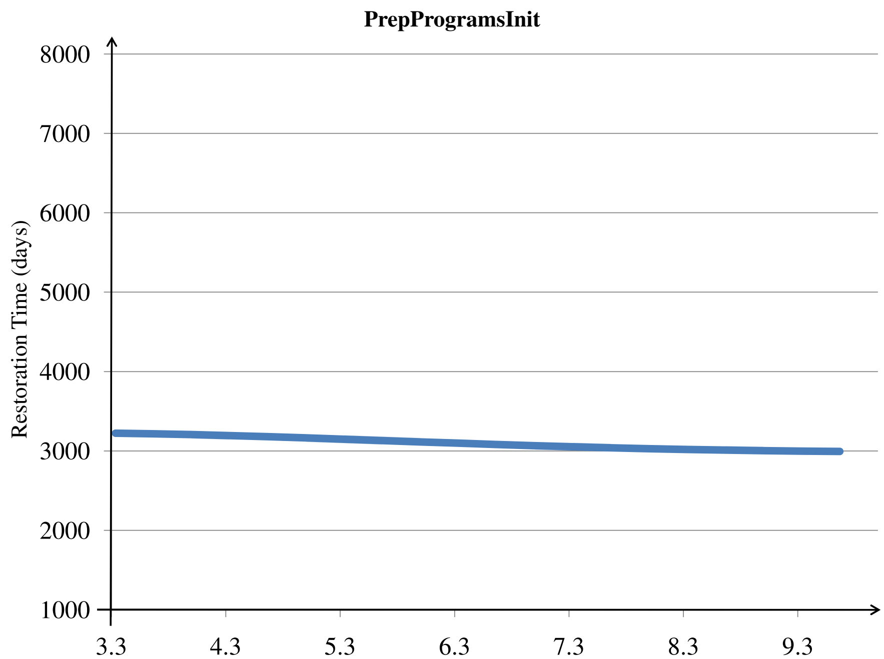


Figure 95: ADEcon single effect on Restoration time

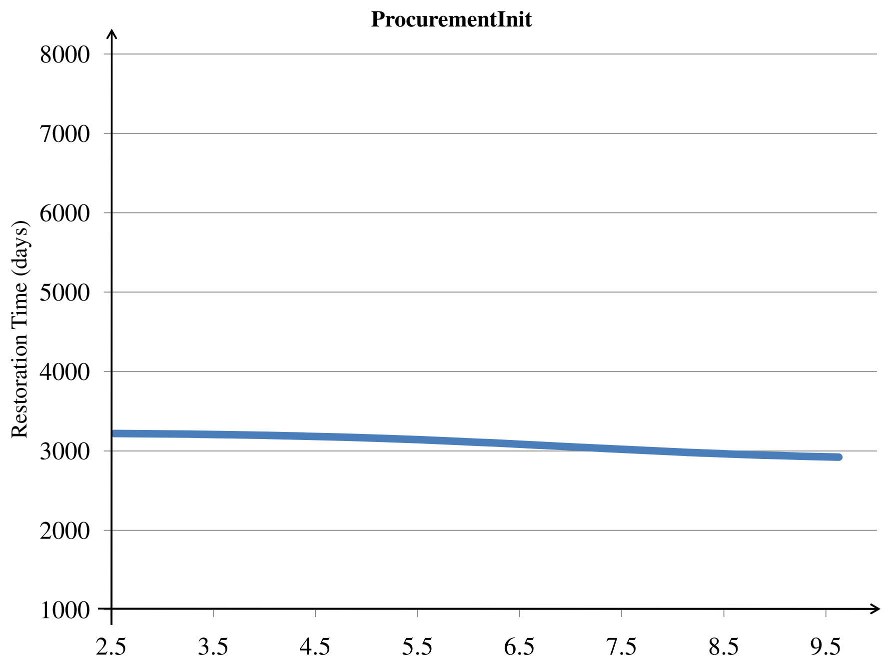


Figure 96: ProcurementInit single effect on Restoration time

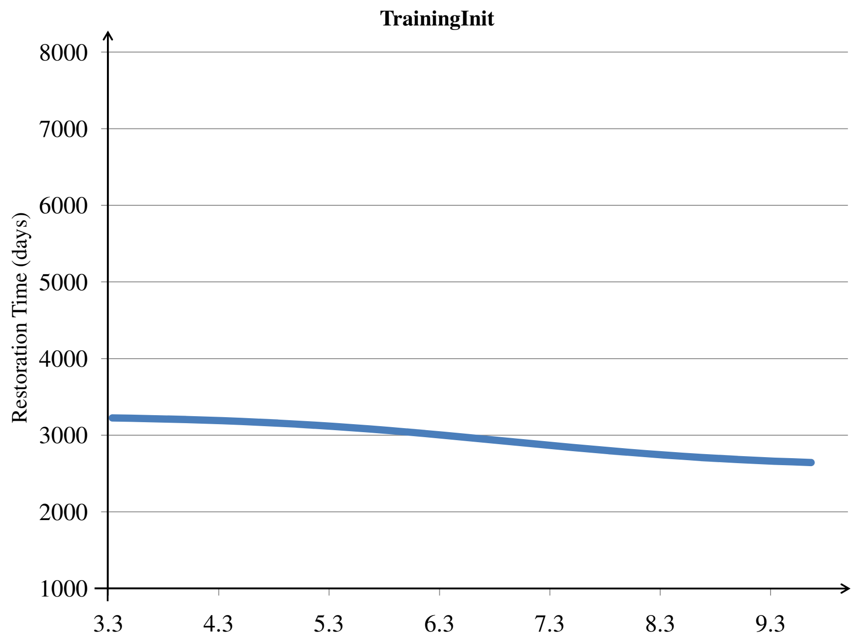


Figure 97: TrainingInit single effect on Restoration time

8.2.0.32 ProcurementInit

The ProcurementInit parameter in the system model represents the initial amount of procurement activities done in the community to prepare for a coming disaster. Typically these activities include securing the resources needed that will be prepositioned, the transport for the prepositioning, and other resources needed primarily for immediate response activities. Figure 96 shows the single effect that the parameter has on the total restoration time. For higher values of ProcurementInit, the restoration time is lower, but the effect is not a strong one. It may become stronger if mixed with one or more other effects. The effect is reasonable since if more resources are available or are able to quickly be secured for distribution after a disaster, the immediate response phase will go more smoothly and transition more quickly into the restoration phase, lowering the restoration time.

8.2.0.33 TrainingInit

The TrainingInit parameter in the system model represents the initial amount of training activities implemented or offered in a community or to members of the community which help to increase preparedness for a disaster occurrence. Some of these training activities may include emergency first responder training, emergency management training, training exercises, evacuation exercises, and any inter-community exercises conducted across different regions. Figure 97 shows the single effect that the parameter has on the total restoration time. Intuitively the graph shows that the restoration time is decreased for increased amounts of training. The training helps to smoothen the response phase as well as some of the rebuilding activities, and also increases the amount of communication within the different planner and responder groups.

8.2.0.34 Disaster Severity

One last effect which was explored was not in the list of selected parameters. This parameter was selected to be constant in the testing because of its effects on the rest of the system. Small changes in the severity were causing the model to fail with certain values in other parameters.

Figure 98 shows the single effect that the parameter has on the total restoration time.

The effect does slightly increase the restoration time as the severity increases, but through the moderate and even somewhat severe disaster range the restoration time does not change significantly.

8.3 Surrogate Model Development

8.3.1 Addressing System Complexity

Because of the number of parameters which will be needed to describe or quantify the system and also be used for system exploration to determine system behavior, it is possible that this available computing capability will be inadequate to provide timely information about the system characteristics and emerging trends. In light of this consideration it is necessary for exploration of an option which may serve to decrease the complexity of the system or

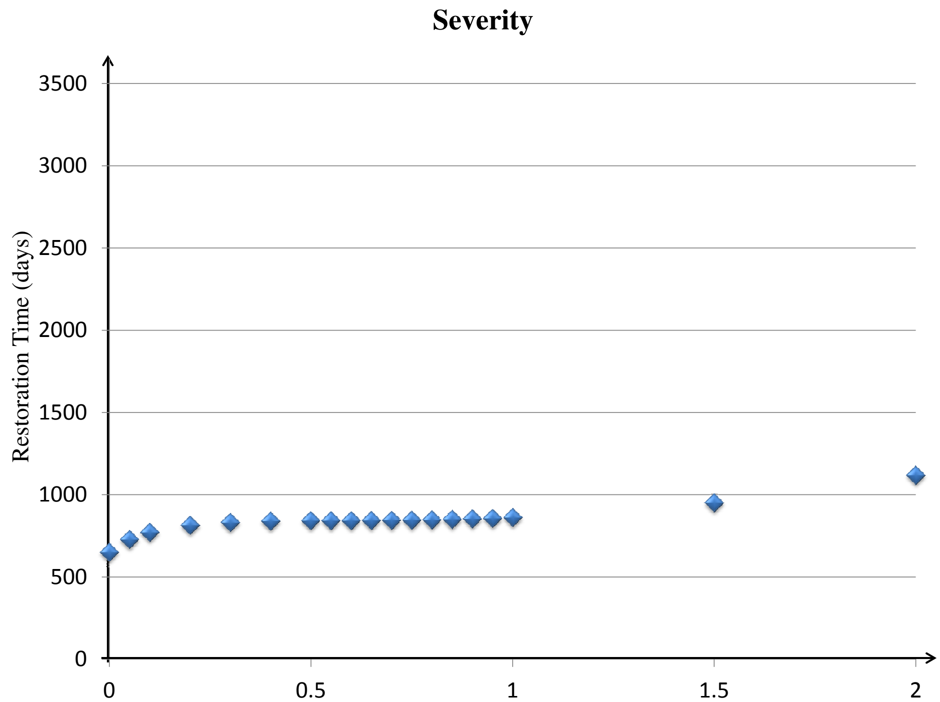


Figure 98: Severity single effect on Restoration time

enable a greater degree of time compression to allow for faster information provision.

Three available options are:

- system dynamics code + exploration experiment design
- surrogate or meta model + exploration experiment design
- system dynamics code + reduced exploration experiment design

The selected option was the surrogate or meta model with an exploration design. The metamodel enables the full exploration to be done while also reducing the time needed to do so.

8.3.2 Surrogate Modeling Methods

It is recognized that logic- and knowledge-based systems are available for modeling in this context. However, both types of systems do not enable quantitative comparison of system states that is needed and the logic systems would be very complex to set up.

Two other methods were considered for surrogate modeling, Response Surface Models, and Neural Network Models.

8.3.2.1 Response Surface Methods

Response surface method models complex systems through a simpler equation, which is developed through multi-variate regression techniques. The data used for the regression is generated through design of experiments methods which enable the most information to be gathered from a given experimental effort. This is helpful when experimental resources, such as computational power or time, are limited. The typical form of a response surface model is a second order quadratic equation with the form shown in Equation 116. [96]

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j + \varepsilon \tag{116}$$

From Equation 116 [96]:

y	=	response or objective parameter
β_i	=	regression coefficients for first degree terms
β_{ii}	=	coefficients for the pure quadratic terms
β_{ij}	=	coefficients for the cross-product terms
ε	=	error term which is assumed to be negligible

However, for the system of concern in this research, many of the relationships are non-linear and this is known from the development of the system dynamics model. Also, after the system sensitivity analysis was conducted, there were suspected higher order effects present but the available resources did not allow for the exploration to determine which of those higher order effects were the strongest.

8.3.2.2 Neural Network

Francis also showed that neural networks are valuable in fitting models to data containing interactions. [63]

Neural networks are suited for regressing against more complex networks, particularly ones that have more mixed effects. The BRAINN program developed in the ASDL by Carl Johnson and Jeff Schutte enables a user to fit a neural network to data in spreadsheet format through an efficient user interface. The program runs using Matlab.

Each type of regressed model is much faster than most of the detailed software available, but at a lesser degree of detail. However within the proper ranges, if the model is properly developed it will be acceptable as a surrogate model. The user can then use this model to play different "games" with the variable values or possible scenarios, where different parameter "sets" are perturbed in the surrogate model to observe the system behavior under those circumstances.

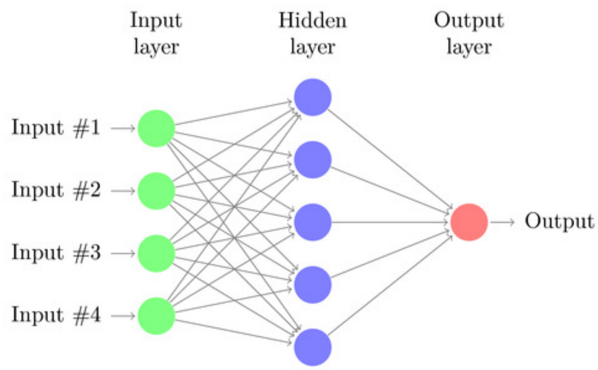


Figure 99: Neural Network Diagram [54]

To help address some of the time uncertainties and relationship complexities, a neural network may also be used and will be particularly helpful if some of the parameter-response relationships are complex and non-linear. Neural Networks have been applied in various optimization situations. The setup of artificial neural networks are modeled after neuron interactions in the brain. In the applications, NNs form relationships between inputs and outputs (See Figure 99). This network, like the network of connections between the neuron input signals and the output signals, is trained with data sets once the mapping has been complete, to fine tune the performance of the neural network.

Neural Networks are used to approximate functions and recognize patterns in data sets. The neural network can also be set up and tested even if users have limited amounts of data. There are available techniques that are used to deal with these limited data. [124] Neural Networks have been used to model evacuation scenarios [174] for comparative studies and performance evaluation [150].

In order to reduce the number of variables by selecting the ones which are the most

Table 40: System Dynamics Modeling Software Selection

Surrogate Modeling Options	Parameters		
	Behavior	Setup	Higher Order
Response Surface	4	4	2
Neural Network	4	5	4

effective, a sensitivity analysis was done to reduce the number of variables. Even after the variable reduction, thirty three variables remained, and a thorough system exploration would have been too high in time requirements. Because of this, a space-filling design was developed using JMP software. An augmenting design was added and was run through the system dynamics model. The results were gathered and stored.

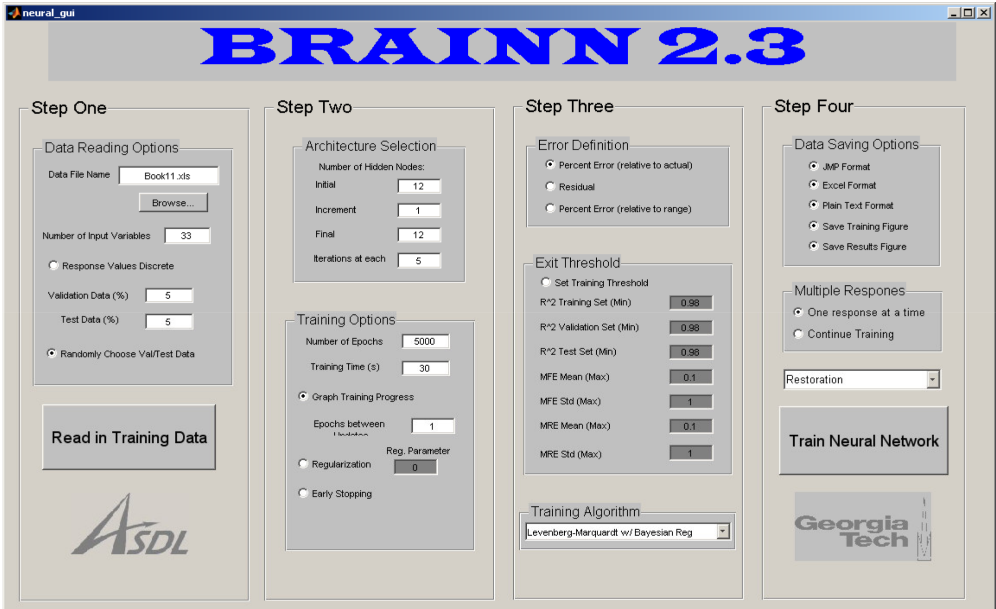
Because the system exploration is necessary to develop the understanding of the system and enable information presentation there does need to be a way to know and also provide information about the effects of changes in the system parameters. Consideration of alternate methods was conducted.

8.3.3 Neural Network Development

The neural network was selected as the surrogate model type and the development of the neural network was done in BRAINN, a Matlab interface program developed by Johnson and Schutte in ASDL. The front screen of the interface is seen in Figure 100. The input data was a Latin Hypercube design generated in JMP with an augmented design based on the original Latin Hypercube design. The Latin Hypercube design was chosen because of its space-filling characteristic. Because the space to be explored was complex and the current research was not too concerned with extrapolation capabilities, an internal space-filling design was needed.

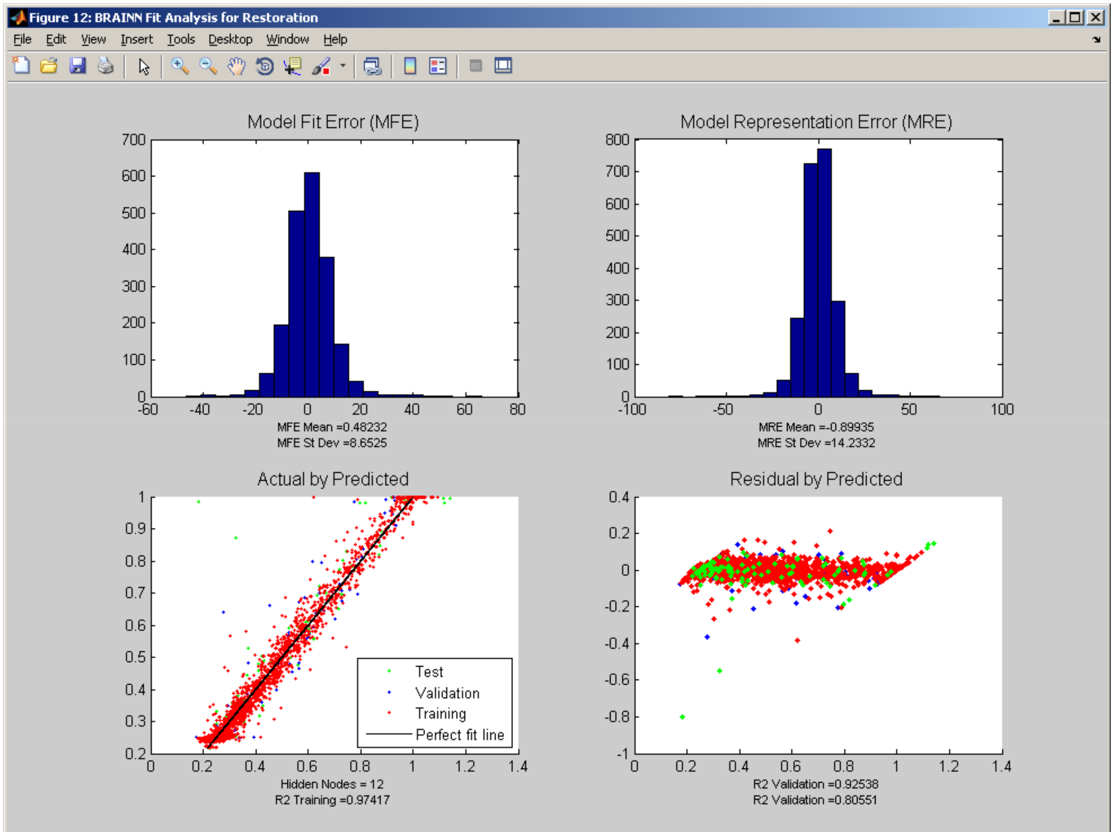
The best resulting neural network was a network with twelve hidden nodes. This network had the highest R-squared values for both the model training as well as the model validation. The training and validation data were sampled randomly from within the provided data set. The model representation error and model fit error are shown in Figure 101. The The MRE and MFE mean and standard deviation are in percentages. While the standard deviation (St Dev) percentage should be below ten percent (or 0.1) the MRE for the 12

Figure 100: BRAINN 2.3 - neural network development interface



node neural network was the best value for other neural network development attempts with fewer hidden nodes. Having a greater amount of hidden nodes did not improve the MRE and MFE significantly, and also increased the network development time. There are several outliers visible in the Actual by Predicted and Residual by Predicted graphs but the BRAINN 2.3 interface did not provide information as to which points were outliers. Extreme outliers could be selected by setting up the developed neural network in JMP and finding the greatest response error values but only to a certain degree. Because the training data with outliers left in the model were still within acceptable ranges for the Actual by Predicted and Residual by Predicted graphs, the extra steps were not taken to remove them. However the behavior of the data in the Residual by Predicted graph hints that higher order factors may be influencing the system behavior. While this was unable to be explored with the time used to develop the methodology discussed in this research, higher order effects should be included in the system exploration step of any implementation of the methodology. The neural network was used to generate data for the test scenarios and

Figure 101: MRE and MFE of 12 Node Neural Network



also for the optimization algorithm.

8.4 Second Order Effects

Second order effects are of interest as well, but if each factor pair were tested at all 20 levels as in the single effects testing, there would be

$$33 * 32 * (20 * 20) = 422,400 \tag{117}$$

runs needed. However, based on the way the single effects look, a 3 level test or 5 level test would suffice if the higher order effects are not a lot more complex than the single effect behaviors.

$$33 * 32 * (5 * 5) = 26,400 \tag{118}$$

$$33 * 32 * (3 * 3) = 9,504 \tag{119}$$

Having the second order effects will enable observations of some of the higher level effects on the restoration time. Some of the second order effects will not be significant, similar to the first order or single effects, but the system exploration will enable that information to be shown. Appendix D.1 shows each effect combined with the strongest single effect which is the Prep Param1 effect (Figure 93).

The developed neural network model was set up in JMP Statistical Software in order to utilize the three dimensional graphing capabilities. One of the second order effects is shown in Figure 102. The combined effect can be seen where for higher values of Adjust-Preparedness combined with higher values of PrepParam1, the Response (restoration time) is reduced more than for the single effect of either parameter. For higher levels of Adjust-Preparedness but lower levels of PrepParam1 there is an upper limit to the Response. The top of the graph in Figure 102 also shows the different isolines which mark the value of the Response parameter over the gradient of the surface.

From a planning perspective, when looking at implementing long term improvement changes, if resources are available for improving one factor more than another, they can be allocated accordingly to still improve the Response. In Figure 102 if the Prep Param1 parameter is currently at 0.5 (the middle of its selected range) and being held constant, the isolines indicate where the AdjustPreparedness effect changes the Response. The axes for each variable including the Response go from approximately zero to approximately one. The zero-to-one range represents for zero: the lowest bound allowable by the system, and the highest bound represents the highest bound on the value allowable by the system.

8.5 *Mixed Higher Order Effects*

Effects of factors will be more difficult to show because as factors increase in complexity, more experiment designs would be needed if more system exploration is desired. However, because of the speed at which the neural network simulations are able to be done, more of the system may be explored in a lesser amount of time.

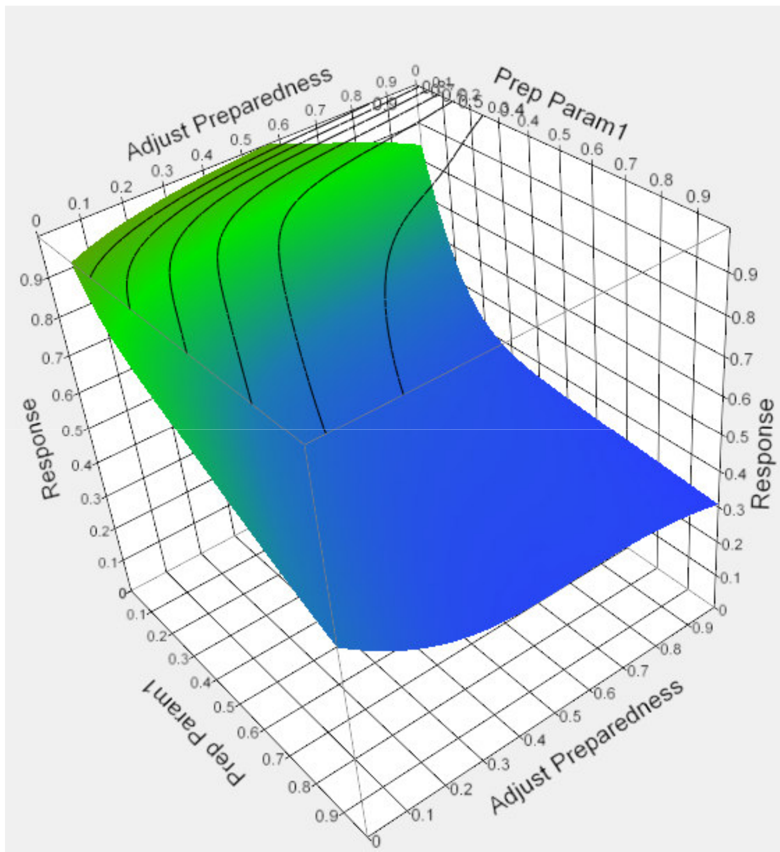


Figure 102: Prep Param1 x AdjustPreparedness Mixed Effect

8.6 Scenarios

Different aspects of the community are developed as a result of a community's focus on change as a part of increasing resilience after a disaster, which will shorten the time required for restoration. The different development focus points are actually changes within a group of data elements. Overall every parameter in the system model is made up of an aggregate of various relating terms which enable system quantification.

The results presented in this section include an original scenario situation where the community of interest has not been making any community changes in order to increase the resiliency after a disaster. For Shelby County this meant taking data from current or near current-day statistics. For Orleans Parish the pre-Hurricane Katrina data was used in order to assess changes in restoration time from the pre-disaster status and also observe implemented changes in different areas of the system model.

Three different categories of changes were implemented in the model, and each category was also assessed in a combination with the others for two-factor effects and one three-factor effect. Each implementation of changes also included the two-year, five-year, and ten-year time periods of implementation of changes. These time periods assume that within the time period each data element or change has been implemented to the community in a way that is reflected by the value of the data element.

Table 51 in Appendix C.1 shows the different parameters broken down into data elements. The color coding show the different variables included in the aspect focus groups of variables and adjusted accordingly by changing the data element values. The data elements, sub-parameters, and parameters are grouped by color within the table, with the Development-related components highlighted in blues, the preparedness components highlighted in light greens, and the response components highlighted in light orange. The next few sections explain the various changes applied to the different components in the improvements of the different aspects of the community.

Some issues with setting up scenarios in the spreadsheet arose when some of the values were outside of the limits of the developed system model. Because the model does not perform very well under high extrapolation demands it is not recommended to use values outside the limits. Values should be set to the limits if they are greater or smaller than the high and low limits, respectively. A penalty function may also be added which slows the search as it approaches the limits, to keep the values within the design space. The scenario assessment done here was done this way as well. Addressing the range limitations is done in Chapter 11.

8.6.1 Selected Communities

As has been mentioned in the beginning of this chapter, the selected specifics for the community and disaster are for a suddent disaster type which overwhelms local resources to immediately respond to damages. For the first scenario, the chosen setting was the city of Memphis (Shelby County, TN) which is near the New Madrid Fault Line. While the New Madrid Seismic Zone (NMSZ), which is the area containing the fault line, has not produced any large quakes in the past two hundred years, the possibility of a quake along the magnitude of 8.0 or higher has caused more attention to be given to this area as far as response planning is concerned. Data provided by Wheeler et al. [171] shows the frequency of different magnitude earthquakes in the past few decades in Figure 103.

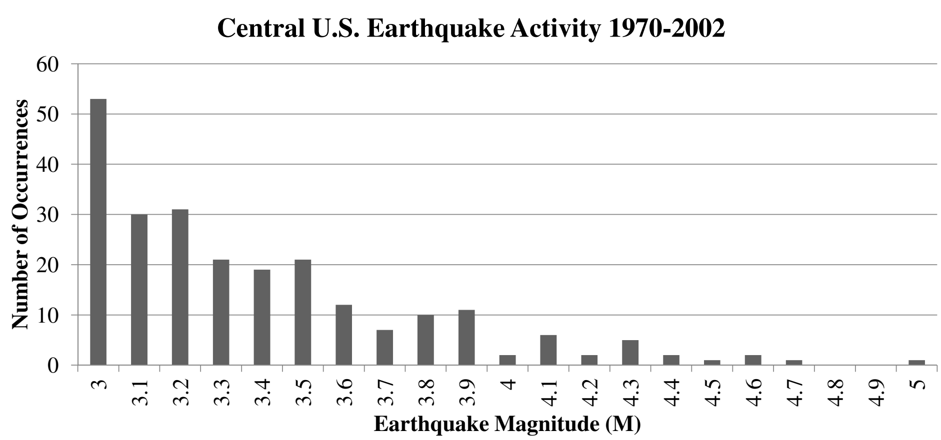


Figure 103: Central United States Seismic Activity 1970-2002 [171]

With such a large metropolis near the fault line, and very little warning often accompany earthquakes, the city and surrounding counties and states are preparing for post-disaster repercussions. While the intensity of the event will not be varied, different tests will examine the effect of focusing on one, two, or three of the community development aspects through one iteration of the disaster cycle.

The second scenario was an event which had already occurred, but for a community which was still in the US under similar legal jurisdiction and policy. The chosen second setting was Orleans Parish just prior to the landfall and destruction caused by Hurricane Katrina in 2005. The developed system model had been set up with initial ranges based more on the Shelby County parameter values.

Some of the values of Orleans Parish were out of the range of the model. The extrapolation accuracy was very very low, so if values were out of range, they were adjusted to the nearest value in range. Future model developments would have ranges adjusted to more global values. This includes changing the normalization calculations and also checking in the system dynamics model to make sure that none of the values or ranges would cause any singular case failures.

For each of the selected communities, Shelby County, TN and Orleans Parish, LA, the majority of the data elements were filled in from available statistical findings. For Orleans Parish, values from 2005 and previous were used in order to not pre-emptively include the effects of Hurricane Katrina, which affected population, job, and industry statistics. For each test case, the restoration time was observed for different combinations of parameter groups (Development, Preparedness, Response), which were assumed to be implemented over different time periods (0, 2, 5, and 10 years).

If initial data was unavailable, it was reasonably estimated or omitted from assessment calculations. For the 2, 5, and 10 year implementation periods, the parameter values were estimated as slow changes over the implementation period in the direction which would reduce the restoration time. The 2, 5, and 10 year implementation values for the data parameters can be seen in Appendices C.3, C.4, and C.5. The initial community values can be seen in Table 52 in Appendix C.2.

8.6.2 Preparedness Improvement

The sub-parameters and data elements varied in the preparedness improvement focus were selected for their relationship with parameters which affected the preparedness of the community. Each of the different parameters which affect the preparedness of the community have initial values which represent the initial preparedness of the community before the disaster is even predicted and before warning is given, if there is any warning.

Some of the sub-parameters and data elements fall beyond the control of the community developers and planners and are assumed to remain constant through the period of time which changes are implemented. For this research, a zero-time set of quantified measures is taken, as well as a 2-year, 5-year, and 10-year implementation period. During this time the community is assumed to have completed implementation of certain changes to bring the community to the level which is specified at those points in the quantified measures sets.

During the model setup, the initial sub-parameters which were assigned to each parameter were set to be dependent on whether or not another disaster has a high probability of occurring. The assumption is that for disasters which are more likely to occur, the local community residents as well as authorities will put more effort into personal and community preparedness for the event. In the system model setup the specific sub-parameter "probability of another disaster occurring" is repeated for each parameter which it affects.

The "PrepParam1" parameter quantifies the contribution of preparedness to the amount of aid which a community is able to receive and implement after a disaster occurs. This parameter is dependent also upon the "probability of another disaster occurring" as well as the quality of preparedness programming. Tables 53 and 54 show the values for the parameter changes for both communities - Shelby County in TN and Orleans Parish in Louisiana in pre-Hurricane Katrina days.

"Collaboration" is listed as a sub-parameter for Adjust Pro, which quantifies the collaboration which occurs after a disaster has already happened. The data-elements for collaboration may be improved in preparedness implementations, which is why it is included as a preparedness sub-parameter for changes.

Some of the values of the sub-parameters and data-elements were outside of the range of values used to develop the model. Extrapolation with the developed model gives very inaccurate results, so measures with values beyond the model ranges were set to be at value closest to the out-of-range value. This was an issue with the Orleans Parish data, and an extra column at the beginning is included with the adjusted 0 year data to show which values were changed. The Preparedness Aspect data did not need adjustment but Response and Development data did.

For the Orleans Parish data there was also an amount of warning time in which the disaster was imminent. This warning time was not present for the Shelby County data since Shelby County was simulated with an earthquake, and Orleans Parish with a hurricane. The difference in warning time reflects this.

8.6.3 Response Improvement

The sub-parameters and data elements varied in the Response improvement focus were selected for their relationship with parameters which affected the response capability of the community. Because the community improvement focus is on response, the sub-parameters and data elements which are not a part of the response aspect of the community are assumed to be constant. Also if the values were already at a very desirable level on the range, as in the case of the "Implement Priority" or "Amountt of Aid being sent" for the different community aspects (Social, Economic, Environmental, and Physical), they were assumed to remain constant. Not all aspects had measures at that level, so for less desirable levels, the data elements were adjusted over the year implementation periods. Likewise if a particular sub-parameter or data element may be attributed more to restoration activities, which are long-term, it was also left constant.

Specific data elements relating to the immediate response performance were selected based on importance shown through literature and research of media coverage of different disasters. These should be refined if implementing for a particular community, with some expert input and perhaps even more extensive research of literature and media coverage of disasters.

The damage from the disaster was also assumed to remain constant through the year implementation periods. Tables 55 and 56 in Appendix C.4 show the different values used in the response improvement focus.

8.6.4 Development Improvement

The Development aspect of the community or region was defined to include social, physical, environmental, and economic infrastructure. The environmental measures were researched but not fully developed with this research, and a small group of measures were preliminarily selected. However the data availability for the selected measures was low and the Environmental Development parameter has been omitted from the quantification. Chapter 11 addresses this issue and sets forth potential solutions. The environmental state of any particular region is an important parameter to include with response and restoration planning. An unstable environment increases the vulnerability of a community to the effects of a disaster and may worsen both immediate and long term effects of such an event.

Within the social indicators, adolescent fertility rates were set for improvement over the 2, 5, and 10 year mark, and the average duration of education was increased, along with the adult literacy rate. The unemployment rate was also reduced while the GDP per capita was increased.

The physical infrastructure improvement was a little more difficult to develop an improvement plan over the 2, 5, and 10 year period. The setup of the system model includes such sub-parameters as replacement costs, design levels, number of facilities, and for appropriate cases, the number of hospital beds or number of students. The replacement costs are less desirable when they are higher, based on the developed model, but for an improvement plan which constructs another hospital over the 10 year period, the replacement cost will go up even if the hospitals are able to accommodate more patients.

In the same vein, the school design levels are medium based on the HAZUS software default data, and money spent on improving the design of the schools will enter the replacement cost, which may decrease the desirability of investing resources in this aspect. This occurs even if having an increased design level means that students in a school building with a high design level would be safer in the event of an earthquake or hurricane. The value used in the model is a cumulative one, and planners should consider implementing a measure which more accurately quantifies the improvement offered to a community through building another emergency facility or improving the design of certain shelters and community buildings and structures. Tables 57 and 58 in Appendix C.5 show the selected improvement values used in the development improvement focus.

8.6.5 Combined Improvement with Preparedness, Response, and Development

The combined improvement focus areas were also tested in this scenario. The combination of any two or three of these different focus areas was included in the scenario testing as the different improvements from each aspect all occurring through the 2, 5, and 10 year periods. For a community focused on improving preparedness and response, the preparedness improvements and response improvements are all implemented in parallel over the improvement periods.

The improvement scenarios for combined community aspects included for the 2, 5, and 10 year periods with both Shelby County, TN and Orleans Parish, LA in pre-Katrina state were:

- Preparedness and Response
- Response and Development
- Development and Preparedness
- Development, Preparedness, and Response.

8.6.6 Scenario Results

Each of these scenarios implemented a series of changes in different parameter values, representing improvements or changes that a community may make in order to improve certain aspects of the system. Because some of the parameters are not specifically tied to any particular community actions or changes, they are estimates of how things might change. Adding expert input would improve the validity of these estimates, and enable a connection between changes in representative values and tangible changes within the community.

Figure 104: Restoration Time for Single Aspect Focus (Shelby County, TN)

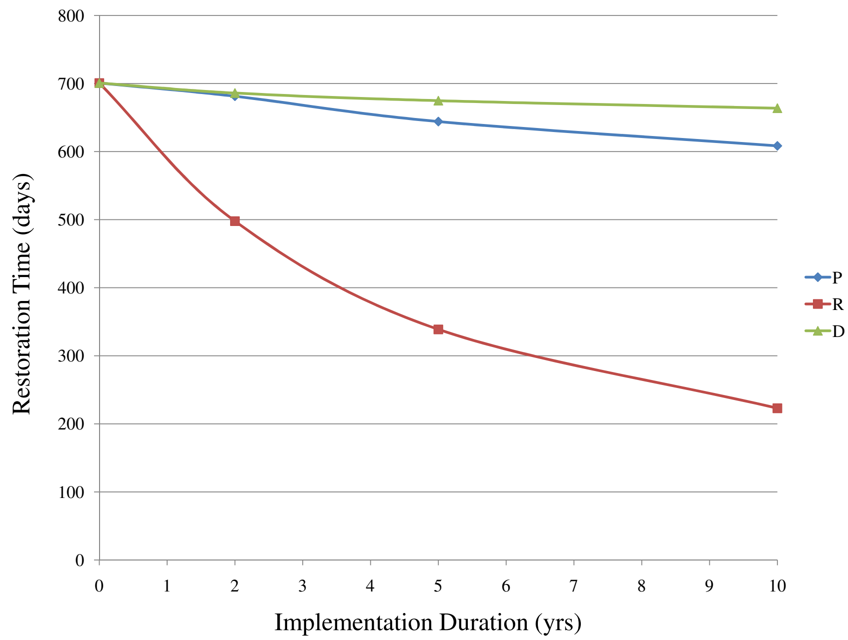
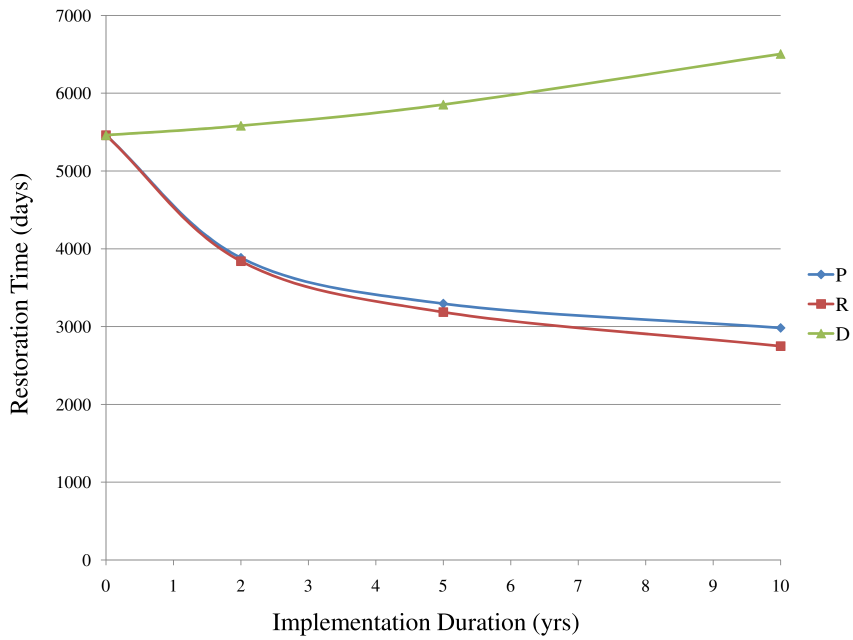


Figure 104 shows the combined results for the different aspect improvement focuses that a community might choose to focus on in Disaster Response and Restoration planning. The different selected parameters were chosen in groups that focused on only one aspect improvement (Development, Response, and Preparedness). The current or original state for the community is set as the 0 year mark. In this test both Developmental improvements and Preparedness improvements helped to reduce the restoration time somewhat, but the Response improvement focus had the strongest effect on the restoration time.

The same test scenario was done for Orleans Parish in its Pre-Katrina state (0 year state) with a hurricane disaster instead of an earthquake as was tested for Shelby County. The combined results for different aspect improvement focuses are shown in Figure 105. For Orleans Parish, the Response and Preparedness improvement focus has more effect on the restoration time than development improvements. If implemented, the development improvements actually increase the restoration time for the community.

The model is set up so that the cost of building hospitals and other infrastructure

Figure 105: Restoration Time for Single Aspect Focus (Orleans Parish, LA pre-Katrina)

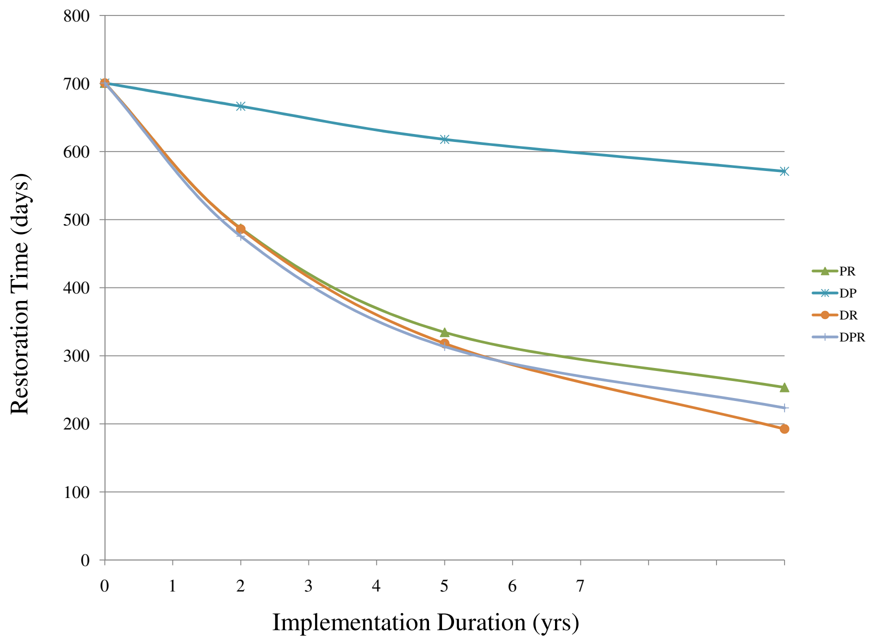


is detrimental to the restoration time, since building more buildings increases potential rebuilding after a disaster. This aspect of the model may need to be adjusted in the future with an urban planning measure which enables proper urban planning to improve the restoration time even if more development is done within the infrastructure of the community. The combined improvements are shown in Figure 106.

If communities have entered into intra-community collaboration, particularly at a leadership level, among different agencies or planning organizations, the community may be able to focus on more than one improvement aspect at a time if resources allow. The effects of two-aspect improvement focus and a three-aspect or all-aspect improvement focus are shown for Shelby County, TN in Figure 106.

Figure 106 shows that if the combined focus aspects include Response parameters, the effect is a significant improvement from the combined aspect which did not include Response (DP). However, the preparedness-development combined aspect focus still improved the restoration time over the different implementation durations. For Orleans Parish in

Figure 106: Combined Aspect Focus (Shelby County, TN)



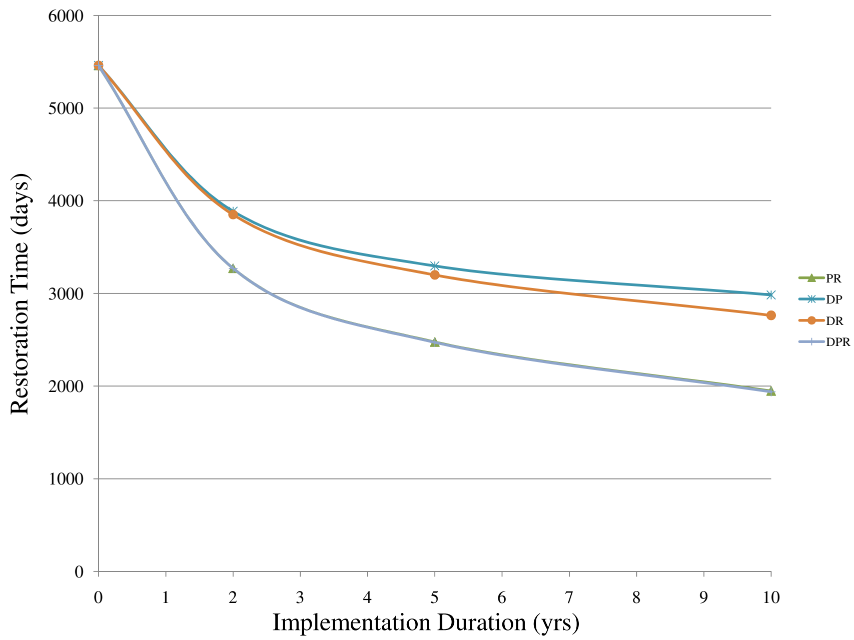
Louisiana, however, the trends shown in Figure 107 are a little different than those shown for Shelby County.

8.7 System Optimization

Another method of addressing needed improvements may be done through the implementation of an optimization method for complex, nonlinear systems with high levels of interdependency. While a user could assess some system effects for single parameters within the model, many effects are mixed with several factors and it would take much longer to assess multi-factor effects in trying to optimize a system manually.

By focusing on improvements in certain areas, the community planners intend to improve the response performance or other community indicators such as restoration time. The optimization method for a complex space may reveal different parameters on which to focus improvement efforts. However since the optimization method performs its calculations without the human involvement, the method may arrive at a different group of improvements

Figure 107: Combined Aspect Focus (Orleans Parish, LA)



which may bring as much of an improvement (or more) than if the selected improvements had been implemented in the community. The method enables an additional perspective on the improvement behavior of the community.

By setting the available parameter ranges to community-realistic boundaries which describe potential changes which the community has the resources to implement, the optimization may also be used to identify the possible improvement in the resilience capability.

Three available algorithms commonly used to optimize complex systems were considered for application in the optimization of a disaster response and restoration system model. The system is nonlinear and has many different parameters with multi-factor effects.

8.7.0.1 Genetic Algorithm

This algorithm is implemented when needing to minimize or maximize nonlinear design spaces with interdependent variables. The steps in the algorithm mimic gene reproduction to arrive at an optimal system configuration through a number of generations of reproduction.

Benefits of using this optimization method include:

- few assumptions required regarding design space
- no gradient information needed
- robust
- can be hybridized with other optimization methods
- functions with multiple local optima can still be optimized

Qualities this optimization method lacks:

- general (although robust)
- chromosome length will be longer for more parameters
- larger search spaces will need larger initial population

Genetic Algorithm Steps

1. Make initial population
2. Evaluate initial population
3. Assign fitness to population
4. Duplication of best fit group of population
5. Mixing method: crossover, mutation, linkage, and/or inversion
6. Evaluate and assign fitness to mixed population
7. Repeat from step 4 until stopping criterion satisfied

The stopping criterion may be based on the number of generations which have reproduced or an error minimum which has been met.

8.7.0.2 Particle Swarm Optimization

This algorithm is used when needing to optimize nonlinear functions. The principle of swarm searching is used in this algorithm, in the same way that a group of animals might swarm to a food source. Information about the best spot is passed throughout the group, or population, and the speed at which a member of the group moves toward the best spot changes depending on how far away from the best spot that member is currently.

Benefits of using this optimization method include:

- effectiveness for finding global optima
- simple to implement - few parameters used in code
- robust
- used for multi-variable functions

Qualities this optimization method lacks

- may not find global optimum
- no gradient use (can benefit or be detrimental)

Particle Swarm Optimization Steps

1. Make initial population
2. Evaluate population "Parameters"
3. Update best position for parameters if applicable and best overall position
4. Apply step size for each parameter (random)
5. Adjust step size based on nearness of best
6. Iterate until stopping criterion is satisfied

The stopping criterion may be based on the number of iterations which have been completed, or an error minimum which has been met.

8.7.0.3 Simmulated Annealing

This algorithm is used for optimization problems with large numbers of parameters. The steps in the methodology mimic cooling schedules for different metals. As the metal cools, the molecules in the metal settle into the optimum configurations for resting.

Benefits of using this optimization method include:

- good solution found even with noisy data

- more solution space is accessed
- computation effort increases slowly as dimensions in the problem increase

Qualities this optimization method lacks:

- may not find global optimum
- may be more complex to set up since cooling schedule is required

Simulated Annealing Steps

1. Initial population generation
2. Implement trades and evaluate (may be random selection for trade/move)
3. Permit fewer "'bad"' trades over time (iterations)
4. Iterate until stopping criterion satisfied

Similar to the two other methods the stopping criterion may be the number of iterations or the value of a minimum error which is met.

8.7.0.4 Selected Method and Application

While any of the three optimization methods mentioned in the previous section would be sufficient for this task in the research, the chosen method was the particle swarm optimization due to the simplicity in its setup.

In order to implement a top-down capability through this methodology, an optimization method is needed to provide some value to different response plans. From a top-down perspective the optimization can show which areas will need to be improved in order to get the optimized objective parameter(s).

The method selection in this case does not mean that any particular choice is superior to the others in its optimization capability. The selected algorithm, particle swarm optimization, was chosen because the programming needed for this algorithm was simplistic in nature and did not require a large number of external function calls.

The programmed algorithm, PSO, searches in a given range. The search direction and speed can be regulated, and this was done for the developed system model. The positive direction velocity was given a maximum value and the negative direction was allowed (to a negative limit) as well.

The stopping criterion were a max number of iterations, or a minimum error value. The best overall (found optimum) is found, given or retained retained and denormalized so you can see how much of a change would be needed from the original value.

The search algorithm does not always give the same optimized parameters, this is because of the shallow gradient of the slope for most of the parameters. There are many local optima, as well as a system space which only changes slightly as the parameter values change. Because of this the search was done several different times and the best parameter values and outputs were kept for the top solutions. The best of these solutions was selected and the data processed to show the changes for each parameter.

Once the changes for each parameter are known, assessment can be done for the sub-parameters and data elements to see which are viable options for changing the parameter values. This choice may also be left to planners. Then, one can just assess the needed parameter changes. For this research the assumption is made that those changes are implemented.

Some of the changes will be more difficult to implement, such as a sex ratio (data parameter which affects Devel SocialInit). In addition to being a difficult data parameter to control, it is also just one element of several which would need to change to affect the overall measure, Devel SocialInit. Many of these options require input from involved personnel and professionals and should be implemented with such knowledge.

The optimization was set up using MATLAB software and used a function which calculated the objective parameter, response time, based on the developed neural network surrogate model. The initialization included an initial best-per-iteration point, and best-overall point which were adjusted throughout the optimization.

Limitations for the search regions were set by implementing the initial population to be seeded within the ranges of the model. If during the optimization the search went outside the model ranges, there was a control loop to check and bring the exceeded parameter back to the edge of the design space. Some of the optimized solutions had a negative restoration time when converted back to original units by un-normalization. The algorithm code contains a constraint that prevents solutions with the negative restoration time from being included in the optimization. If a goal restoration time is desired, for a quantified amount of improvement in the objective parameter instead of a minimization, the minimum limit may be changed to that number, but the number in day units must be converted to the normalized value before it is put into the algorithm.

Because the design space is complex, the number of swarm agents was increased to four thousand to provide better coverage through the space. The stopping criterion for the search were a maximum number of iterations, or a minimum error, which was set as the difference between the last point and the current point. With a larger number of swarm agents, there is a greater breadth of coverage of the design space, and the best in each iteration will reach the global or near global optimum more quickly. This increased the optimization time in the algorithm but the increase in search time was acceptable for the time available.

To generate a group of potential solutions for the optimum restoration time, the optimization was run fifty times. Even with the large number of swarm agents and adjustments made to the other stopping criterion and search parameters, the global optimum restoration time was difficult to find. It is possible that variations in the global optimum found through the algorithm come from the variations in the input data. During the optimization if the algorithm input ranges were too large and no constraints were put on the search, the optimized solutions would be outside of the design space. However if the ranges were too narrow the solution might be too constrained. Future method development should include improving the model relationships and consequently the developed surrogate model.

From the fifty different minimum restoration times, the ten best were selected based on the minimization of the restoration time as well as the minimum amount of change for each parameter (distance from the community's current state). This would reduce the cost of the change on the community to reach the new parameter values. These ten were then ranked to show the changes needed in each parameter. A community, in order to implement any of these plans, would need to break down each parameter into the elements of that parameter and assess which changes within those elements need to be applied so that the parameter value will change to affect the restoration time according to the optimization schedule. The community would then need to make those changes to complete implementation.

Ranking The ranking was done by implementing the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Methodology The two criteria for ranking are the effect on restoration time and the amount of change needed at the parameter level. The restoration time is measured by the percentage change in restoration time from the optimization compared to the current calculated restoration time of the community. The amount of change needed at the parameter level is measured by the composite Euclidean distance of the solution (for all of the contributing parameters) from the original community parameter values. In short, the goal is to find the solution which provides the maximum improvement in restoration time with the minimum amount of changes to the parameter values.

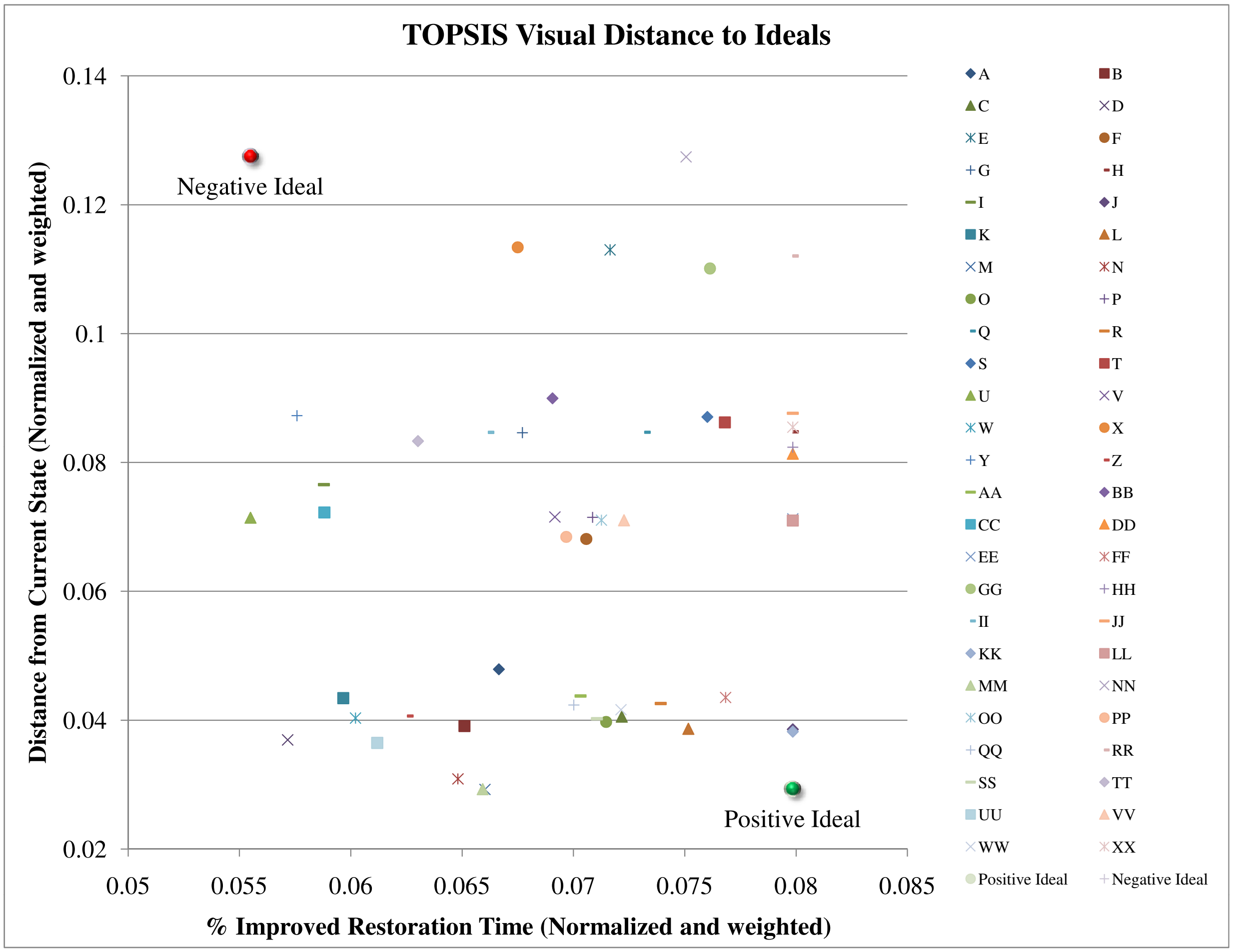
The distance from current state was calculated and normalized for the ranking calculation. The lowest distance from current state and the greatest improvement within the fifty alternatives were set as the positive ideal parameter values, and the greatest distance from current state and the lowest improvement within the fifty alternatives were set as the negative ideal parameter values.

All fifty alternatives are shown in Figure 108. The fifty generated alternatives and their parameter values are included in Appendix C.6. The "closeness to positive ideal" parameter is also included, along with the rank number based on closeness to positive ideal.

While several of the generated alternatives are near the positive ideal, none are at the exact location as the positive ideal. This Pareto frontier shows the limit of the community to its improvement.

Selected parameter ranges within the capability of the community and narrower than the current may yield a different group of optimized solutions, and most likely a different closest-to-ideal solution. This solution may exhibit a lower amount of improvement in the response parameter, but may also require less severe changes in the parameters, which may

Figure 108: Optimized Alternatives



be achieved more reasonably by the community.

The best alternative with its parameter values (greatest closeness to positive ideal value) is shown in Table 41. The "Number" parameter is the order in which the alternatives were generated, going from A to Z to AA to XX.

The highest ranked parameter, or the one with the highest Closeness value, was alternative number KK. The parameters for that particular solution may be seen in Table 41. This particular solution is shown in Figure 109 as a comparison of the original community values with the optimized solution. The normalized values are shown in the radargram.

For some parameters, the optimized values are lower than the original values. Two of

Table 41: Alternative Solution Number KK (Highest Closeness Value)

Parameter	Value
Number	KK
Rank	1
Closeness	0.91152
AD Econ	0.62
AD Envir	0.62
AD Phys	0.62
AD Soc	0.62
Adjust Preparedness	0.327713
Adjust Pro	0.325
Adjustment DSD	1
Adjustment flowExt	0.025
Adjustment flowRes	0.0625
Adjustment flowRest	0.004226
Adjustment flowUn	0.0625
Aid Param1	0.16683
AidDelayAdjust	0.00025
AidExternalFraction	0.26
AidResponseFraction	0.24
AidRestoreFraction	0.42
AidUnofficialFraction	0.058961
CollabInit	2.7375
D EconFactor2	0.73
D EnvirFactor2	0.58
D PhysicalFactor2	0.78
D SocialFactor2	0.62
Devel EconInit	0.1223
Devel EnvirInit	0.125
Devel SocialInit	0.15637
DevelPhysInit	0.19972
Fraction	0.45366
InitialAid	5.08767
Prep Param1	0.32560
PrepositionInit	2.7375
PrepProgramsInit	3.5
ProcurementInit	2.7375
TrainingInit	3.5
Restoration	0.00055

these values are AdjustPro and Adjustment flowRest. Reducing Adjust Pro would mean that the increase in restoration time for higher values of the parameter would be reduced. However, for implementation purposes, this means that the amount of collaboration during

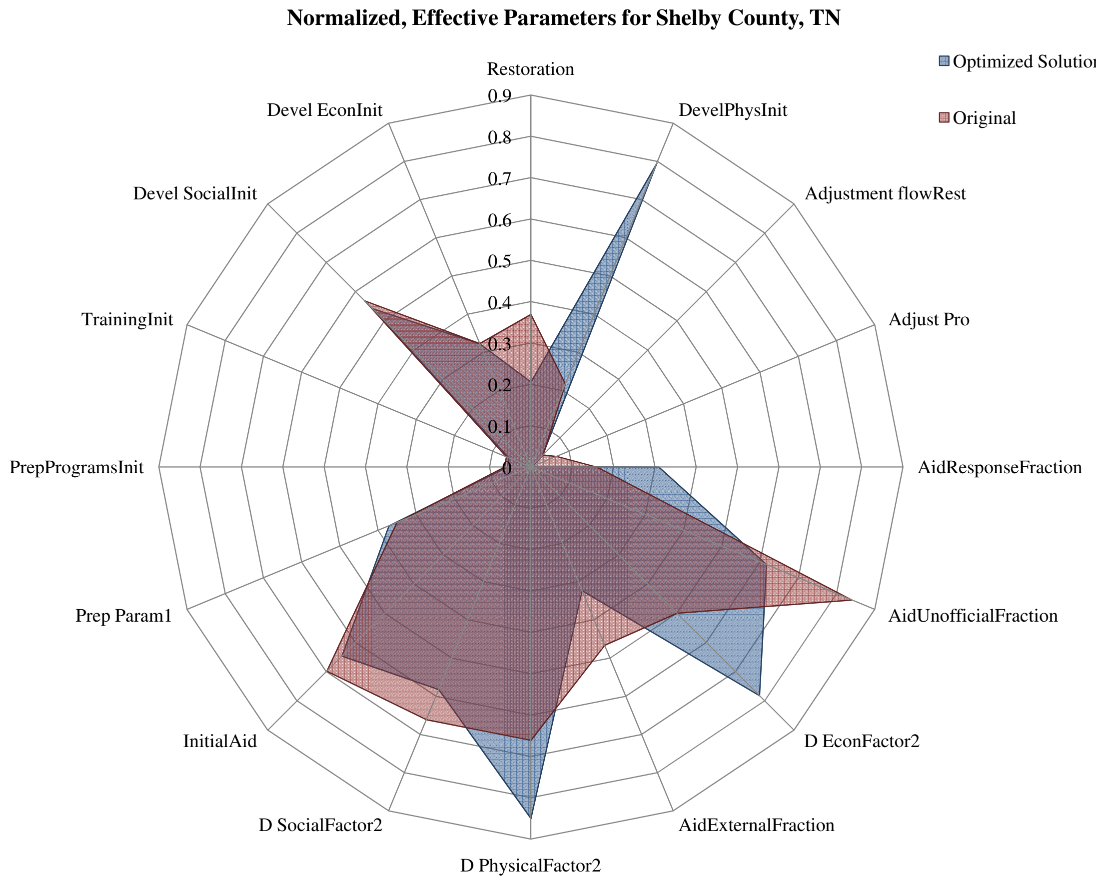


Figure 109: Comparison of Number KK with original solution for Shelby Cty, TN

the post-disaster response phase, or that contributes to the amount of post-disaster resources procured, should be reduced. This may be contrary to current disaster response planning and may be an parameter relationship which needs further clarification. Significant amounts of reduction may consume needed resources as well. Planners should need to assess whether there are other alternatives which do not require such a large amount of reduction that will still reduce the amount of restoration time.

The Adjustment flowRest is a parameter which represents the amount of restoration aid being received into the community and increases the restoration time when the values increase. In the best optimal alternative the value is greatly reduced. This would mean that a community implementing this optimum would put its restoration resources elsewhere. However this is not reasonable since resources contributing toward restoration would still be required and would prolong restoration time if reduced. These values may be showing a lower limit, that is, if the values are reduced, but the other variables are still increased there may not be a detrimental value to the restoration time. If this occurs, each solution should be thoughtfully considered and the implications of such changes in these parameters should be considered carefully.

Other parameters which are increased from the original values include AidResponse-Fraction, D EconFactor2, D SocialFactor2, DevelPhysInit, and Prep Param1. The greatest increase is in the DevelPhysInit parameter, which means that the physical development of the community must be improved or made more resistant to the earthquake-type of disaster. Because the increase is so great, it may be more difficult to implement, in which case some of the other generated alternatives might be considered, or the settings might be entered into the custom graph section of the visualization to see how things would change if the parameter was increased to a lesser amount.

CHAPTER IX

ESCAAPE STEP 5: DECISION MAKING

Information from the system exploration and tests offers insight regarding the community. Decision makers planning for disaster response and restoration for a community can benefit from the information offered by the framework developed in this research. However, the potential volume of available information is very large and must be presented to decision makers in a way which will provide useful information for decision making.

9.1 Presentation of Results

The community development levels and restoration time provide some insight into the system, but in order to provide analysts and planners with more helpful information about their system, the findings must be presented in a way that offers this information. In order to know how best to improve their system or which aspects of the system to focus on, some types of information will be more helpful and enabling than others.

Disaster response planners are operating under limited budget (in preparedness phases, particularly) as well as limited time since many planners fulfill different roles within the federal government. If non-federal workers elect to pursue developing their emergency management abilities and knowledge in their free time, it is likely that they also have other professional or humanitarian roles and responsibilities which may not even be in the same field.

The purpose of visualization techniques is to provide a comprehensive method through which information may be relayed, and by adjusting some specifics about the information being presented, insights may be provided into system behavior. Planners may also be interested in addressing capability gaps, enabling efficient distribution of funds and resources, and overall improvement of resiliency. In Chapter 11 a full capability of the methodology is briefly discussed as a future endeavor. However, the visualization described in this research deals more with merely the visualization of the results of the methodology as a part of the supplication of information for decision making.

The resultant visualizations provide an idea of which aspects of the community, if improved, should allow for greater reduction in the restoration time. A slighter effect may require a longer time for improving the restoration time for a community. If resources become an issue during the implementation of improvements before the disaster, a community would be able to see which areas would respond the most to improvements and effectively allocate the resources they do have.

There are three sections in the visualization for ESCAAPE decision support. Figure 110 shows a screenshot of the visualization.

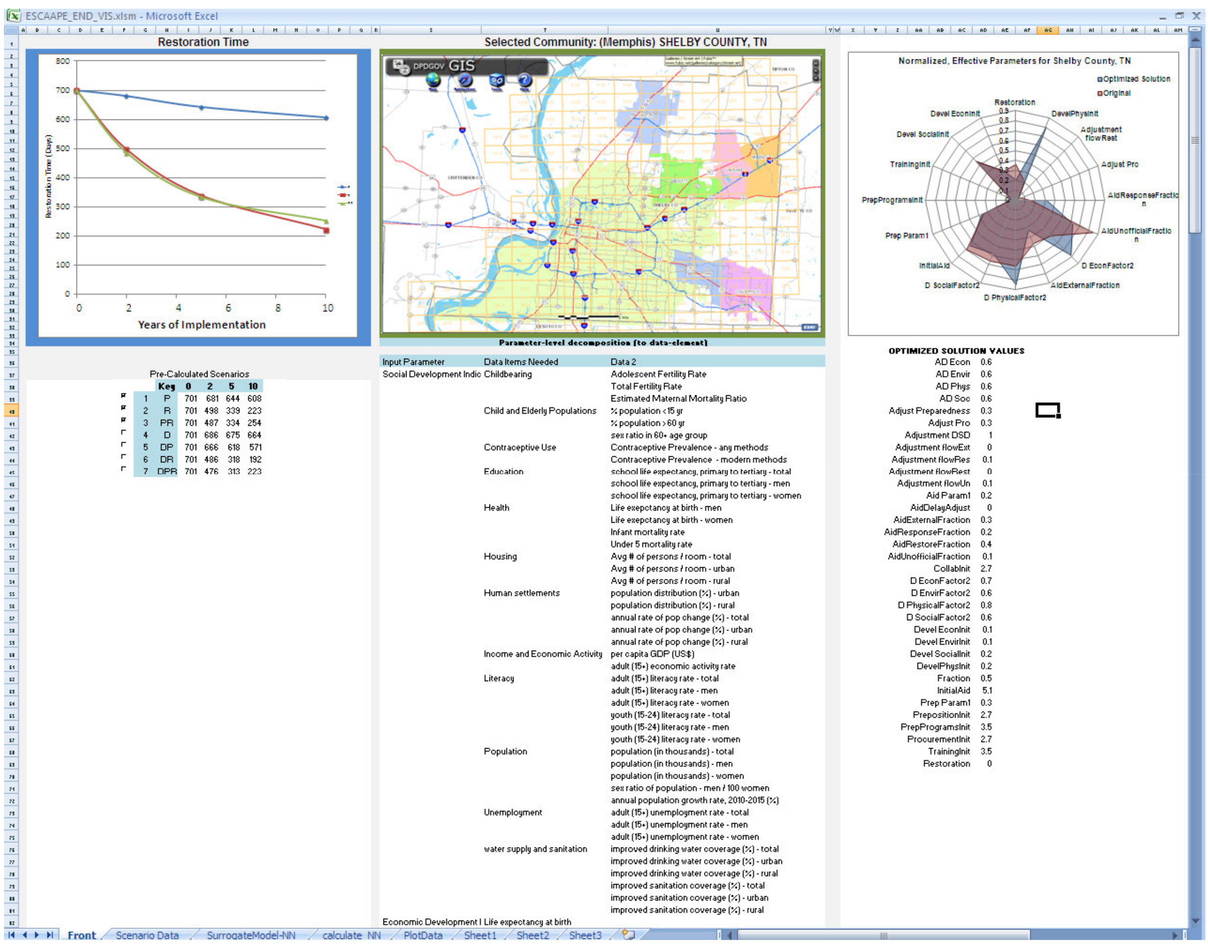


Figure 110: Visualization for Information presentation in ESCAAPE

- System Definition and Decomposition

The parameter, sub-parameter, and data element decomposition of the system is shown in the center of the visualization area.

- Scenario Assessment and Comparison

  The user-input scenarios with the varied implementation time are shown on the left side of the visualization area.

- Optimized Solution

  The optimization generated fifty alternatives. The closest ranked alternative based on the TOPSIS ranking is shown on the right side of the visualization area. The radargram shows the original community parameter values and compares them to the optimized solution.

Planners will be able to see which aspects need to be improved on, and the relative amount of improvement shown in a graph. The "Distance" parameter shows the amount of change which is needed in a parameter, but an expert or committee of experts would need to carefully breakdown the parameter into different areas which will respond to changes and affect the parameter. Some possible areas of change which are a part of the parameter decomposition may be more difficult to implement than others. An example of this would be for the initial level of social development. The "sex ratio" parameter is something in the community that would be more difficult to forcibly change, than the "unemployment rate" parameter, for example.

Because several data elements compose each of the parameters, the difficulty for improvement in a parameter depends on the different data elements which compose the parameter and the improvement difficulty of those elements. Ultimately the concern is to expend fewer resources as far as changes within the community are concerned, but with greater effect on improving the restoration time of a community.

Based on the location of the current community within the graph and the relationships with all of the other variables it may be difficult to assess whether improvements made in any one particular parameter or area will significantly change the restoration time. Within that parameter's aspect category, it may also be important to assess whether or not the measures of the aspect have changed or improved at all with a change in a particular parameter.

However, because of the nature of the system, the model has many interdependencies and reflects these interdependencies with complex behavior. Many changes in single parameter or aspect values may only result in slight changes or no changes in the restoration time. Including the optimization alternatives in the planning considerations enables options which implement changes in several parameters at a time.

While the optimized changes as well as the user-defined scenarios offer direction for improvement based on the inputs, any implementation of alternatives should have extensive input from deeply involved emergency management personnel or individuals invested in the community professionally or in a humanitarian sense. An implementation plan should be developed with specific actions that will improve the aspects of the community which are measured by the parameters of interest. With the involvement of individuals that are already involved within the community in implementing change, the specific actions should then be carried out for the implementation of the selected plan to improve the restoration time of the community.

9.2 Application in Disaster Response Planning

The methodology is purposed to be an enabler of community quantification for both development prior to a disaster as well as an assessment of different planning scenarios. It is meant to function at a system level but intake data at a detailed level. Planners may select performance or response metrics at a system level, and proceed to evaluate and compare a selected community after implementing the steps in the methodology.

9.2.1 Example Application in Resource Allocation

An example was conducted of how the ESCAAPE methodology might be used to assess resource allocation options. The resources available to aid in the immediate response after a disaster are important to performing critical response functions. In particular, assets such as those used in search and rescue will help to increase the number of rescued persons. With too few assets, stranded or trapped persons may suffer worse effects of their injuries or may not live to be rescued. Examples of this are evident in the response to both Hurricane Katrina in New Orleans in 2005 and in Haiti after the 2010 Haiti Earthquake. [153, 110, 52, 47, 40, 12]

The parameter for fraction of missing persons found alive, in the model is not further decomposed. However, to show the application in resource allocation, the parameter is further decomposed to the following:

- Support Asset Allocation - having more search assets allocated to a community will increase search and rescue capability by enabling search and rescue teams to cover a greater area in less time, and provide access to areas which may otherwise be inaccessible after a disaster.

- Percentage of Area Covered by Rescue Parties - if rescue parties are able to cover more areas in their search for trapped or injured persons, it is likely that more trapped or injured persons will be found.

- Severity of Disaster - an increased severity in the disaster may increase the damage to the community infrastructure which may both trap and/or injure more persons and make rescuing them more difficult.

Support Asset Allocation may be then further decomposed to the following:

- Assets Allocated: Yes or No - If the assets have not been allocated prior to the disaster, a delay will occur while the proper permissions are acquired to allow the deployment of the assets.

- Group of Assets Allocated - This parameter might assume different combinations of available assets, with the perspective that more assets will increase the number of found persons by enabling search parties to cover more area.

The normalization values are as follows: Where the assets group are the following: In the case of this example, the Assets have been properly allocated, and the Group of Assets Allocated is 3 Helicopters with 2 UAVs. This gives the following values to the parameters:

Table 42: Asset Allocation Normalization

	Normalization Value		
Parameter	0.1	0.5	0.9
Assets Allocated: Yes or No	NO		YES
Group of Assets Allocated	A	B	C

Table 43: Asset Groupings

Asset	A	B	C
Helicopter	< 3	3	5
UAV	0	2	5

$$\text{Assets Allocated} = YES = 0.9$$

$$\text{Group of Assets Allocated} = B = 0.5$$

With an equal weighted sum as the aggregation function to provide a value to the Support Asset Allocation, the value calculation is as follows:

$$\begin{aligned}\text{Support Asset Allocation} \quad & w \times \text{ Assets Allocated} + w \times \text{Group of Assets Allocated} \\ & = 0.5 \times 0.9 + 0.5 \times 0.5 \\ & = 0.7\end{aligned}$$

The values for the two other parameters at the same level as Support Asset Allocation are assumed or selected as:

$$\begin{aligned}\text{Percent of Area Covered by Rescue Parties} \quad & = 0.6 \\ \text{Severity of Disaster} \quad & = 0.65\end{aligned}$$

The Percent of Area Covered by Rescue Parties may be found through expert input or from assessing prior search and rescue capabilities. The Severity of the Disaster is another parameter in the model, and for this example was set to be 0.65.

By an equal weighted sum calculation, these three parameters are aggregated to provide a value for the Fraction of Missing Found Alive as follows:

$$\begin{aligned}\text{Fraction of Missing Found Alive} =& w \times \text{Support Asset Allocation}\\ &+ w \times \text{Percent of Area Covered by Rescue Parties}\\ &+ w \times \text{Severity of Disaster}\end{aligned} \tag{120}$$

with the numerical values:

$$\begin{aligned}\text{Fraction of Missing Found Alive} &= \frac{1}{3} \times 0.7 + \frac{1}{3} \times 0.6 + \frac{1}{3} \times 0.65\\ &= 0.72\end{aligned} \tag{121}$$

This supplies the Fraction of Missing Found Alive parameter value at the next highest level, where the equal weighted sum calculation for the Efficiency of Response Aid parameter is as follows:

$$\begin{aligned}\text{Efficiency of Response Aid} =& w \times \text{Fraction of Missing Found Alive}\\ &+ w \times \text{Fraction of Injured Who Received Aid}\\ &+ w \times \frac{\text{Amount of Food Distributed}}{\text{Amount of Food Needed}}\end{aligned} \tag{122}$$

with the numerical values:

$$\begin{aligned}\text{Efficiency of Response Aid} &= \frac{1}{3} \times 0.65 + \frac{1}{3} \times 0.8 + \frac{1}{3} \times 0.4\\ &= 0.62\end{aligned} \tag{123}$$

If the asset allocation is selected so that option C of the group of assets allocated is five helicopters and five UAVs, then the selection is normalized as follows:

$$\begin{aligned}\text{Assets Allocated} &= YES = 0.9\\ \text{Group of Assets Allocated} &= C = 0.9\end{aligned}$$

with the consequent calculations as follows:

$$\begin{aligned}\text{Support Asset Allocation} \quad & w \times \text{Assets Allocated} + w \times \text{Group of Assets Allocated}\\ &= 0.5 \times 0.9 + 0.5 \times 0.9\\ &= 0.9\end{aligned}$$

If value for the other two parameters at the same level as the Support Asset Allocation parameter do not change, then the calculation for the value for the Fraction of Missing Found Alive parameter is as follows:

$$\begin{aligned}\text{Fraction of Missing Found Alive} &= \frac{1}{3} \times 0.9 + \frac{1}{3} \times 0.6 + \frac{1}{3} \times 0.65 \\ &= 0.72\end{aligned} \tag{124}$$

The Efficiency of Response Aid parameter would then be calculated:

$$\begin{aligned}\text{Efficiency of Response Aid} &= \frac{1}{3} \times 0.72 + \frac{1}{3} \times 0.8 + \frac{1}{3} \times 0.4 \\ &= 0.64\end{aligned} \tag{125}$$

For the selected support assets, the effect of the allocation of a greater number of assets has now been demonstrated to show a quantified change in the Efficiency of the Response Aid. Previous planning methodologies for communities to implement in disaster response planning did not involve quantification of the effects of changes in resource allocation or any other type of improvement changes which may be implemented in a community.

Application potential for this community exist in assessment and preparedness and response planning, areas which are critical to the resilience capability of a community.

9.2.2 Example Application in Resource Assessment

Resource assessment applications are also possible with the implementation of the framework. An example is explored in the context of the assessment of air facilities and the capability added by the acquisition of an air facility. For disaster response, air facilities enable distribution to areas which may be inaccessible after a disaster. This is especially critical in communities where the disaster may destroy transportation infrastructure, making aid difficult to distribute in certain parts of the community. For some communities such as island nations, air facilities add capability for receipt of external aid, or other forms of aid when roads are destroyed.

The importance of air facilities and the added aid receiving capability was demonstrated in the aftermath of the Haiti earthquake in 2010. A single runway and the confusion due to a high volume of incoming aid and few resources and personnel available to organize operations at the air facility as well as incoming aircraft that were unable to refuel, the incoming aid was delayed in its distribution as victims of the earthquake remained without food, water, and shelter for several weeks. [29, 20]

In this assessment the parameter to be decomposed similar to the previous example is the AidDelayAdjust parameter, which scales the delay in the aid which occurs after the disaster. A greater parameter value represents a higher amount of delays being experienced by the community. The original developed model used Preparedness and Severity as the data element values to be aggregated. This assumes that a higher level of preparedness will enable the community to experience fewer delays, while a higher severity disaster will increase the amount of delays.

For this assessment the assumption is made that a collaborative workshop has resulted in a consensus for another parameter to be included as a data element for the AidDelayAdjust parameter. This selected parameter is a receiving capability amount.

This may then be incorporated into the data aggregation. Further decomposition based on available information or expert input may select the following data elements: Fraction of roadways still accessible, Fraction of runways in operation, and Fraction of docks in operation.

The Fraction of operating docks and roadways will be assumed and held constant for this exercise. Their values are:

$$\begin{aligned} \text{Fraction of accessible roadways} &= 0.05 \\ \text{Fraction of operating docks} &= 0.05 \end{aligned}$$

In the Haiti Earthquake community, no runways were initially open, so the Fraction of operating runways = 0.

The aggregation of the values for the AidDelayAdjust parameter is as follows:

$$\begin{aligned} \text{ReceivingCapability} &= w \times \text{Fraction of accessible roadways} \\ &+ w \times \text{AidDelayAdjust} + w \times \text{Fraction of operating runways} \\ &= \frac{1}{3} \times 0.05 + \frac{1}{3} \times 0.05 + \frac{1}{3} \times 0 \\ &= 0.033 \end{aligned} \tag{126}$$

$$
\begin{aligned}
\text{AidDelayAdjust*} &= w \times \text{Preparedness} + w \times \text{Severity} + w \times \text{ReceivingCapability} \\
&= \frac{1}{3} \times 0.005 + \frac{1}{3} \times 0.3 + \frac{1}{3} \times 0.033 \\
&= 0.1113
\end{aligned} \tag{127}
$$

Because a greater parameter value means greater delays, and the data elements are normalized so that greater means fewer delays,

$$
\begin{aligned}
\text{AidDelayAdjust} &= 1 - \text{AidDelayAdjust*} \\
&= 0.8887
\end{aligned} \tag{128}
$$

If an air facility is required, however, the Fraction of operating runways will have a value of 0.5 (assuming that there are two airports, each with one runway, and one is operating and the other has been rendered inoperable by the earthquake).

Then, the aggregation of the values for the AidDelayAdjust parameter is as follows: The aggregation of the values for the AidDelayAdjust parameter is as follows:

$$
\begin{aligned}
\text{ReceivingCapability} &= w \times \text{Fraction of accessible roadways} \\
&\quad + w \times \text{AidDelayAdjust} + w \times \text{Fraction of operating runways} \\
&= \frac{1}{3} \times 0.05 + \frac{1}{3} \times 0.05 + \frac{1}{3} \times 0.5 \\
&= 0.2
\end{aligned} \tag{129}
$$

$$
\begin{aligned}
\text{AidDelayAdjust*} &= w \times \text{Preparedness} + w \times \text{Severity} + w \times \text{ReceivingCapability} \\
&= \frac{1}{3} \times 0.005 + \frac{1}{3} \times 0.3 + \frac{1}{3} \times 0.033 \\
&= 0.1668
\end{aligned} \tag{130}
$$

Because a greater parameter value means greater delays, and the data elements are normalized so that greater means fewer delays,

$$
\begin{aligned}
\text{AidDelayAdjust} &= 1 - \text{AidDelayAdjust*} \\
&= 0.8332
\end{aligned} \tag{131}
$$

Because the model is developed with an objective parameter which addresses long term restoration, the long-term restoration capability is not significantly affected by this change.

The minimal effect on the aid being sent to the community (Aid parameter) is shown in Figure 111. The effect is shown by the area of the graph inside the red circle. It is minimal because the model output is a long-term assessment of the parameter values. The disaster occurs at Time = 100, and the blue data trend shows the trend for the community with one functioning air facility (runway). The red data trend shows the trend for the community with no functioning air facility (runway). In a community, the initial delay in aid receipt and distribution will not significantly affect the long-term community restoration. There will be a greater effect on the amount of casualties after the disaster. This, or other post-disaster response parameters, may be incorporated into the model with further research and guidance from experts.

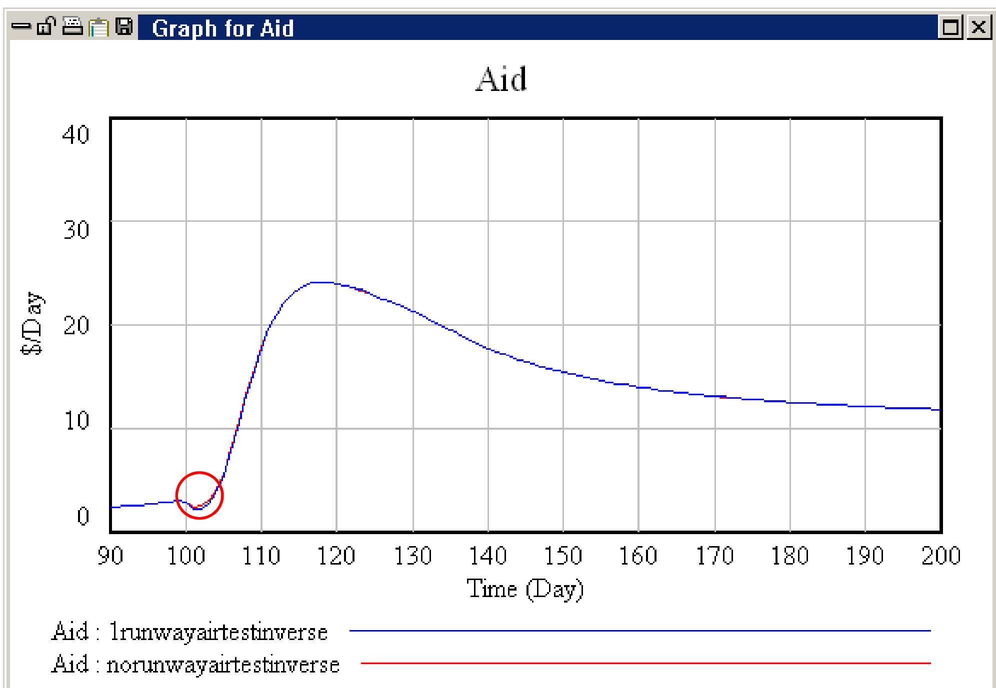


Figure 111: Air Facility Effect on Aid

Figure 9.2.2 shows the effect of the air facility presence on the amount of delay that the community experiences in receiving the aid which is sent. The red data trend shows that the community with no air facility presence will experience an amount of delay greater than the blue data trend, which is the community with one functioning air facility. While this delay parameter is not connected to the response performance, the model may be modified to reflect that inter-parameter relationship.

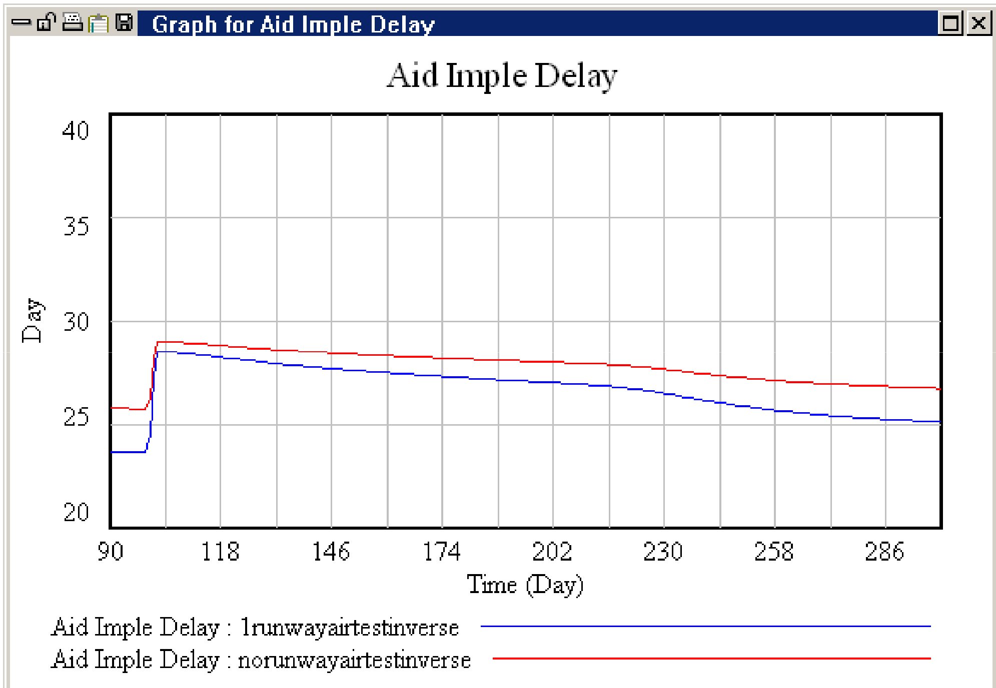


Figure 112: Air Facility Effect on Aid Delay

Additional expert input is also required to further develop the relationship between the aid delay and the effect on the implementation rate of the aid in the community. This type of assessment requires more response level parameters. This is possible with the implementation of the ESCAAPE methodology. The current model was not developed with that capability, but the potential for assessing both short and long-term effects of air facility resources exists.

9.2.3 Application in Community Assessment

This capability may be implemented for the purposes of community assessment. Some aspects of the community may be assessed to be areas of strength while other aspects of the community may be areas which may need improvement. By identifying these aspects through system definition and quantifying the extent to which different aspects affect the community restoration time, a quantitative comparison may be made of the state of the community to a prior or projected state of the community or a set standard or "ideal" community.

9.2.4 Application in Community Preparedness, Response, and Restoration Planning

For the purposes of community preparedness, response, and restoration planning, this capability enables quantification of the effects of different actions or improvements which may be implemented in the community.

Different changes may have stronger or weaker effects on the response capability of the community. If the response parameter(s) or objective parameter(s) has been selected to represent the priorities of the planners, assessment of different improvement scenarios may be done, and information provided as to which scenario provides the greatest effect on the community objective parameter(s).

The community may also address multi-disaster planning, or all-hazards planning in which resilience to more than one type of disaster is addressed during planning. The previously discussed Matrix of Disaster Alternatives provides a selection matrix for different disaster scenarios which may provide a starting point for assessment.

CHAPTER X

CONCLUSIONS

A review of the completed work, contributions, and a revisitation of the research questions and hypotheses is included in this chapter.

10.1 General Concluding Points

10.1.1 Completed Work

Development was done of a methodology for Exploration of System-level Capability through Aggregation and Analysis of Parametric Elements which enables disaster response and restoration planners to quantify the effect of implemented changes on a community. This was implemented to example communities based on data from actual communities within the United States. Selected parameter combinations may be changed to represent different community improvement plans, which enable the comparison of different plans for effectiveness in improving the objective parameter. The effects of allocated community resources may also be tested to determine which have the most desirable effect on the objective parameter.

10.1.1.1 Standardized Planning Methodology

The ESCAAPE methodology was developed to enable Exploration of System-level Capability through Aggregation and Analysis of Parametric Elements.

Step 1: Selection Selection of system boundaries and included disaster type or types.

Step 2: Definition Decomposition and definition of system aspects, parameters, subparameters, and connection of these components with data elements which enable quantification.

Step 3: Development Set up system model in appropriate environment and with appropriate inter-parameter and system-level relationships and metrics, and verify and validate the model.

Step 4: Exploration Set up a simulation environment which uses the system model to determine the behavior of the system based on an experiment.

Step 5: Decision Making Make information from system exploration available to decision makers and planners to aid in decision making and to contribute to the implementation of improvements to the community which will help to reduce the time to restoration after a disaster.

10.1.2 Contributions

The author synthesized a methodology for parametric exploration of a community to provide decision support information to disaster preparedness, response, and restoration planning personnel. The methodology enables long-term assessment of a community's capability for restoration after a disaster event by parameterization of the components of the community, which link different aspects to be detrimental or helpful in the community restoration process. The methodology also enables quantification of changes in community characteristics.

The author demonstrated an example of the methodology implementation for a community addressing a future disaster hazard and a community which had previously experienced a disaster occurrence. For both communities, the author demonstrated the effects of improvement implementation for different groups of improvements, or focus areas.

The author demonstrated the application of parametric systems design to a highly complex, highly layered, and interdependent system which experiences and must recover from sudden and overwhelming external disturbances. This was done in an environment where system behaviors are not well documented and have little historical basis.

10.2 Verification of Hypotheses and Research Questions

10.2.1 Area 1: Assessment of Current Capability

10.2.1.1 Hypothesis One

Application of parametric design principles will improve current disaster response and restoration planning practices by adding capability which is currently not present in the field.

- The ESCAAPE Methodology achieved the application of parametric design principles to a system model of Shelby County.
- The improvement to current response and restoration planning practices is achieved by the added capability for quantification, assessment, and comparison of the effect of improvement implementation plans, represented in the model by the community focus areas, on the selected objective parameter, Restoration Time.
- A background review of current capabilities revealed that the aspect of the humanitarian logistics field which focuses on disaster response planning capability currently does not have this capability.

10.2.1.2 Related Questions

1. What capabilities are currently present in the field? The background review of available literature and expertise revealed that:
    - Current Disaster response planning takes place reactively after a disaster occurrence. Shortfalls revealed during the post-disaster response and restoration period are identified and addressed within the community.
    - Current focus is actively done in the areas of forecasting, collaboration, resilience planning, and all-hazards planning.
    - Current planning tools include collaboration exercises, response management collaboration meetings, disaster prediction through simulation programs utilizing GIS data, vulnerability assessment through community metrics from the

humanitarian logistics field, and performance feedback through media coverage and post-disaster assessment research.

2. What capabilities are currently needed?

    - Currently there exists a need for a comprehensive framework which will provide a means for planning to implement changes to communities to improve the response and resilience to disasters. This framework may also be developed to add value to the implementation of the changes, to provide a quantitative or financial basis for the changes.
    - There also exists a need for technical standardization. This is needed in order to standardize metrics which enable the development of a general response plan testing area or platform which communities may make specific to their community characteristics. Technical standardization will also enable the knowledge of behavior of community aspects to be developed through the research methodology.

3. How will parametric design principles be applied?

    - In this research, parametric design principles were applied through the parametrization of the community as a system. This enabled system behavior to be assessed in light of a selected response or performance variable. The system itself was specified by selecting values for each of the parameters which were reflective of the system characteristics.
    - Much of this parameter data came from different data statistics available to the public. The parametrization steps were included in the developed methodology for Exploration of System-level Capability through Aggregation and Analysis of Parametric Elements (ESCAAPE). ESCAAPE Steps can be seen in the previous section.

4. Which capabilities will be added by the application of the principles?

- Quantification - effects of implemented changes may be observed by the performance metric. This enables testing and assessment.
- Testing - different selected changes and their effect on the community restoration capability may also be observed by effect on the performance metric. Communities may test different changes and select the most effective for implementation and better use of resources.
- Assessment - the community restoration capability may be assessed and compared to another community or to the same community under different circumstances. This enables development of a community benchmark or standard.

10.2.2 Area 2: Parametrization of the System

10.2.2.1 Hypothesis Two

Representation of the community as a system through model development will enable quantified community assessment and comparison.

- This was achieved by developing the community system model as a system dynamics model, whose verification of the development level of the community showed that the model behavior was representative of the community disaster cycle response and restoration phases.
- A quantified objective parameter, Restoration Time, enabled comparison of communities. The communities of Shelby County and pre-Hurricane Katrina Orleans Parish were assessed by comparing effect of the community focus areas on the objective parameter.

10.2.2.2 Related Questions

1. What type of model will best represent the community as a system?

   The answer to this question was achieved through system type assessment and model selection.

System Type Assessment helps to determine some of the characteristics of the system, such as the complexity of the system as far as the system behavior, some of the parameters and information which is being passed within the system, and how interdependent the parts of the system are.

In this research, the system was found to be complex in behavior, with high levels of interdependency among the system parameters. Within the system, resources are passed back and forth among the different parameters through time. The resources may be skilled personnel resources, financial resources, or supply resources.

Model Selection occurs once the type characteristics of the system are known, and if the model selection needs a surrogate model to provide even faster information this would also be considered in the model selection.

From the review of applicable system models, the selected model was a system dynamics model. In this model, the system was decomposed to several levels, the lowest of which was connected to different data elements to provide quantification. The relationships among the parameters were included in the model. The surrogate model was to be used if the original system model was not fast enough to provide information. The chosen surrogate modeling method was a neural network, which was able to capture complex system information for a system with many parameters.

2. How will model development be done?

   The model development was done by the following steps:

   - System selection - Shelby County, TN, was selected as the community to be defined. Selection of other communities may also be done using the morphological matrix.
   - System definition - the selected community was decomposed to different elements. The levels of system decomposition were then connected to specific data elements.
   - System development - after the decomposition has been done, relationships were developed among the different components. These relationships enable a model

to be developed in the selected system dynamics software. The VENSIM software was used, as well as an equal weighted sum by which the data elements were connected with the model input.

System parameter relationships to the objective parameter are developed during the original model planning and development. Relationships can extend across different hierarchical levels. The relationships determined through the literature research and used in the model need further definition.

For the model developed in this research, sub-parameters and data element values were equally weighted and aggregated to the parameter level. However with more knowledgeable input, from emergency response professionals or humanitarian logistics organizations, the weights might be shifted to reflect more correct relationships. This may also be done to improve the aggregation methods as well as the relationships within the system model itself. This will improve the calculated effect on the objective parameter, which will improve system exploration and the information which can be provided.

Past Disasters , reports, or reliable media coverage contributed to the development of inter-parameter and inter-data-element relationships. Some of the reviewed disasters are listed in Table 44 with the particular locales reviewed in the research. The severity column uses the most common rating scale. The value listed is the greatest known severity recorded for the event.

- How will the model enable community assessment?

  A response parameter is defined, which enables community assessment. Different system-level parameter values may also be observed over the simulation times to assess the community behavior as the response and restoration occur.

Objective parameters help to quantify the effect of changes to the response assessment. For this situation, restoration time for the community was selected

Table 44: Partial list of disasters reviewed in this research

Year	Type	Severity	Name	Location
1812	Earthquake	7.0-8.1 M	1812 New Madrid Earthquakes	Southeast US (TN, MO, AK)
1951	Flood		Great Flood of 1951	US (KS, MO)
1999	Flood		Vargas Tragedy	Venezuela
2004	Earthquake	9.2 M_W	Indian Ocean Tsunami	Sumatra, Indonesia
2005	Hurricane	CAT5	Hurricane Katrina	US (FL, LA, AL, MS) and Caribbean
2005	Hurricane	CAT5	Rita	US (TX, LA)
2006	Hurricane	CAT4	Hurricane Ike	Caribbean and US (AL)
2008	Cyclone	CAT4	Cyclone Nargis	Myanmar
2008	Earthquake	7.9 M_W	Sichuan Earthquake	China
2010	Earthquake	7.0 M_W	Haiti Earthquake	Haiti
2011	Earthquake	9.0 M_W	Tohuku Earthquake	Japan

as the objective parameter. One parameter is the minimum although more may be selected. Model development and surrogate model development may be a little more complex with more objective parameters.

Restoration time for the community will change depending on the state of the community and different aspects. It provides a helpful metric in the sense that a disaster striking while a community is still rebuilding will prolong the time the community needs to restore themselves and also may intensify the effects of the disaster.

- What kind of assessment will be able to be done?
  - Quantification - effects of implemented changes may be observed by changes in the performance metric
  - Testing - different selected changes and their effect on the community restoration capability may also be observed by effect on the performance metric
  - Assessment and Comparison - assessment of current community state and comparison to the effects of any changes (or comparison to other communities) is made possible as well through observed changes in performance metric.
- How will the model enable community comparison?

Simulation enables quantified parameters to have data generated from the developed model. This gives value to the response parameters based on the input data elements. Different experiment designs used in simulation can provide information for sensitivity analysis, widescale system behaviors, or specific experimental studies for particular circumstances. This research included sensitivity analysis to reduce the number of variables used in the system exploration, and system exploration to understand the behavior of the objective parameter based on changes in the selected variables.

Scenario comparison is done once simulations are complete. Different potential changes made to a community may be implemented into the model, simulated, and compared to see which one affects the objective parameter in the most desirable manner. Different communities may also be compared to assess which differences in the communities contribute to greater or shorter response times. For this research, within one community, three different aspects were selected as improvement focus areas.

The improvement focus areas were Development, Response, and Preparedness. Different data elements were attributed to each focus area and as the simulated implementation period was increased, the values of the data element were changed to reflect an assumed improvement made by the community in those areas. Two communities, Orleans Parish in Pre-Hurricane-Katrina state and current Shelby County state, were assessed for single improvement focus aspect areas, and were also compared with each other. Differences in community input values may be visualized in the form of a radargram.

10.2.3 Area 3: Application of Response Planning Methodology

10.2.3.1 Hypothesis Three

The development of a methodology for Exploration of System-level Capability through Aggregation and Analysis of Parametric Elements will improve disaster response and restoration planning objectives by enabling implementation plan comparison and selection.

- The ESCAAPE methodology enables a community to parametrically decompose system aspects for quantification by available data elements.

- As changes are made to the community through implementation plans, the effect on the objective parameter is shown and provides information for disaster response planning professionals to select a more effective implementation plan.

10.2.3.2 Related Questions

1. What steps will be included in the methodology? The methodology steps were synthesized from related methodologies in business process re-engineering, engineering design, and military response planning. The methodology includes the following steps:

    - **Step 1: Selection** Selection of system boundaries and included disaster type or types.

    - **Step 2: Definition** Decomposition and definition of system aspects, parameters, sub-parameters, and connection of these components with data elements which enable quantification.

    - **Step 3: Development** Set up system model in appropriate environment and with appropriate inter-parameter and system-level relationships and metrics, and verify and validate the model.

    - **Step 4: Exploration** Set up a simulation environment which uses the system model to determine the behavior of the system based on an experiment.

    - **Step 5: Decision Making** Make information from system exploration available to decision makers and planners to aid in decision making and to contribute to the implementation of improvements to the community which will help to reduce the time to restoration after a disaster.

2. What are the objectives?

    The objective of the disaster response and restoration planning is to reduce the impact from the disaster and also enable the community to more quickly restore itself to its previous state. Once this is accomplished, the restoration can continue into further development of the community.

Based on this, the quantified objective parameter for this research was selected as the Restoration Time of the community because it provided a value for the planning objective. The value is a long-term indicator of the resilience capability of the community.

3. How will the objectives be quantified and improved?

   The Restoration Time was quantified by defining the recovery period as the time between the disaster occurrence and when the community reaches a goal level of development higher than the one in the pre-disaster community. Based on the relationships developed in the model, some of the parameters have a significant effect on the objective parameter and may either improve it (reduce the restoration time) or worsen it (increase the restoration time, leaving the community vulnerable to disasters or other events before it may be able to deal with such occurrences).

   If the parameter values change in a way which improves the restoration time, these changes, if actually taking place in the community, may cause an improvement in the community resilience.

4. What is an implementation plan?

   An implementation plan refers to a number of changes to occur within a community with the objective of improving the community restoration time. Several changes may be recommended after the system exploration and assessment. These changes should be tested within the community model so that their effectiveness on the restoration time are confirmed, with quantified effects shown in the model. In this way, different plans may be compared or tested. The implementation itself should be carried out by community residents and leaders in a planned fashion.

   Because no precedent is available for this research, some estimated changes at the data level were selected to represent changes to community parameters. Expert input and further data gathering may help to provide some general precedents to implementation plans developed in this research.

One of the implementation plans in the model was the scenario improvement focus areas, where a group of selected changes was made over time in order to improve the objective parameter. An example of an implementation plan focusing on improving the community preparedness over three different time increments is shown in Table 45.

5. How will the implementation plan be compared and selected? Three different focus area implementation plans were tested and compared visually by graphical comparison of the objective parameter. Other plans may be developed and compared with these plans. The selection of the plan depends on the decision maker, planner, or committee who is testing the different plans.

   The graphical comparison of the implementation plans can be seen in Figures 106 and 107 in Chapter 8.

Table 45: Example of Shelby County TN Preparedness Focus Area Implementation Plan

Model Parameter	Decomposed Parameter Components	Original	2 year	5 year	10 year
Preparedness TrainingAdjust	Collaboration	2.737	2.75	3	3.25
Preparedness ProgramAdjust	Collaboration	2.737	2.75	3	3.25
TrainingInit	Budget Status	1	1	1	1
	Recentness of last disaster	0	0	0	0
	probability of another disaster occurring	0.085	0.1	0.2	0.3
PrepProgramsInit	Budget Status	1	1	1	1
	Recentness of last disaster	0	0	0	0
	probability of another disaster occurring	0.085	0.1	0.2	0.3
ProcurementInit	Amount of warning	0.01	0	0	0
	Budget Status	1	1	1	1
	Recentness of last disaster	0	0	0	0
	probability of another disaster occurring	0.085	0.1	0.2	0.3
PrepositionInit	Amount of warning	0.01	0	0	0
	Budget Status	1	1	1	1
	Recentness of last disaster	0	0	0	0
	probability of another disaster occurring	0.085	0.1	0.2	0.3
CollabInit	Amount of warning	0.01	0	0	0
	Budget Status	1	1	1	1
	Recentness of last disaster	0	0	0	0
	probability of another disaster occurring	0.085	0.1	0.2	0.3
Wt TrainProc		0.5	0.5	0.55	0.6
Wt Prog Proc		0.2	0.2	0.22	0.25
Wt TrainPrep		0.5	0.5	0.6	0.7
Wt ProgPrep		0.2	0.2	0.3	0.32
Wt TrainColl		0.5	0.6	0.7	0.8
Wt ProgColl		0.2	0.3	0.4	0.5
Adjust Pro	Training Organization	0.7	0.75	0.85	0.9
	Communication	0.5	0.6	0.65	0.75
	Procurement	0.5	0.6	0.7	0.75
	Prepositioning	0.4	0.5	0.55	0.65
Prep Param1	Preparedness programming	0.8	0.85	0.9	0.95
	probability of another disaster occurring	0.085	0.1	0.2	0.3
	Recentness of last disaster	0	0	0	0

CHAPTER XI

RECOMMENDATIONS FOR FUTURE WORK

Because this research was a self-directed and non-externally funded work, the potential breadth of the implementation may be further realized from more extensive research and added resources provided by expert input which may come by means of a collaborative workshop or other collaborative network event which enables provision of feedback from experts within the disaster response and restoration planning field. This list and brief description of future work and how one might go about accomplishing it is not comprehensive in topic or solution method. Those implementations will be left to those who are beginning to implement this method in their communities.

11.1 Range Limitations

Range limitations were high in the developed model. For values outside of those ranges the extrapolation accuracy was very low, so even if another community were to be selected and defined, any values that are beyond the bounds in the model either must be considered to be the nearest bound which would put them back at the edge of the range space. When implementing the data for Orleans Parish, this became an issue although the community was still within the US.

Future work would begin with the model development, where the model would be developed under circumstances which allow it to be considered over a wider variety of parameter values. This would allow for a model which would be able to properly model other values without needing to add a lot more data or bring back each point from the edge of the design space if it happens to go beyond the allowed ranges.

11.2 Model Development

Incorporating data from various disaster scenarios would also help to make a more robust system model. The implementation of actual disaster data would give more insight into system behavior and the effects of different parameters and measures on the objective parameter.

The model may also be developed to include a higher level of detail. Data is available for US census tracts, which are smaller than counties, and because they are smaller, they are also more homogeneous, which may reduce variability. The aggregation to the county level will also need to be done, however. If the census tract level of detail causes a significant increase in the computational requirements needed for the assessment, however, this may not be helpful to address that level of detail. The volume of data required for the system definition and development and the volume of data produced during the system exploration may be reduced by reducing the parameters and required data elements.

11.2.1 International Communities

Expansion to non-US communities will increase the capability of the model to address global humanitarian issues. Greater understanding of foreign governments and humanitarian practices will enable the model to be adjusted or developed accordingly. With international involvement, the amount of collaboration using the ESCAAPE methodology may be increased, and the method for implementing international aid may change for the better. Currently international communities do not fall within all of the ranges for the model parameters.

11.2.2 Value Provision

Another perspective to include in model development is to select or develop a simpler way to provide value to the model input parameters and objective parameters. One discussed method was to enable weighting bias within the data parameter aggregation. Another way to provide value may be to assess each of the data parameters and use the value from the most vulnerable element in the parameter. This may reflect actual community practices more accurately depending on the parameter and the data elements.

An example of this type of value provision would be for the physical development level, which for this research was selected as the exposure of the buildings, the design level of different categories of buildings which may be critical during the response, and also shelter capacity if available. In the case of the Haiti Earthquake, the most sensitive parameter may be the design levels of the buildings. Because the quality of the building construction did not withstand the 2010 earthquake, the shelter capacity became irrelevant, and because many of the government buildings were destroyed, there were few buildings which could serve as response headquarters or other critical structures which are needed during the response. If the design level of buildings parameter was selected as the indicator for the physical development level, this would reduce the amount of data which is required for the model input and with the proper parameter values, reflect the most vulnerable element of that aspect of the community.

11.2.3 Model Validation

The community model validation process must also be further developed. Currently system exploration offers comparison capability on a relative scale. In order to assess community state and its accuracy in reflection of an actual community, the model development within the framework execution should implement data elements for which data is available to check against model behavior during the simulation. A potential method for implementing this type of validation was not possible for the model developed for this research.

1. Model Definition

    - Retain simplicity in selecting parameters during decomposition.
    - Capture expertise about the community through decomposition and definition workshop or collaborative meeting to provide more information about parameter selection and decomposition.

2. Model Development

    - Retain simplicity in developing inter-parameter relationships.
    - Enable all factors to be included in relationship development testing by allowing factor input by the user during simulation setup without needing to modify the system model.

- Include comparison of system level metrics to the available data for the community at different points during the simulation
- Calibrate model to reflect the behavior of the community in the system-level metrics by adjusting the values of the factors within the inter-parameter relationships in the developed model.

11.3 Financial Assessment

While the Cost parameter is a complex one as far as its relationships with the rest of the parameters, it is nevertheless critical to adding validity to different implementation recommendations which result from applying the ESCAAPE methodology to different communities no matter how large the community is. Because disaster planning is not critical when no disaster is occurring or has occurred in the recent past, planning resources may not be allocated for improving a community's ability to complete restoration when the disaster does occur. The cost parameter, if implemented properly to the system model, would also enable more quantitative assessment of different solutions or focus area comparisons and may also be used as a constraint in the assessment.

11.4 Environmental Development Indicators

Another important parameter which was not implemented in the developed system model due to a lack of understanding of the complexity of the elements within the parameter and its relationships with other parameters and data elements within the model, was the inclusion of different environmental development indicators. There are fifty one available within the Environmental Vulnerability Index (EVI) alone, which have been clearly defined and even given some numeric values which are also defined at particular levels of intensity in SOPAC's EVI definition booklet. [2]

11.5 Deployability

The different steps in this methodology which were demonstrated in this research, but after assessments and presentation of the information, the whole process was completed with at least five different software programs, most of which are quite significant in cost. The flexibility of the ESCAAPE methodology does not require the specific programs which were used in this research to illustrate the capability. In order for a community to utilize the same information despite limited resources, a future consideration should be an aggregation of the different software functionalities, but not necessarily the programs, which is available for deployment in a single package or exported software program. This would enable planners to use the same software to collaboratively plan better. It would also reduce interfacing difficulties during planning because planners would all be working from a common background for that particular community or scenario.

APPENDIX A

ASSESSMENT OF DATA ELEMENT WEIGHTING VARIATIONS

During the original system model and relationship development, the different data elements are combined, or aggregated, to give a value to the input parameters which they define. The aggregation is done by an equal weighted sum of the different data elements to the input parameter.

Arguably, for each parameter at any of the levels where the equal weighted sum is used to aggregate either the data elements or the parameters in the next level, there may be a certain parameter or parameters whose influence is stronger than the others. Because that information must be provided either by further research or by input from an expert who is familiar with the community or community behaviors, it was not available for this research.

To test whether or not the effect of the weightings is significant to the model response parameter, several parameters or data elements were set to a higher weight than the other parameters at their level for that particular aggregation. The restoration time was recalculated without changing the values of any of the parameters. The weighting changes, input values, and responses are shown in Table 46.

Table 46: Weighting Significance Test

Parameter	Weighting Test					
DevelSocialInit	0.163	0.165	0.163	0.163	0.163	0.163
DevelEconInit	0.1224	0.1224	0.0961	0.1224	0.1224	0.1224
DevelEnvirInit	0.125	0.125	0.125	0.125	0.125	0.125
DevelPhysInit	0.1281	0.1281	0.1281	0.1076	0.1281	0.1281
Aid Param1	0.2212	0.2218	0.2212	0.2212	0.2212	0.2212
Adjustment flowRest	0.2473	0.2473	0.2473	0.2473	0.2473	0.2212
Restoration	1382	1372	1411	1407	1382	1382

Each of the selected parameters is weighted to a particular value x, and the other parameter weightings are calculated by the following equation:

$$x_{np} = \frac{1 - x_p}{n_x - 1} \tag{132}$$

where

$$x_{np} = \text{non primary weight value} \tag{133a}$$

$$x_p = \text{primary weight value (selected by user)} \tag{133b}$$

$$n_x = \text{number of components for the parameter} \tag{133c}$$

The weighting changes for each test are as follows:

- Test 1: The population parameter of the Initial Social Development Level (Devel SocialInit) was weighted to 0.2, and all the other parameters were weighted to 0.0727.

- Test 2: The GDP parameter of the Initial Economic Development Level (Devel EconInit) was weighted to 0.5 and the other parameters were weighted to 0.1667.

- Test 3: The Dollar Exposure parameter of the Initial Physical Development Level (Devel PhysInit) was weighted to 0.3 and the other parameters were weighted to 0.14.

- Test 4: The Fraction of Missing Found Alive parameter of the Response flow scaling parameter (Adjustment flowRes) was weighted to 0.4 and the other parameters were weighted to 0.08571.

- Test 5: The Time to Repair Transportation Infrastructure parameter of the Restoration flow scaling parameter (Adjustment flowRest) was weighted to 0.2 and the other parameters were weighted to 0.07273.

The changes in the weightings do affect the Restoration Time for some weighting changes, but implementing biased weightings requires selection of the values with expert input. This should be done prior to any system testing or exploration.

APPENDIX B

DEVELOPMENT OF METRICS

There are various aspects of the disaster response planning process which remain compartmentalized even within a specific community as it plans its disaster response. The necessity of metrics has not escaped planners and analysts, but because of the nature of the different aspects, standardization of improvement measurement metrics remains minimal.[72]

Standards for preparedness (programmatic or infrastructural) are decided by field experts. This is reasonable since the field experts understand what level the standards must be set so that overall safety can be assured and risks minimized. After a disaster does occur, infrastructural and transportation buildings and roads must be rapidly assessed to be either safe, so aid resources can be transported over them, or unsafe, so repairs can begin as soon as possible, and this is done by experts who are familiar with the region and transportation policies and infrastructure.

Any field-specific terms or preset metrics would be understandable to one who works in the field, which is why no common standardized metrics have been developed yet. Even if there were one metric, it would be difficult to allow comparisons between different communities, or even one community as it has changed over the past 10 years or more, because all of them contain terms which may have very different values.

B.1 Why Metrics are Necessary

With current metrics that are too general and might be too disjointed, it has always been a need in the disaster response field but there is no current standardized practice or set of metrics. Having some metrics would enable a comparison in a community from year to year as well as community to community and also enable self-conducted surveys or checks.

While a decision-making interface can be developed, within this research the information gathered for the methodology serves to provide a more holistic picture of the system itself and enable analysis capabilities for some of the information.

Although this method and the available tools are either very general or very specific and if more detailed information is needed the components of the methodology may need to be switched to a more detailed software program to fit the desired level of detail. The objectives for having simulations is to provide a higher level understanding of the community for preparedness planning, and while it does not need to be extremely detailed it should be as detailed as possible.

Metrics will enable this information to be properly aggregated into a form that makes comparison possible. Currently no system exists which enables a user or analyst to assess on a quantitative scale how prepared a community is for a disasters. If a user is interested in assessing where gaps in development or preparedness exist within a community, relative to a number of years ago, the application of relevant metrics will enable such assessments. If a user or community is interested in looking at the effects of increased resiliency of their community, from 2, 5, and 10 year implementation plans, having metrics would enable a value to be given to the changes made within the community in terms of objective value.

If there is a gap within some of the community aspects which are hindering improvements of the community resiliency, applying metrics to the available resource allocation will enable more efficient implementation of development or preparedness programming within the system. Additionally, tracking some of the critical measures related to the response and restoration of the community will enable an assessment of the response performance of the community and enable improvements which may help to save more lives after a disaster and enrich more lives during the restoration phase.

For certain metrics, different parameters of the community will be measured, and residents may self-assess and find areas where they need to take steps toward being more prepared or less vulnerable toward disasters. While not extensively done within this research, having measures of various response and restoration aspects will also add value to the costs associated with changes made in the community, if the effect of those changes can be quantified and justified both financially and in changes in response and restoration.

B.2 Currently used Metrics in Humanitarian Fields - Disaster Response

Currently disaster response planners assess improvements in a general manner, which was particularly apparent during the response in the weeks and months after Hurricane Katrina. The general metric is whether the response was acceptable or unacceptable. This was an observation which materialized after assessing disaster response coverage for several different US disasters.

The different aspects can be broken down as well into different functions and assessed to be either acceptable or unacceptable. Clearly the response and emerging restoration process was unacceptable on many levels. This was verbalized to local, national, and international media outlets by numerous individuals and groups from both within and outside of the community. Because of the high level of dissatisfaction which was verbalized through media coverage, post-disaster assessment research was done and assembled into a variety of reports which began to pinpoint some of the deficient areas in the response. Because of the lack of recorded precedent, however, little comparison with other communities or a hypothetical ideal response was made except for documentation developed from research which supported the view that the particular response was inadequate.

However, because of this, the response in 2011 was different when several tornadoes passed through Alabama and caused a significant amount of damage. The response performance in that event, based on public opinion was generally acceptable, given the conditions. [131]

Through interaction with federal planning officials and representatives, it has become apparent that the approach to disaster response and restoration planning involves few quantified metrics. Officials may rely more on personnel with greater experience to continue to develop response and restoration planning. n example of this planning process comes from collaboration done to prepare the Departments of Transportation of different states for a potential large scale disaster in FEMA's Region IV.

Within planning revisions done by the Department of Transportations, relevant measures such as bridge conditions after an earthquake are selected based on a committee decision with the final decision made by the assigned staff member. This type of measure development is done through expert input in a committee format. During meetings of the relevant committees, experts from different communities are brought together for collaboration and helpful input for particular issues regarding the aspects of the community which they deal with that need clarification or need selection of particular details so that each interacting community understands the same standards. [6]

B.2.1 Extent of Use of Developed Metrics From Related Fields

Other humanitarian fields have developed a few different types of metrics to evaluate the states of different communities, particularly with regards to their vulnerability as a community.

The main focus of developing and using these indices is so that the development and vulnerability of small island developing nations (in particular) may be assessed. If a disaster happens, some nations may be in more need of critical aid than others, and knowing which nations have less time to receive aid after a disaster will enable more effective disaster response. If a disaster happens and affects the health and wealth of a particular nation, in this case some developing island nations, that setback in development may affect the development of other nations as well. If, for example, an island nation exports a food staple which is imported by a nearby island nation as a primary import, if a disaster occurred on the exporting nation's island, the nearby island nation's food supply would be affected, if the nation itself was not already directly affected by the disaster.

B.2.2 Currently applicable metrics

B.2.2.1 Human Development Index [156]

The Human Development Index is a measurement of the development of a region, typically a country. This index (HDI) is made of measurements from three areas of human development: long healthy life, knowledge, and decent standard of living.

These indicators are measured from various region statistics, normalized to be dimensionless, and then aggregated for the HDI value. Each of the dimensionless indices has a minimum value of 0 and maximum value of 1, and with a maximum and minimum goalpost

Table 47: Goalposts for Human Development

Indicator	Max	Min
Life expectancy at birth (years)	85	25
Adult literacy rate (%)	100	0
Combined gross enrollment ratio (%)	100	0
GDP per capita (PPP US$)	40,000	100

value of the information used in the index. The dimensionless index is calculated as follows:

$$\text{Dimensionless Index} = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \tag{134}$$

For the three areas of human development, the goalpost values are shown in Table 47[1].

The values are taken from country data, reinforcing the concept that the HDI, as an index of the state of a region, represents a snapshot of what that region was like at the moment which the data is taken, and is not a value from a model of a system.

The values used in the three areas are

* Long healthy life: life expectancy at birth
* Knowledge: Adult literacy index, Gross enrollment index
* Standard of Living: GDP per capita

This index and other similar indices are measurements which enable comparison among the regions or nations in the world. Available data can also provide the trend for a country's HDI over a time period. Figure 113 shows the HDI history for Haiti, and compares it to multi-national standards from different regions of the world. The HDI average for the Latin America and Caribbean region is also shown, in blue. Figure 113 shows the gap between Haiti's development and the development of surrounding countries in the same area.

The implementation of the HDI offers possibilities toward comparison of the state of a nation prior to its disaster occurrence and will enable the connection of this index to vulnerabilities prior to the disaster as well as assessment of differences in disaster response.

[1] The upper limit of adult literacy is 99% in calculation but the implied maximum is 100%.

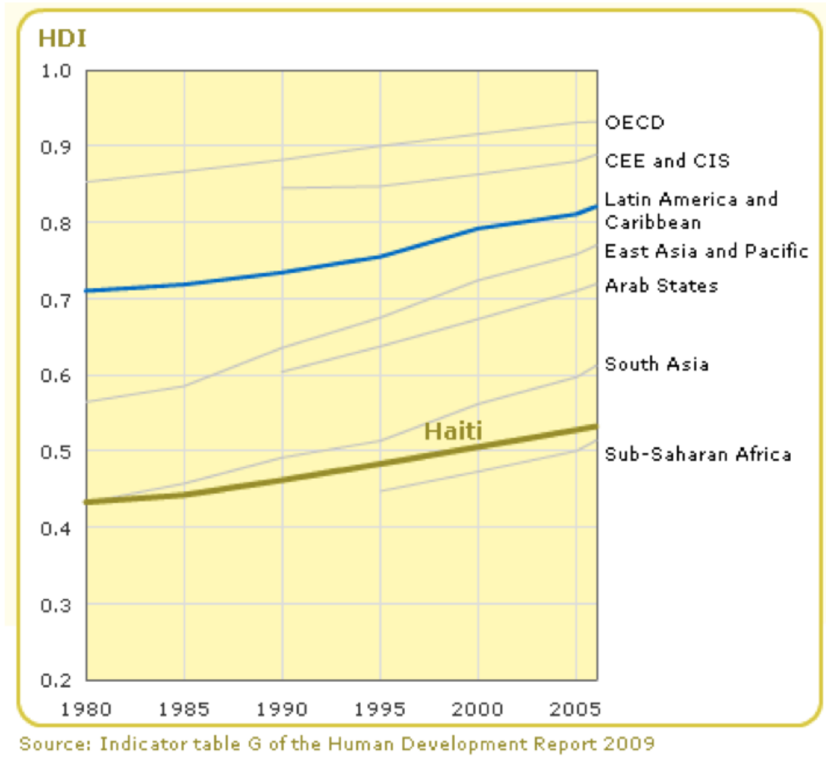


Figure 113: Human Development Index Trend - Haiti [77]

The HDI does not represent "preparedness" so much as it represents a country's ability to be prepared or their ability to rebuild after a significant event has occurred.

B.2.2.2 Vulnerability Indices

The term "vulnerability index" refers to the index or indices developed to show levels of vulnerability that a country or region may have to events or other external influences which can adversely affect the development and resilience of that country or region. A country or region is vulnerable in the social, economic, and environmental areas of development.

B.2.2.3 Environmental Vulnerability index

The particular vulnerability index developed by the South Pacific Applied Geoscience Commission (SOPAC), the United Nations Environment Programme (UNEP) and multi- and inter- national partners is used to measure vulnerability to natural environmental forces. The environmental vulnerability index (EVI) is meant to complement social and economic

Table 48: EVI Value Categories [158]

Vulnerability	EVI Value
Extremely vulnerable	365+
Highly vulnerable	315+
Vulnerable	265+
At risk	215+
Resilient	<215

vulnerability indexes to add to the perceived vulnerability of a country or region. [158] An online database and EVI calculator is available at www.vulnerabilityindex.net.

The EVI is currently used to measure the vulnerability of small island developing states (SIDS). The effects of past events and risk of future events are incorporated into the EVI. There are fifty indicators which are scored on a scale of 1 (Resilient) to 7 (Vulnerable) and fall into categories of weather & climate, geology, geography, resources & services, and human populations. An example EVI calculation is shown in Appendix D. The EVI was developed to be absolute, so that different countries or regions can evaluate themselves individually and not by a standard. This was enabled in the way that the scoring was developed. Table 48 shows the different levels of vulnerability calculated from the EVI.

B.2.2.4 Economic Vulnerability Index

An economic vulnerability index (EcVI) was developed by Briguglio and Galea [25] in a study and published to explain the vulnerability of SIDS even if those countries had high GDP per capita values. Economic vulnerability and economic resilience are related and are both affected by natural hazard events, particularly in SIDS, the type of region for which the EcVI was developed. The EcVI does not include resilience measures and such an index would be useful in assessing a nation or region's ability to rebuild economically after a disaster.

Four measures contribute to the EcVI score: economic openness, export concentration, peripherality, and dependence on strategic imports. Economic openness is measured by the ratio of exports, imports, or an average of both, as a percentage of GDP. The export concentration is measured by a concentration index which includes goods and services, a measure which Briguglio augmented from its measure of merchandise in the original United Nations Conference on Trade and Development (UNCTAD) index. Peripherality refers to the isolation of a region or country from commercial centers, and is calculated by the ratio of transport and freight costs to imports. The dependence on strategic imports refers to the level of dependence a country or region has on its imports. The calculation used for this measure is average imports of commercial energy as a percentage of domestic energy production. [25]

The measures are standardized by a procedure similar to the goalpost standardization used in the HDI. Briguglio and Galea combine the EcVI with the GDP per capita to form the Economic Vulnerability Index Augmented by Resilience (EVIAR).

B.2.2.5 Social Vulnerability Index

A social vulnerability to economic hazards index (SoVI) was developed by the Hazards & Vulnerability Research Institute. While this index considers 42 different parameters which consolidated to 11 factors, in the study no correlation was found to exist between vulnerable US counties and disaster declarations. [39] It may be helpful to assess the relationship between the rebuilding process in disaster-declared counties and the SoVI.

Figure 117 shows the relative social vulnerability of US counties.

B.2.2.6 Disaster Severity Scale

Another factor which plays significantly into a community's ability to respond is the severity of the disaster occurring in that community. One type of severity scale measures the severity of the event itself, such as the Saffir-Simpson Hurricane Scale, which measures the sustained wind speed and rates hurricanes on a scale of 1 to 5. [133] Various other severity scales exist for specific types of natural, chemical, or biological hazard events. Each of these scales are independent of each other, use different units, or if dimensionless, have different maximum or minimum goalpost values.

Scales exist to measure the severity of earthquakes[89][88], hurricanes [133], floods [145], fires [130], droughts [117], volcanic eruptions[129], terrorist events [115] [43], thunderstorms [44], tornadoes [64], tsunamis [139] [118], winter storms [108], heat waves [111], landslides

Sign Adjustment	Factor	Name	Dominant Variables	Correlation
-	1	Socioeconomic Status	QPOVTY	-0.86
			QED12LES	-0.85
			QCVLBR	0.81
			PERCAP	0.82
II	2	Age	MEDAGE	-0.89
			QKIDS	0.88
			QSSBEN	-0.83
			PPUNIT	0.83
			BRATE	0.80
			QPOP65O	-0.80
+	3	Development	COMDEVDN	0.99
			MAESDEN	0.98
			EARNDEN	0.97
			HODENT	0.95
			HUPTDEN	0.89
			RPROPDEN	0.74
+	4	Rural Agriculture	QLANDFRM	0.73
			NNRESPC	0.65
			QPCHCG	-0.65
			QRFRM	0.63
			HOSPTPC	0.57
			MDHSEVAL	-0.50
+	5	Race and Gender	QFEMLBR	0.84
			QFHH	0.59
			QAGRI	-0.58
			QBLACK	0.56
			QVOTE	-0.55
+	6	Race	QASIAN	0.76
+	7	New Immigrants	QINDIAN	-0.76
			MIGRA	0.53
+	8	Ethnicity	QSPANISH	0.77
+	9	Gender	QFEMALE	0.81
			QSERV	-0.58
+	10	Infrastructure Employment	QTRAN	0.85
+	11	Economic Dependence	DEBTREV	0.98

SoVI = +(- Factor 1) + (II Factor 2) + Factor 3 + Factor 4 + Factor 5 + Factor 6 + Factor 7 + Factor 8 + Factor 9 + Factor 10 + Factor 11

Figure 114: SoVI Calculation Screenshot [4]

[142], and pandemics. [28]

While some of the scales take into account the energy expended in the event of a particular type of disaster, the scales primarily describe the intensity of the event from a geological point of view and do not include effects on physical metropolitan infrastructures or the extent of damages as a measurable part of disaster severity.

An example of this difference in scale is the use of the Richter scale, which measures earthquake magnitude based on released seismic energy. [89] This scale is also used with the Modified Mercalli Intensity Scale, which measures the intensity of an earthquake based on subjective perception of the earthquake. The intensity measures differently over different areas depending on the distance from the epicenter. [88]

Table 49: Disaster Severity Scale Score Breakdown

Classification	Grade	Score
Effect on infrastructure	Simple	1
	Compound	2
Impact Time	>1 hour	0
	1-24 hours	1
	>24 hours	2
Radius of impact site	<1 km	0
	1-10 km	1
	>10 km	2
Number of dead	<100	0
	>100	1
Average severity of injuries	<1	0
	1-2	1
	>2	2
Rescue time	<6 hours	0
	6-24 hours	1
	>24 hours	2
Total		1-13

In 1990, a Disaster Severity Scale was developed by de Boer [42]. This scale utilized seven parameters which described the effects of the disaster on a region. The score goes from zero to thirteen. The parameters used are:

1. Effect on infrastructure
2. Impact Time
3. Radius of Impact Site
4. Number of Dead
5. Number of Injured
6. Average severity of injuries sustained
7. Rescue time

and are graded as shown in Table 49[2].

The use of the DSS in assessment of disaster effects is limited in some ways. Natural disasters tend to have higher scores than man-made disasters though the effects may have

[2]©2005 Ferro [61]. The effect on infrastructure is the addition of impact site and filter area. The rescue time is the addition of time to rescue, first aid, and transport.

significant differences. The DSS also does not easily differentiate between similar disasters for which one has left many homeless and the other has not (for example). The DSS also does not account for differences in infrastructure development prior to the disaster. [61] However, this scale does enable comparison of effects of a variety of disaster types in different communities.

B.2.3 Population Data

Other disaster effects assessments are made using basic population data. Dolfman et al. [49] assesses some of the Katrina response by observing the economic industries' changes in profits as well as changes in employment. Dolfman et al. first identified the three main industries in the New Orleans economy and assessed the growth rates and levels of these industries in the years leading up to Hurricane Katrina. Research was then completed which showed the changes in employment and income in those industries after Hurricane Katrina and for up to two years afterward.

B.3 Quantifying New Parameters

Are there relevant and useful metrics developed to aid in disaster response planning? Extra data gathering during a disaster or disaster response is not something that planners and responders may have the resources to do. However, if the data can significantly aid analysis of the response and improvements for the planners and community, there may be some value to the extra data gathering. If certain data is already gathered during non-disaster times and could be used to help plan community restoration after a disaster, implementation of parameter use for disaster response and restoration based on gathered data would be easier.

Dwyer, et al. [51] have presented a method for developing indicators for a community. Their focus was developing an assessment for social vulnerability from indicators based on data availability and indicator relevance.

Their methodology was as follows:

1. Indicator Selection

    (a) Literature Review

   (b) Develop selection criteria

   (c) Select vulnerability indicators

2. Risk Perception Questionnaire

   (a) Develop questionnaire

   (b) Generate hypothetical individuals

   (c) Distribute questionnaire

3. Decision Tree Analysis

   (a) Apply decision tree analysis

   (b) Develop decision rules

   (c) Establish high vulnerability classes

4. Synthetic Estimation

   (a) Select case study area

   (b) Develop synthetic estimates

   (c) Map vulnerability scenarios

Dwyer, et al. used a methodology which relied heavily upon expert opinion and individual polling via questionnaires. This may be the best method in that draws the most expert opinion and common knowledge into the metrics. Citizens in different demographics have greater understandings of how events such as disasters may affect their lives more than an observer would. Additionally, many experts are drawing on decades of experience in their areas, often from firsthand experience and interactions, and are another source of greater understanding about particular aspects of a community.

Time limitations prevented this method from being fully implemented in this research, but through the review of this process by Dwyer, et al. and other available data and indicators, some metrics can be developed in a way that leaves flexibility for better indicators or metrics to be included to better represent the state of a community.

B.4 Method Used to Develop Metrics

The method for metric development was tied closely with the system development, since for both tools that were needed in the overall methodology, metrics and system parametrization, a significant amount of work was needed for both. Some parameters were already emerging in the disaster response and humanitarian logistics field as important metrics and indicators, and those were taken into consideration and often used as examples when working on community-specific metrics which would serve in each phase of the disaster response process.

Metric development occurred concurrent with the development of the disaster and community system model parameters and relationships among the parameters. The process may be separated into several steps which are defined as follows:

1. Emergent Natural Measures: Through the process of developing the system model, different parameters and components are selected based on the different aspects of the system. As these parameters are selected, and their relationships need to also be selected, some natural measures emerge which enable these relationships to be developed. There may be a large number of natural measures which may be potentially enabling for model development.

2. Assessment of Natural Measures: When the measures emerge, unless they may all be incorporated into the system model, there will need to be a filtering of these measures for more streamlined model development and also to keep the structure of the model at the ground level as simple as possible since the system itself is already somewhat complex.

   (a) *Applicability*: The measures must have applicability for the parameter or component to which they would be attributed. As an example, an applicable measure for a parameter such as "Response Efficiency"' might be "Average patient triage time"' or "Number of patients seen in one day by one triage station"' instead of "Number of head injuries."' The last example measure may be applicable for other parameters but would not be applicable to the response efficiency.

(b) *Availability*: Selecting obscure or difficult-to-obtain measures may increase the time needed to gather data. Particularly during the immediate response phase, data measures often take a backseat to emergency operations and medical emergency response. While various technologies and advances in the medical data entry field are enabling the increased availability of data with less confusion and less rigorous data entry procedures, measures which require extra data recording and or entry may not be as easy for responders to provide. During the restoration and preparedness phases, the same is true. Often emergency response planning personnel and community restoration personnel function in several different roles within the response and restoration field as well as other fields which may not be significantly related to disaster response and community restoration. Additional bookkeeping and accountability in data gathering would be an added item to an already long list of things that need to be done.

(c) *Quantifiability*: The measures, if qualitative initially, must be quantifiable in a way which may be aggregated to provide system information to top-level metrics. With different objectives depending on the planner, weights may be changed in order to selectively bias the system dependency on certain measures. However for the initial development of the system model weights were all set to equal in the aggregation of the measures unless specific relationships were defined within the model.

(d) *Meaningfulness*: Within the developed system model, the testing of the different measures should show that the selected measures are meaningful and reasonable in the model behavior over the relevant intervals for the different parameters which the metrics are aggregated to define.

B.5 Gathering Data for Metric Measurement Foundation

In order to provide some information from the methodology, data is needed. Once the various metrics have been chosen and their components selected, the data needs to be composited unless one source contains all of the data needed. There are some issues that arise with data gathering.

Source Diversity: with data coming from different sources and in many different reporting formats, the reliability of the data may be unknown in some cases. Sources chosen should be from sources as reliable as possible.

Source year diversity: some data elements are not measured in the same year, but provided the rate of change of the data element is not significant, the most recent data gathered may be acceptable. For this research, the most recent and current values were used. If no reliable sources were available for the past few years , data from the next higher scale was used if a value or average from a reliable source was available. A planner or user might also look at adding an element of uncertainty to some data if current-year data is unavailable but a previous year value is known and an approximate growth rate is available or can be calculated.

Scale Diversity: many data elements are recorded at different levels of detail. If the data is a mean percentage or fraction that is representative of the estimated data for the desired level of detail, it may be acceptable to the user. In some cases if data from a different scale is not used, data for that data element may be unavailable.

Unavailable Data: this issue comes up for different data elements. Different options for filling in unavailable data will be discussed in Chapter 7. For this research, since the data is aggregated to feed into the user parameters, parameters will still have values if some of the data elements are missing. However the fewer remaining elements there are, the more influential each element will become if equal weighting is assigned.

Having some flexibility in the development of the system enables better information as it becomes available (via literature, reports, or expert inputs). In order to enable flexibility in the system development, the system definition must be setup so that the values can be changed without too much difficulty.

Data Sources In disaster response times it is difficult to include added demands for data, during both response and restoration times. During the response phase life-and-death urgencies for rescues and medical needs takes precedence over data input unless a system is set up to automatically include the needed data points. During the restoration period, data may need to be recorded consistently over a long period of time, but there may already be some difficulty in accountability with responsibility in the first place. Adding extra data collection here would need to be done in such a manner which does not increase the burden on restoration organizations.

During the process of this method development, data elements were selected which were more generally available or could be easily estimated. Many data bureaus or non-profit humanitarian and/or social organizations are less proprietary in their approach to information, but also seek to provide accurate and meaningful data in order to improve distribution and implementation of aid within societies.

As a general rule, the following sources were considered acceptable.

- United Nations research divisions
- US Federal statistical bureaus
- Federal Agencies which provide statistical information
- reliable news sources (major or reputable news corporations - such as CNN or The New York Times)
- Database driven data used in response simulations (such as GIS data or HAZUS input data)

B.6 Social Indicator Value Sources

Name	Description
MED_AGE90	Median age, 1990
PERCAP89	Per capita income (in dollars), 1989
MVALOO90	Median dollar value of owner-occupied housing, 1990
MEDRENT90	Median rent (in dollars) for renter-occupied housing units, 1990
PHYSICN90	Number of physicians per 100,000 population, 1990
PCTVOTE92	Vote cast for president, 1992—percent voting for leading party (Democratic)
BRATE90	Birth rate (number of births per 1,000 population), 1990
MIGRA_97	Net international migration, 1990–1997
PCTFARMS92	Land in farms as a percent of total land, 1992
PCTBLACK90	Percent African American, 1990
PCTINDIAN90	Percent Native American, 1990
PCTASIAN 90	Percent Asian, 1990
PCTHISPANIC90	Percent Hispanic, 1990
PCTKIDS90	Percent of population under five years old, 1990
PCTOLD90	Percent of population over 65 years, 1990
PCTVLUN91	Percent of civilian labor force unemployed, 1991
AVGPERHH	Average number of people per household, 1990
PCTHH7589	Percent of households earning more than $75,000, 1989
PCTPOV90	Percent living in poverty, 1990
PCTRENTER90	Percent renter-occupied housing units, 1990
PCTRFRM90	Percent rural farm population, 1990
DEBREV92	General local government debt to revenue ratio, 1992
PCTMOBL90	Percent of housing units that are mobile homes, 1990
PCTNOHS90	Percent of population 25 years or older with no high school diploma, 1990
HODENUT90	Number of housing units per square mile, 1990
HUPTDEN90	Number of housing permits per new residential construction per square mile, 1990
MAESDEN92	Number of manufacturing establishments per square mile, 1992
EARNDEN90	Earnings (in $1,000) in all industries per square mile, 1990
COMDEVDN92	Number of commercial establishments per square mile, 1990
RPROPDEN92	Value of all property and farm products sold per square mile, 1990
CVBRPC91	Percent of the population participating in the labor force, 1990
FEMLBR90	Percent females participating in civilian labor force, 1990
AGRIPC90	Percent employed in primary extractive industries (farming, fishing, mining, and forestry), 1990
TRANPC90	Percent employed in transportation, communications, and other public utilities, 1990
SERVPC90	Percent employed in service occupations, 1990
NRRESPC91	Per capita residents in nursing homes, 1991
HOSPTPC91	Per capita number of community hospitals, 1991
PCCHGPOP90	Percent population change, 1980/1990
PCTURB90	Percent urban population, 1990
PCTFEM90	Percent females, 1990
PCTF_HH90	Percent female-headed households, no spouse present, 1990
SSBENPC90	Per capita Social Security recipients, 1990

Figure 115: SoVI Parameters and Factors [39]

Dimensions of Social Vulnerability

Factor	Name	Percent Variation Explained	Dominant Variable	Correlation
1	Personal wealth	12.4	Per capita income	+0.87
2	Age	11.9	Median age	−0.90
3	Density of the built environment	11.2	No. commercial establishments/mi^2	+0.98
4	Single-sector economic dependence	8.6	% employed in extractive industries	+0.80
5	Housing stock and tenancy	7.0	% housing units that are mobile homes	−0.75
6	Race—African American	6.9	% African American	+0.80
7	Ethnicity—Hispanic	4.2	% Hispanic	+0.89
8	Ethnicity—Native American	4.1	% Native American	+0.75
9	Race—Asian	3.9	% Asian	+0.71
10	Occupation	3.2	% employed in service occupations	+0.76
11	Infrastructure dependence	2.9	% employed in transportation, communication, and public utilities	+0.77

Figure 116: SoVI Factors and Percentage of Variance [39]

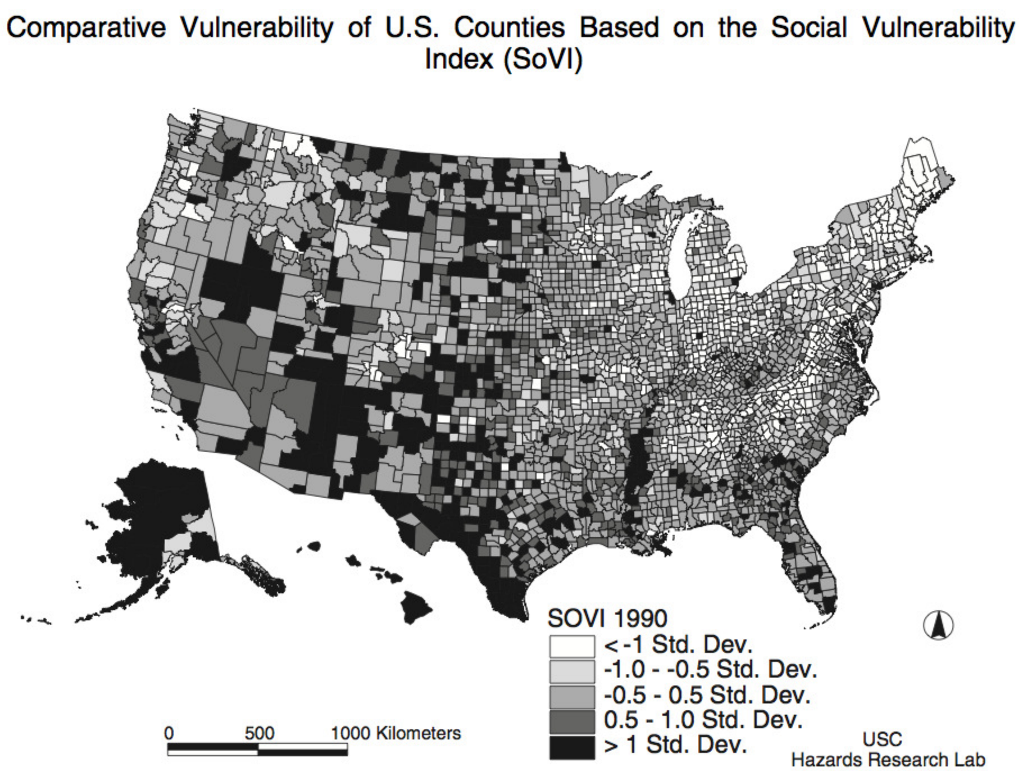


Figure 117: Social Vulnerability Index for Counties in the US

Table 50: Initial Social Development Parameters for Shelby County, TN

Indicator	Data Element	Value	Year	Source
Childbearing	Adolescent Fertility Rate	66	2011	http://www.countyhealthrankings.org
	Total Fertility Rate	2	2004	http://unstats.un.org
	Estimated Maternal Mortality Ratio	24	2004	http://unstats.un.org
Child and Elderly Populations	% population <15 yr	22.84505276	2009	http://factfinder.census.gov
	% population >60 yr	14.27052906	2009	http://factfinder.census.gov/
	sex ratio in 60+ age group	64.25205065	2009	http://factfinder.census.gov
Contraceptive Use	Contraceptive Prevalence - any methods	0.62	2010	http://www.guttmacher.org
	Contraceptive Prevalence - modern methods	0.584	2010	http://www.guttmacher.org

Continued on next page

Table 50 – continued from previous page

Indicator	Data Element	Value	Year	Source
Education	school life expectancy, primary to tertiary - total	11.55935	2008	http://data.un.org
	school life expectancy, primary to tertiary - men	11.55182	2008	http://data.un.org
	school life expectancy, primary to tertiary - women	11.56727	2008	http://data.un.org
Health	Life expectancy at birth - men	72.4	2004-2006	http://health.state.tn.us/statistics
	Life expectancy at birth - women	78.4	2004-2006	http://health.state.tn.us/statistics
	Infant mortality rate	13.8	2006	http://www.shelbycountytn.gov
	Under 5 mortality rate	N/A		
Housing	Avg no. of persons / room - total	0.483858705	2009	http://www.city-data.com

Continued on next page

Table 50 – continued from previous page

Indicator	Data Element	Value	Year	Source
	Avg no. of persons / room - urban	N/A		
	Avg no. of persons / room - rural	N/A		
Human settlements	population distribution (%) - urban	0.93	2009	http://www.city-data.com
	population distribution (%) - rural	0.03	2009	http://www.city-data.com
	annual rate of pop change (%) - total	0.004	2009	https://edis.commerce.state.nc.us
	annual rate of pop change (%) - urban	N/A		

Continued on next page

Table 50 – continued from previous page

Indicator	Data Element	Value	Year	Source
	annual rate of pop change (%) - rural	N/A		
Income and Economic Activity	per capita GDP (US$)	38420.78163	2009	http://quickfacts.census.gov
	adult (15+) economic activity rate	0.65	2008	http://unstats.un.org
Literacy	adult (15+) literacy rate - total	0.14	2003	http://nces.ed.gov
	adult (15+) literacy rate - men	N/A		
	adult (15+) literacy rate - women	N/A		
	youth (15-24) literacy rate - total	N/A		

Continued on next page

Table 50 – continued from previous page

Indicator	Data Element	Value	Year	Source
	youth (15-24) literacy rate - men	N/A		
	youth (15-24) literacy rate - women	N/A		
Population	population (in thousands) - total	918	2009	http://factfinder.census.gov
	population (in thousands) - men	438	2009	http://factfinder.census.gov
	population (in thousands) - women	480	2009	http://factfinder.census.gov
	sex ratio of population - men / 100 women	91.28229167		

Continued on next page

Table 50 – continued from previous page

Indicator	Data Element	Value	Year	Source
	annual population growth rate, 2010-2015 (%)	0.004		
Unemployment	adult (15+) unemployment rate - total	0.097	2009	http://factfinder.census.gov
	adult (15+) unemployment rate - men	0.088	2009	http://factfinder.census.gov
	adult (15+) unemployment rate - women	0.087	2009	http://factfinder.census.gov
Water supply and sanitation	improved drinking water coverage (%) - total	0.98	2002	http://www.who.int
	improved drinking water coverage (%) - urban	N/A		

Continued on next page

Table 50 – continued from previous page

Indicator	Data Element	Value	Year	Source
	improved drinking water coverage (%) - rural	N/A		
	improved sanitation coverage (%) - total	0.98	2002	http://www.who.int
	improved sanitation coverage (%) - urban	N/A		
	improved sanitation coverage (%) - rural	N/A		

APPENDIX C

TABLES

C.1 Decomposition and Categorization of Parameters

Table 51 shows the different parameters broken down into data elements. The color coding show the different variables included in the aspect focus groups of variables and adjusted accordingly by changing the data element values. The data elements, sub-parameters, and parameters are grouped by color within the table, with the Development-related components highlighted in blues, the preparedness components highlighted in light greens, and the response components highlighted in light orange.

Table 51: Parameter Categories

Parameter	Sub-Parameter	Data Element
Devel SocialInit	Childbearing	Adolescent Fertility Rate
		Total Fertility Rate
		Estimated Maternal Mortality Ratio
	Child and Elderly Populations	% population $<$ 15 yr
		% population $>$ 60 yr
		Sex ratio in 60 + age group
	Contraceptive Use	Prevalence (any method)
		Prevalence (modern methods)
	Education	School life expectancy, primary to tertiary - total
		School life expectancy, primary to tertiary - men
		School life expectancy, primary to tertiary - women
	Health	Life expectancy at birth - men
		Life expectancy at birth - women

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
		Infant mortality rate
		Under 5 mortality rate* [1]
	Housing	Avg. # of persons / room - total
		Avg. # of persons / room - urban *
		Avg. # of persons / room - rural *
	Human Settlements	Population distribution (%) - urban
		Population distribution (%) - rural
		Annual rate of Pop. change (%) - total
		Annual rate of Pop. change (%) - urban *
		Annual rate of Pop. change (%) - rural *
	Income and Economic Activity	Per Capita GDP (US $)
		Adult (15 +) economic activity rate

Continued on next page

[1]* Data for this element was unavailable and element was not used

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Literacy	Adult (15 +) literacy rate - total
		Adult (15 +) literacy rate - men*
		Adult (15 +) literacy rate - women *
	Population	population (thousands) - total
		population (thousands) - men
		population (thousands) - women
		sex ratio of population (men / 100 women)
		annual pop. growth rate (%) projected for 2010-2015
	Unemployment	Adult (15 +) unemployment rate - total
		Adult (15 +) unemployment rate - men
		Adult (15 +) unemployment rate - women

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Water supply and Sanitation [2]	Improved drinking water coverage (%) - total
		Improved drinking water coverage (%) - urban *
		Improved drinking water coverage (%) - rural *
		Improved sanitation coverage (%) - total
		Improved sanitation coverage (%) - urban *
		Improved sanitation coverage (%) - rural *
Devel EconInit	Life expectancy at birth	
	Adult literacy rate	
	Gross Enrollment Ratio	
	GDP per capita (PPP US. $)	

Continued on next page

[2]For regions with significantly low coverage in this sub-parameter, assessments should include improving this coverage, however for US communities most are already at very high amounts of coverage

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
Devel EnvirInit [3]	Soil and Water - Inherent Soil Productivity	Topsoil depth *
		Soil organic carbon *
		Total available water capacity *
		Bulk density *
	Soil and Water - Ground water availability	Annual aquifer recharge budget *
	Losses from Agricultural Systems - Surface	Nutrients *
		Sediment *
		Pesticides *

Continued on next page

[3] More specific and relevant measures should be selected with in depth literature reviewing and expert input if possible for this parameter if including in assessments

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Losses from Agricultural Systems - Leaching	Nitrates *
		Pesticides *
DevelPhysInit	Dollar exposure by general occupancy	Building exposure
		Content exposure
		Total
	Medical care facilities	Replacement cost [4]
		Backup power (yes/no)
		No. of facilities
		No. of beds
		Design Level [5]

Continued on next page

[4]This value increased if more facilities were built.

[5]In the US communities of interest, medical care facilities were built at high design levels but this data element should be included if design levels are any value below the highest one

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Emergency Operation Centers - emergency response	Replacement cost
		No. of facilities
		Design Level
		Backup power (yes/no)
	Police Stations - emergency response	Replacement cost
		No. of facilities
		Design Level
		Backup power (yes/no)
	Fire Stations - emergency response	Replacement cost
		No. of facilities
		Design Level
		Backup power (yes/no)

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	School facilities	Replacement cost
		No. of facilities
		Design Level
		Backup power (yes/no)
		No. of students
Adjustment DSD[6]	Genocide (yes/no)	
	Adverse regime change (yes/no)	
	Ethnic war (yes/no)	
	Civil war (yes/no)	
	Disaster 0 to 3 years ago (yes/no)	
	Disaster 3 to 10 years ago (yes/no)	
	Disaster 10 + years ago (yes/no)	

Continued on next page

[6] Current or recent events affecting stability of region

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
DevelFundingBudget [7]	Inadequate	
	Adequate	
	Surplus	
DevelProgramsBudget	Inadequate	
	Adequate	
	Surplus	
DF Adjustment		
DP Adjustment		
Stability Flow Adjust	Development level	
	Stability level	
DF DevelFraction		
DP DevelFraction		

Continued on next page

[7] Budget and funding quantification is currently simplified to 3 settings based on how things have been funded historically: inadequate, adequate, and surplus

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
D SocialFactor1	Development Component Level	
	Implement Capability	
	Implement Priority	
	Nearness to event	
D SocialFactor2	Damage aggregate	
	Amount of aid being sent	
	% working of communications	
	Response status	
	Prior development level	
D EnvirFactor1	Development component level	
	Implement Capability	
	Implement Priority	
	Nearness to event	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
D EnvirFactor2	Damage aggregate	
	Amount of aid being sent	
	% working of communications	
	Response status	
	Prior development level	
D EconFactor1	Development Component Level	
	Implement Capability	
	Implement Priority	
	Nearness to event	
D EconFactor2	Damage aggregate	
	Amount of aid being sent	
	% working of communications	
	Response status	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Prior development level	
D PhysFactor1	Development Component Level	
	Implement Capability	
	Implement Priority	
	Nearness to event	
D PhysFactor2	Damage aggregate	
	Amount of aid being sent	
	% working of communications	
	Response status	
	Prior development level	
Fraction	Population density	
	Urban infrastructure density	
	Preparedness	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Severity	
	Distance from location	
PreparednessTrainingAdjust	Collaboration	
PreparednessProgramAdjust	Collaboration	
InitialFundingTotal [8]	Level	
InitialFundingBudget [9]	Level	
TrainingInit	Budget status level	
	Recentness of last disaster	
	Probability of another disaster occurring	
PrepProgramsInit	Budget status level	

Continued on next page

[8] inadequate <1, adequate =1, surplus >1
[9] inadequate <1, adequate =1, surplus >1

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Recentness of last disaster	
	Probability of another disaster occurring	
ProcurementInit	Amount of time warning	
	Budget status level	
	Recentness of last disaster	
	Probability of another disaster occurring	
PrepositionInit	Amount of time warning	
	Budget status level	
	Recentness of last disaster	
	Probability of another disaster occurring	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
CollabInit	Amount of time warning	
	Budget status level	
	Recentness of last disaster	
	Probability of another disaster occurring	
Wt TrainProc		
Wt Prog Proc		
Wt TrainPrep		
Wt ProgPrep		
Wt TrainColl		
Wt ProgColl		
Adjust Pro	Collaboration	Organization - training
		Communication

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
		Action - procurement
		Action - prepositioning
Adjust preparedness	Development	
	Stability	
	Recentness of last disaster	
Prep Param1	Preparedness programming	
	Probability of another disaster occurring	
	Recentness of last disaster	
	Stability	
AidDelayAdjust	Preparedness	
	Severity	
AidParam1	Social Development	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Preparedness	
	Transportation system damages	
InitialAid	Currently receiving aid from previous	
	disaster (yes/no)	
	Recentness of last disaster	
	Development	
Adjust MC		
Adjust CS		
World State	Stability of global economy	
	Ongoing wars in developed nations	
	Non-war social crises in aid nations	
	Current disasters in aid nations	
	Developing disasters in aid nations	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
	Ongoing wars in developing nations	
	Non-war social crises in developing nations	
	Current disasters in developing nations	
	Developing disasters in developing nations	
AidUnofficialFraction	Approximate amount	
AidExternalFraction	Aid received	
	Fraction of aid implemented to the economy	
AidResponseFraction	Approximate amount	
AidRestoreFraction	Approximate amount	

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
Adjustment flowExt	efficiency of external aid	amount of food needed [10]
		disaster response drinking water needed*
		shelter needed*
		survivors who require aid*
		survivors who require aid and receive partial treatment*
		survivors who require aid and receive none*
		missing persons found alive
		amount of debris which needs to be removed (m^3/km^2 of land)
		community debris removal rate capability (m^3/ mo.)
		projected time to remove debris (months)

Continued on next page

[10]* All data elements are for the fraction of needed aid which was provided beyond the capacity of of the community to provide that particular aid

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
		time needed to remove and process bodies (weeks)
		available fraction of needed capability to remove and process bodies
		counseling needs *
		reconnection time for families (wks)
		relocation time for families (wks)
		re-assimilation time for families (months)
		time to repair transportation infrastructure (to 75 % functional)
		time to repair buildings (to 50% functional)
		time to repair utilities (to 50% functional)
Adjustment flowUn	efficiency of unofficial aid	amount of food needed [11]

Continued on next page

[11]* All data elements are for the fraction of needed aid which was provided beyond the capacity of of the community to provide that particular aid

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
		disaster response drinking water needed*
		shelter needed*
		survivors who require aid*
		survivors who require aid and receive partial treatment*
		survivors who require aid and receive none*
		missing persons found alive
Adjustment flowRes	efficiency of response aid	amount of food needed [12]
		disaster response drinking water needed*
		shelter needed*
		survivors who require aid*

Continued on next page

[12]* All data elements are for the fraction of needed aid which was provided beyond the capacity of of the community to provide that particular aid

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
		survivors who require aid and receive partial treatment*
		survivors who require aid and receive none*
		missing persons found alive
Adjustment flowRest	efficiency of restoration aid	amount of debris which needs to be removed (m^3/km^2 of land)
		community debris removal rate capability (m^3/ mo.)
		projected time to remove debris (months)
		time needed to remove and process bodies (weeks)
		available fraction of needed capability to remove and process bodies
		counseling needs *
		reconnection time for families (wks)

Continued on next page

Table 51 – continued from previous page

Parameter	Sub-Parameter	Data Element
		relocation time for families (wks)
		re-assimilation time for families (months)
		time to repair transportation infrastructure (to 75 % functional)
		time to repair buildings (to 50% functional)
		time to repair utilities (to 50% functional)

C.2 Initial Community Values

Table 52 shows the initial parameters for both Shelby County and Orleans Parish.

Table 52: Initialization Values

Parameter	Sub-parameter	Data Element	Shelby	Orleans
DevelSocialInit	Childbearing	Adolescent Fertility Rate	66	72.7
		Total Fertility Rate	2	2
		Estimated Maternal Mortality Ratio	24	24
	Child and Elderly Populations	% population <15 yr	22.84505276	22.2
		% population >60 yr	14.27052906	15.1
		sex ratio in 60+ age group	64.25205065	60.80896963
	Contraceptive Use	Contraceptive Prevalence - any methods	0.62	0.62
		Contraceptive Prevalence - modern methods	0.584	0.584
	Education	school life expectancy, primary to tertiary - total	11.55935	11.55935
		school life expectancy, primary to tertiary - men	11.55182	11.55182

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		school life expectancy, primary to tertiary - women	11.56727	11.56727
	Health	Life expectancy at birth - men	72.4	68.4
		Life expectancy at birth - women	78.4	79.5
		Infant mortality rate	13.8	10.8
		Under 5 mortality rate		
	Housing	Avg # of persons / room - total	0.483858705	2.574616
		Avg # of persons / room - urban		
		Avg # of persons / room - rural		
	Human settlements	population distribution (%) - urban	0.93	0.99

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		population distribution (%) - rural	0.03	0.01
		annual rate of pop change (%) - total	0.004	0.047
		annual rate of pop change (%) - urban		
		annual rate of pop change (%) - rural		
	Income and Economic Activity	per capita GDP (US$)	38420.78163	49561.84
		adult (15+) economic activity rate	0.65	0.65
	Literacy	adult (15+) literacy rate - total	0.14	0.6
		adult (15+) literacy rate - men		

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		adult (15+) literacy rate - women		
		youth (15-24) literacy rate - total		
		youth (15-24) literacy rate - men		
		youth (15-24) literacy rate - women		
	Population	population (in thousands) - total	918	485
		population (in thousands) - men	438	227
		population (in thousands) - women	480	258
		sex ratio of population - men / 100 women	91.28229167	88.16445376

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		annual population growth rate, 2010-2015 (%)	0.004	0.047
	Unemployment	adult (15+) unemployment rate - total	0.097	0.055
		adult (15+) unemployment rate - men	0.088	0.122
		adult (15+) unemployment rate - women	0.087	0.109
	water supply and sanitation	improved drinking water coverage (%) - total	0.98	0.98
		improved drinking water coverage (%) - urban		
		improved drinking water coverage (%) - rural		
		improved sanitation coverage (%) - total	0.98	0.98

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		improved sanitation coverage (%) - urban		
		improved sanitation coverage (%) - rural		
DevelEconInit	Life expectancy at birth		75.4	73.95
	Adult literacy rate		0.14	0.6
	gross enrollment ratio		0.89	0.891136578
	GDP per capita (PPP US$)		38420.78163	49561.83744
DevelEnvirInit	soil and water - inherent soil productivity	topsoil depth	0.5	0.5
		soil organic carbon		
		total available water capacity		
		bulk density		
	soil and water - ground water availability	annual aquifer recharge budget		

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	losses from ag systems - surface processes	nutrients		
		sediment		
		pesticides		
	losses from ag systems - leaching processes	nitrate-nitrogen		
		pesticides		
DevelPhysInit	Dollar exposure by general occupancy - total	building exposure	70370025	35127486
		content exposure	46974755	22482312
		total	117344780	57609798
	Medical care facilities	replacement cost	117040	1002629.19
		backup power (y/n)	0	0
		# of facilities	12	25
		# beds	4163	5078

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		design level (to disaster)	HC	H
	Emergency Operation Centers	replacement cost	1760	890
		# facilities	2	1
		design level	MC	M
		backup power (y/n)	0	0
	Police stations	replacement cost	44352	44856
		# facilities	36	36
		design level	MC	M
		backup power (y/n)	0	0
	Fire stations	replacement cost	6864	2670
		# facilities	13	5
		design level	MC	M
		backup power (y/n)	0	0
	School facilities	replacement cost	134640	1011529.47
		# facilities	306	196

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		design level	MC	M
		backup power (y/n)	0	0
		# students	182978	104342
Adjustment DSD	genocide?		0	0
	adverse regime change (recently or current)?		0	0
	ethnic war?		0	0
	civil war?		0	0
	disaster 0-3 years ago?		0	0
	disaster 3-10 years ago?		0	0
	disaster 10+ years ago?		0	0
DevelFundingBudget	Inadequate historically?		0	0
	Adequate historically?		1	1
	Surplus historically?		0	0
DevelProgramsBudget	Inadequate historically?		0	0

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	Adequate historically?		1	1
	Surplus historically?		0	0
DF Adjustment			0.2	0.2
DP Adjustment			0.2	0.2
Stability Flow Adjust	development level		61.26	52.63
	stability level		0.4817	0.3263
DF DevelFraction			0.9	0.9
DP DevelFraction			0.9	0.9
D SocialFactor1	Development Component Level		0.9	0.7
	Implement Capability		0.5	0.3
	Implement Priority		0.9	0.9
	Nearness to event		0.1	0
D SocialFactor2	Damage aggregate		0.5	0.9
	Amt of Aid being sent		0.9	0.9

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	% working of communications		0.5	0.2
	Response status		0.5	0.2
	Prior Development Level		0.9	0.7
D EnvirFactor1	Development Component Level		0.9	0.7
	Implement Capability		0.5	0.5
	Implement Priority		0.5	0.5
	Nearness to event		0.1	0
D EnvirFactor2	Damage aggregate		0.5	0.7
	Amt of Aid being sent		0.5	0.9
	% working of communications		0.5	0.2
	Response status		0.5	0.4
	Prior Development Level		0.9	0.7
D EconFactor1	Development Component Level		0.9	0.8

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	Implement Capability		0.5	0.4
	Implement Priority		0.5	0.5
	Nearness to event		0.1	0
D EconFactor2	Damage aggregate		0.5	0.7
	Amt of Aid being sent		0.5	0.7
	% working of communications		0.5	0.2
	Response status		0.5	0.3
	Prior Development Level		0.9	0.7
D PhysFactor1	Development Component Level		0.9	0.7
	Implement Capability		0.5	0.3
	Implement Priority		0.5	0.4
	Nearness to event		0.1	0
D PhysFactor2	Damage aggregate		0.5	0.8
	Amt of Aid being sent		0.9	0.7

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	% working of communications		0.5	0.2
	Response status		0.5	0.2
	Prior Development Level		0.9	0.7
D Social2Factor1	Development Component Level		0.9	0.7
	Implement Capability		0.5	0.3
	Implement Priority		0.9	0.9
	Nearness to event		0.1	0
D Social2Factor2	Damage aggregate		0.5	0.9
	Amt of Aid being sent		0.9	0.9
	% working of communications		0.5	0.2
	Response status		0.5	0.2
	Prior Development Level		0.9	0.7
D Envir2Factor1	Development Component Level		0.9	0.7

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	Implement Capability		0.5	0.5
	Implement Priority		0.5	0.5
	Nearness to event		0.1	0
D Envir2Factor2	Damage aggregate		0.5	0.7
	Amt of Aid being sent		0.5	0.9
	% working of communications		0.5	0.2
	Response status		0.5	0.4
	Prior Development Level		0.9	0.7
D Econ2Factor1	Development Component Level		0.9	0.8
	Implement Capability		0.5	0.4
	Implement Priority		0.5	0.5
	Nearness to event		0.1	0
D Econ2Factor2	Damage aggregate		0.5	0.7
	Amt of Aid being sent		0.5	0.7

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	% working of communications		0.5	0.2
	Response status		0.5	0.3
	Prior Development Level		0.9	0.7
D Phys2Factor1	Development Component Level		0.9	0.7
	Implement Capability		0.5	0.3
	Implement Priority		0.5	0.4
	Nearness to event		0.1	0
D Phys2Factor2	Damage aggregate		0.5	0.8
	Amt of Aid being sent		0.9	0.7
	% working of communications		0.5	0.2
	Response status		0.5	0.2
	Prior Development Level		0.9	0.7
Fraction	Population density		1189	1965
	urban infrastructure density		481	481

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	Preparedness		5	5
	Severity		0.7	0.7
	distance from location		0.233333333	0
PreparednessTrainingAdjust	Collaboration		2.737	3.125
PreparednessProgramAdjust	Collaboration		2.737	3.125
InitialFundingTotal	Level (+/ = /−)		1	1
InitialFundingBudget	Level (+/ = /−)		1	1
TrainingInit	Budget Status		1	1
	Recentness of last disaster		0	0
	probability of another disaster occurring		0.085	0.05
PrepProgramsInit	Budget Status		1	1
	Recentness of last disaster		0	0
	probability of another disaster occurring		0.085	0.05

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
ProcurementInit	Warning ? (amt of time)		0.01	0.2
	Budget Status		1	1
	Recentness of last disaster		0	0
	probability of another disaster occurring		0.085	0.05
PrepositionInit	Warning ? (amt of time)		0.01	0.2
	Budget Status		1	1
	Recentness of last disaster		0	0
	probability of another disaster occurring		0.085	0.05
CollabInit	Warning ? (amt of time?)		0.01	0.2
	Budget Status		1	1
	Recentness of last disaster		0	0
	probability of another disaster occurring		0.085	0.05

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
Wt TrainProc			0.5	0.5
Wt Prog Proc			0.2	0.2
Wt TrainPrep			0.5	0.5
Wt ProgPrep			0.2	0.2
Wt TrainColl			0.5	0.5
Wt ProgColl			0.2	0.2
Adjust Pro	Collaboration	Organization - training	0.7	0.6
		Communication	0.5	0.2
		Action - procurement	0.5	0.2
		Action - prepositioning	0.4	0.3
Adjust preparedness	Development		61.26	52.63
	Stability		0.4817	0.3263
	Recentness of last disaster		0	0
Prep Param1	Preparedness programming		0.8	0.4

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	probability of another disaster occurring		0.085	0.05
	Recentness of last disaster		0	0
	Stability		0.4817	0.3263
AidDelayAdjust	Preparedness		5	5
	Severity		0.7	0.7
AidParam1	Social Development		0	0
	Preparedness		5	5
	Transportation System Damages		0.5	0.5
InitialAid	Currently receiving aid for previous disaster?		1	1
	Recentness of last disaster		0	0
	Development		61.26	52.63
Adjust MC			1	1

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
Adjust CS			1	1
World State	stability of global economy		0.4	0.4
	number of ongoing wars in developed nations		0.7	0.7
	number of social crises (non war) in developed nations		0.4	0.4
	number of current disasters in developed nations		0.2	0.2
	number of developing disasters in developed nations		0.2	0.2
	number of ongoing wars in developing nations		0.6	0.6
	number of social crises (non war) in developing nations		0.5	0.5
	number of current disasters in developing nations		0.6	0.6

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
	number of developing disasters in developing nations		0.7	0.7
AidUnofficialFraction	Approximate data		0.08	0.2
AidExternalFraction	Aid received		0.32	0.75
	Fraction of aid implemented to the economy		0.6	0.75
AidResponseFraction	Approximate data		0.18	0.18
AidRestoreFraction	Approximate data		0.42	0.42
Adjustment flowExt	efficiency of external aid	fraction of amt of food needed beyond capacity of community which was provided	0.5	0.4
		provided disaster response drinking water needed beyond capacity of community	0.5	0.4

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		provided disaster response sanitation needed beyond capacity of community	0.4	0.5
		fraction of amt of shelter needed beyond capacity of community which was provided	0.4	0.3
		fraction of survivors beyond capacity of community which require aid who have received it	0.6	0.7
		fraction of survivors beyond capacity of community which require aid who have received partial aid/treatment	0.3	0.5

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		fraction of survivors beyond capacity of community which require aid who have received none	0.1	0.3
		fraction of missing found alive (efficiency of response)	0.4	0.4
		amt of debris which needs to be removed (m^3/ km^2 of land)	60000	20,550
		community removal rate capability (m^3/mo)	200000	50000
		projected time to remove debris (months)	2	24
		time needed to remove and process bodies (weeks)	6	6

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		capability needed to remove and process bodies, vs available capability	0.5	0.5
		fraction counseling needs which can be met by available counseling services	0.8	0.8
		avg amt of time it takes for families to reconnect (wks)	1	1
		avg amt of time it takes to relocate families (wks)	3	3
		avg amt of time it takes for families to move back into their own houses (months)	5	10
		projected time to repair transportation infrastructure to 75% functional (weeks)	2	2

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		projected time needed to repair buildings to 50% final (months)	5	6
		projected time needed to repair utilities to 50% (wks)	2	3
Adjustment flowUn	efficiency of unofficial aid	fraction of amt of food needed beyond capacity of community which was provided	0.5	0.4
		provided disaster response drinking water needed beyond capacity of community	0.5	0.4
		provided disaster response sanitation needed beyond capacity of community	0.4	0.5

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		fraction of amt of shelter needed beyond capacity of community which was provided	0.4	0.3
		fraction of survivors beyond capacity of community which require aid who have received it	0.6	0.7
		fraction of survivors beyond capacity of community which require aid who have received partial aid/treatment	0.3	0.5
		fraction of survivors beyond capacity of community which require aid who have received none	0.1	0.3

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		fraction of missing found alive (efficiency of response)	0.4	0.4
Adjustment flowRes	efficiency of response aid	fraction of amt of food needed beyond capacity of community which was provided	0.5	0.4
		provided disaster response drinking water needed beyond capacity of community	0.5	0.4
		provided disaster response sanitation needed beyond capacity of community	0.4	0.5
		fraction of amt of shelter needed beyond capacity of community which was provided	0.4	0.3

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		fraction of survivors beyond capacity of community which require aid who have received it	0.6	0.7
		fraction of survivors beyond capacity of community which require aid who have received partial aid/treatment	0.3	0.5
		fraction of survivors beyond capacity of community which require aid who have received none	0.1	0.3
		fraction of missing found alive (efficiency of response)	0.4	0.4
Adjustment flowRest	efficiency of restoration aid	amt of debris which needs to be removed	60000	20,550

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		community removal rate capability	200000	50000
		projected time to remove debris	2	24
		time needed to remove and process bodies	6	6
		capability needed to remove and process bodies, vs available capability	0.5	0.5
		fraction counseling needs which can be met by available counseling services	0.8	0.8
		avg amt of time it takes for families to reconnect	1	1
		avg amt of time it takes to relocate families	3	3

Continued on next page

Continued from previous page

Parameter	Sub-parameter	Data Element	Shelby	Orleans
		avg amt of time it takes for families to move back into their own houses	5	10
		projected time to repair transportation infrastructure at different levels	2	2
		projected time needed to repair buildings at different damage levels	5	6
		projected time needed to repair utilities to different functional levels	2	3

C.3 Preparedness Focus Areas

C.3.1 Values for Shelby County, TN

Table 53: Values for Shelby County Preparedness Improvement Focus

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
TrainingInit	probability of another disaster occurring		0.085	0.1	0.2	0.3
PrepProgramsInit	probability of another disaster occurring		0.085	0.1	0.2	0.3
ProcurementInit	probability of another disaster occurring		0.085	0.1	0.2	0.3
PrepositionInit	probability of another disaster occurring		0.085	0.1	0.2	0.3
CollabInit	probability of another disaster occurring		0.085	0.1	0.2	0.3
Wt TrainProc			0.5	0.5	0.55	0.6
Wt Prog Proc			0.2	0.2	0.22	0.25
Wt TrainPrep			0.5	0.5	0.6	0.7
Wt ProgPrep			0.2	0.2	0.3	0.32
Wt TrainColl			0.5	0.6	0.7	0.8
Wt ProgColl			0.2	0.3	0.4	0.5
Adjust Pro	Collaboration	Organization - training	0.7	0.75	0.85	0.9
		Communication	0.5	0.6	0.65	0.75
		Action - procurement	0.5	0.6	0.7	0.75
		Action - prepositioning	0.4	0.5	0.55	0.65
Prep Param1	Preparedness programming		0.8	0.85	0.9	0.95
	probability of another disaster occurring		0.085	0.1	0.2	0.3

C.3.2 Values for Orleans Parish, LA (pre-Katrina)

Table 54: Values for Orleans Parish (pre-Katrina) Preparedness Improvement Focus

Parameter	Sub-Parameter	Data Element	0yr* [13]	0yr(a)	2yr	5yr	10yr
TrainingInit	probability of another disaster occurring		0.05	0.05	0.1	0.2	0.3
PrepProgramsInit	probability of another disaster occurring		0.05	0.05	0.1	0.2	0.3
ProcurementInit	Warning (amt of time)		0.2	0.2	0.2	0.25	0.3
	probability of another disaster occurring		0.05	0.05	0.1	0.2	0.3
PrepositionInit	Warning (amt of time)		0.2	0.2	0.2	0.25	0.3
	probability of another disaster occurring		0.05	0.05	0.1	0.2	0.3
CollabInit	Warning (amt of time)		0.2	0.2	0.2	0.25	0.3
	probability of another disaster occurring		0.05	0.05	0.1	0.2	0.3
Wt TrainProc			0.5	0.5	0.5	0.55	0.6
Wt Prog Proc			0.2	0.2	0.2	0.22	0.25
Wt TrainPrep			0.5	0.5	0.5	0.6	0.7
Wt ProgPrep			0.2	0.2	0.2	0.3	0.32
Wt TrainColl			0.5	0.5	0.6	0.7	0.8
Wt ProgColl			0.2	0.2	0.3	0.4	0.5
Adjust Pro	Collaboration	Organization - training	0.6	0.6	0.75	0.85	0.9
		Communication	0.2	0.2	0.6	0.65	0.75
		Action - procurement	0.2	0.2	0.6	0.7	0.75
		Action - prepositioning	0.3	0.3	0.5	0.55	0.65
Prep Param1	Preparedness programming		0.4	0.4	0.5	0.6	0.7
	probability of another disaster occurring		0.05	0.05	0.1	0.2	0.3

[13]* - original data column, with out-of-range values adjusted

C.4 Response Focus Areas

C.4.1 Values for Shelby County, TN

Table 55: Values for Shelby County Response Improvement

Focus

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
D SocialFactor1	Implement Capability		0.5	0.6	0.7	0.8
D SocialFactor2	% working of communications		0.5	0.6	0.7	0.8
	Response status		0.5	0.6	0.7	0.8
D EnvirFactor1	Implement Capability		0.5	0.6	0.7	0.8
	Implement Priority		0.5	0.6	0.7	0.8
D EnvirFactor2	Amt of Aid being sent		0.5	0.55	0.6	0.65
	% working of communications		0.5	0.6	0.7	0.8
	Response status		0.5	0.6	0.7	0.8
D EconFactor1	Implement Capability		0.5	0.6	0.7	0.8
	Implement Priority		0.5	0.6	0.7	0.8

Continued on next page

[14]* - Fraction amounts of needed response which were provided to community beyond the capacity of the community to respond properly. Value of 1 means that all of the needed response resource was provided and no need remained.

[15]Projected time to repair transportation infrastructure to 75% functional, in weeks

[16]projected time needed to repair utilities to 50%, in weeks

Table 55 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
D EconFactor2	Amt of Aid being sent		0.5	0.55	0.6	0.65
	% working of communications		0.5	0.6	0.7	0.8
	Response status		0.5	0.6	0.7	0.8
D PhysFactor1	Implement Capability		0.5	0.6	0.7	0.8
	Implement Priority		0.5	0.6	0.7	0.8
D PhysFactor2	% working of communications		0.5	0.6	0.7	0.8
	Response status		0.5	0.6	0.7	0.8
AidUnofficialFraction	Approximate data		0.08	0.06	0.04	0.02
AidExternalFraction	Aid received		0.32	0.3	0.28	0.26
	Fraction of aid implemented to the economy		0.6	0.65	0.75	0.85
AidResponseFraction	Approximate amount		0.18	0.2	0.22	0.24
AidRestoreFraction	Approximate amount		0.42	0.44	0.46	0.48
Adjustment flowExt	Efficiency of external aid* [14]	Food Needed*	0.5	0.6	0.7	0.8
		Drinking Water Needed*	0.5	0.6	0.7	0.8

Continued on next page

Table 55 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
		Sanitation Needed*	0.4	0.5	0.6	0.7
		Shelter Needed*	0.4	0.3	0.2	0.1
		Survivors Needing Medical Aid*	0.6	0.7	0.8	0.9
		Survivors Needing Medical Aid* (partial provision)	0.3	0.25	0.2	0.15
		Survivors Needing Medical Aid* (no provision)	0.1	0.08	0.04	0.02
		Missing Persons Found Alive*	0.4	0.5	0.6	0.7
		Debris Removal capability (m^3/mo)	200000	205000	215000	225000
		Debris Removal Time (mos.)	2	1.75	1.5	1
		Body Removal Time (wks)	6	5	4	3
		Body Removal Capability*	0.5	0.6	0.7	0.8
		Counseling Needs*	0.8	0.85	0.9	0.95

Continued on next page

Table 55 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
		Transportation Repair Time[15] (wks)	2	1.75	1.5	1
		Utility Repair Time[16]	2	1.75	1.5	1

C.4.2 Values for Orleans Parish, LA (pre-Katrina)

Table 56: Values for Orleans Parish Response Improvement

Focus

Parameter	Sub-Parameter	Data Element	0yr	0yr(a)	2yr	5yr	10yr
D SocialFactor1	Implement Capability		0.3	0.3	0.4	0.5	0.6
D SocialFactor2	% working of communications		0.2	0.2	0.3	0.4	0.5
	Response status		0.2	0.2	0.3	0.4	0.5
D EnvirFactor1	Implement Capability		0.5	0.5	0.55	0.6	0.65
	Implement Priority		0.5	0.5	0.55	0.6	0.65
D EnvirFactor2	% working of communications		0.2	0.2	0.3	0.4	0.5
	Response status		0.4	0.4	0.45	0.55	0.65
D EconFactor1	Implement Capability		0.4	0.4	0.5	0.6	0.7
	Implement Priority		0.5	0.5	0.55	0.6	0.65
D EconFactor2	Amt of Aid being sent		0.7	0.7	0.75	0.8	0.85
	% working of communications		0.2	0.2	0.3	0.4	0.5
	Response status		0.3	0.3	0.4	0.5	0.6

Continued on next page

Table 56 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	0yr(a)	2yr	5yr	10yr
D PhysFactor1	Implement Capability		0.3	0.3	0.4	0.5	0.6
	Implement Priority		0.4	0.4	0.45	0.55	0.65
D PhysFactor2	Amt of Aid being sent		0.7	0.7	0.75	0.8	0.85
	% working of communications		0.2	0.2	0.3	0.4	0.5
	Response status		0.2	0.2	0.3	0.4	0.5
Adjustment flowExt	Efficiency of external aid	Food Needed*	0.4	0.4	0.5	0.6	0.7
		Drinking Water Needed*	0.4	0.4	0.5	0.6	0.7
		Sanitation Needed*	0.5	0.5	0.6	0.7	0.8
		Shelter Needed*	0.3	0.3	0.4	0.5	0.6
		Survivors Needing Medical Aid*	0.7	0.7	0.75	0.8	0.85
		Survivors Needing Medical Aid* (partial provision)	0.5	0.5	0.45	0.4	0.35
		Survivors Needing Medical Aid* (no provision)	0.3	0.3	0.25	0.2	0.15

Continued on next page

Table 56 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	0yr(a)	2yr	5yr	10yr
		Missing Persons Found Alive*	0.4	0.4	0.5	0.6	0.7
		Debris Removal Capability (m^3/mo)	50000	50000	55000	60000	65000
		Debris Removal Time (mos)	24	24	20	16	12
		Body Removal Time (wks)	6	6	5	4	3
		Body Removal Capability*	0.5	0.5	0.6	0.7	0.8
		Counseling Needs*	0.8	0.8	0.85	0.9	0.95
		Transportation Repair Time (wks to 75%)	2	2	1.7	1.5	1.3
		Utility Repair Time (wks to 50%)	3	3	2.5	2	1.5

C.5 Development Focus Areas

C.5.1 Values for Shelby County, TN

Table 57: Values for Shelby County Development Improvement Focus

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
Social Development Indicator	Childbearing	Adolescent Fertility Rate	66	60	50	40
		Estimated Maternal Mortality Ratio	24	22	20	18
	Contraceptive Use	Contraceptive Prevalence - any methods	0.62	0.7	0.75	0.8
		Contraceptive Prevalence - modern methods	0.584	0.65	0.7	0.75
	Education	school life expectancy, primary to tertiary - total	11.55935	12	13	14
		school life expectancy, primary to tertiary - men	11.55182	12	13	14

Continued on next page

Table 57 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
		school life expectancy, primary to tertiary - women	11.56727	12	13	14
	Health	Life expectancy at birth - men	72.4	73	74	75
		Life expectancy at birth - women	78.4	78	78.5	79
		Infant mortality rate	13.8	12	11	10
	Income and Economic Activity	per capita GDP (US$)	38420.78	39000	40000	41000
	Literacy	adult (15+) literacy rate - total	0.14	0.12	0.1	0.08
	Population	sex ratio of population - men / 100 women	91.282	92	93	94
	Unemployment	adult (15+) unemployment rate - total	0.097	0.08	0.07	0.06

Continued on next page

Table 57 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	2yr	5yr	10yr
Economic Development Indicators	Life expectancy at birth		75.4	76	77	78
	Adult literacy rate		0.14	0.12	0.1	0.08
	gross enrollment ratio		0.89	0.9	0.92	0.94
	GDP per capita (PPP US$)		38420.78	39000	40000	41000
Physical Infrastructure Development Indicators	Medical care facilities	replacement cost	117040	127000	137000	147000
		# of facilities	12	13	13	13
		# beds	4163	4200	4350	4500

C.5.2 Values for Orleans Parish, LA (pre-Katrina)

Table 58: Values for Orleans Parish Development Improvement Focus

Parameter	Sub-Parameter	Data Element	0yr	0yr(a)	2yr	5yr	10yr
Social Development Indicator	Childbearing	Adolescent Fertility Rate	72.7	68.5	68	67	66
		Estimated Maternal Mortality Ratio	24	24	22	20	18
	Contraceptive Use	Contraceptive Prevalence - any methods	0.62	0.62	0.67	0.7	0.73
		Contraceptive Prevalence - modern methods	0.584	0.584	0.62	0.66	0.7
	Education	school life expectancy, primary to tertiary - total	11.55935	11.55935	12	13	14
		school life expectancy, primary to tertiary - men	11.55182	11.55182	12	13	14
		school life expectancy, primary to tertiary - women	11.56727	11.56727	12	13	14

Continued on next page

Table 58 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	0yr(a)	2yr	5yr	10yr
	Health	Life expectancy at birth - men	68.4	68.4	69	70	71
		Infant mortality rate	10.8	10.8	9	8	7
	Housing	Avg # of persons / room - total	2.574616	2.574616	2.3	2	1.7
	Income and Economic Activity	per capita GDP (US$)	49561.84	49561.84	50000	52000	55000
	Literacy	adult (15+) literacy rate - total	0.6	0.6	0.58	0.55	0.52
	Population	sex ratio of population - men / 100 women	88.164	88.164	89	90	91
	Unemployment	adult (15+) unemployment rate - total	0.055	0.055	0.05	0.045	0.04
Economic Development Indicators	Life expectancy at birth		73.95	73.95	74	74.5	75
	Adult literacy rate		0.6	0.6	0.58	0.55	0.52

Continued on next page

Table 58 – continued from previous page

Parameter	Sub-Parameter	Data Element	0yr	0yr(a)	2yr	5yr	10yr
	gross enrollment ratio		0.891	0.891	0.91	0.93	0.95
	GDP per capita (PPP US$)		49561.84	49561.84	50000	52000	55000
Physical Infrastructure Development Indicators	Medical care facilities	replacement cost	1002629.19	1002629.19	1040000	1080000	1220000
	School facilities	design level	M	M	H	H	H
		# students	104342	164680	164680	164680	164680

C.6 Ranked Alternatives Generated Through Particle Swarm Optimization of the Developed Neural Network

Table 59: Fifty Generated Alternatives

Number	KK	J	L	M	MM	O	C
Rank	1	2	3	4	5	6	7
Closeness	0.91152	0.90808	0.89627	0.87718	0.87636	0.86907	0.86616
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.327713	0.327713	0.327713	0.327713	0.327713	0.327713	0.327713
Adjust Pro	0.325	0.325	0.325	0.325	0.325	0.325	0.325
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.26	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.24	0.24	0.24	0.24	0.24	0.18	0.24
AidRestoreFraction	0.42	0.42	0.42	0.42	0.42	0.42	0.42
AidUnofficialFraction	0.058961	0.057163	0.020000	0.200004	0.020000	0.200004	0.200004
CollabInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
D EconFactor2	0.73	0.73	0.73	0.57	0.57	0.73	0.57
D EnvirFactor2	0.58	0.58	0.58	0.58	0.58	0.58	0.73
D PhysicalFactor2	0.78	0.78	0.78	0.78	0.78	0.78	0.78
D SocialFactor2	0.62	0.62	0.62	0.62	0.78	0.62	0.62
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.15637	0.15637	0.15637	0.15637	0.15637	0.15637	0.15637
DevelPhysInit	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972
Fraction	0.45366	0.39366	0.45366	0.39366	0.39366	0.39366	0.39366
InitialAid	5.08767	5.08767	5.08767	5.37533	5.37533	5.08767	5.08767
Prep Param1	0.32560	0.32958	0.35612	0.36359	0.34344	0.36674	0.40513
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
PrepProgramsInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
ProcurementInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
TrainingInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Restoration	0.00055	0.00059	47.63	140.46	141.45	85.17	78.04

Table 60: 50 Generated Alternatives (continued)

Number	N	SS	WW	R	FF	QQ	B
Rank	8	9	10	11	12	13	14
Closeness	0.86506	0.86292	0.85698	0.85612	0.85573	0.84038	0.83370
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.327713	0.327713	0.327713	0.259100	0.327713	0.327713	0.327713
Adjust Pro	0.325	0.325	0.763	0.763	0.763	0.325	0.325
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.025	0.025	0.025	0.025	0.025	0.384	0.025
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.26	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.24	0.18	0.18	0.24	0.18	0.24	0.18
AidRestoreFraction	0.42	0.42	0.42	0.42	0.48	0.48	0.42
AidUnofficialFraction	0.020000	0.200004	0.200004	0.200004	0.200004	0.020000	0.020000
CollabInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
D EconFactor2	0.57	0.73	0.73	0.73	0.73	0.57	0.73
D EnvirFactor2	0.73	0.58	0.58	0.66	0.73	0.58	0.58
D PhysicalFactor2	0.78	0.78	0.78	0.78	0.78	0.78	0.78
D SocialFactor2	0.62	0.62	0.62	0.62	0.62	0.78	0.62
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.16365	0.15637	0.15637	0.15637	0.15637	0.15637	0.15637
DevelPhysInit	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972
Fraction	0.45366	0.39366	0.39366	0.45366	0.45366	0.39366	0.39366
InitialAid	5.37533	5.08767	5.08767	5.08767	5.08767	5.37533	5.08767
Prep Param1	0.40513	0.40513	0.40349	0.40513	0.40513	0.32090	0.39360
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
PrepProgramsInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
ProcurementInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
TrainingInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Restoration	152.77	89.38	78.37	60.23	30.65	99.88	149.81

C.7 Sensitivity Analysis Data

Table 67 shows the sensitivity analysis data for the single input parameters.

Table 61: 50 Generated Alternatives (continued)

Number	AA	UU	Z	W	D	A	K
Rank	15	16	17	18	19	20	21
Closeness	0.83039	0.81991	0.80776	0.79462	0.79072	0.77852	0.77324
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.259100	0.326180	0.259100	0.259100	0.327713	0.327713	0.259100
Adjust Pro	0.325	0.325	0.325	0.325	0.325	0.325	0.325
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.373	0.025	0.025	0.025	0.025	0.384	0.201
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.29	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.24	0.24	0.24	0.18	0.18	0.24	0.18
AidRestoreFraction	0.48	0.42	0.42	0.42	0.42	0.48	0.42
AidUnofficialFraction	0.020000	0.020000	0.200004	0.200004	0.113001	0.020000	0.020000
CollabInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
D EconFactor2	0.73	0.57	0.57	0.73	0.57	0.57	0.73
D EnvirFactor2	0.58	0.58	0.73	0.58	0.58	0.58	0.58
D PhysicalFactor2	0.78	0.78	0.78	0.78	0.78	0.78	0.78
D SocialFactor2	0.78	0.62	0.62	0.62	0.62	0.62	0.78
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.15637	0.15637	0.16365	0.15637	0.16365	0.15637	0.16365
DevelPhysInit	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972
Fraction	0.45366	0.45366	0.45366	0.45366	0.39366	0.39366	0.39366
InitialAid	5.37533	5.08767	5.08767	5.08767	5.08767	5.08767	5.08767
Prep Param1	0.34594	0.37287	0.40513	0.40513	0.40513	0.33469	0.40513
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
PrepProgramsInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
ProcurementInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
TrainingInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Restoration	96.84	189.60	175.77	199.49	230.46	134.07	205.08

Table 62: 50 Generated Alternatives (continued)

Number	F	PP	LL	EE	VV	OO	P
Rank	22	23	24	25	26	27	28
Closeness	0.60491	0.59962	0.59562	0.59335	0.58083	0.57851	0.57334
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.259100	0.259100	0.327713	0.327713	0.327713	0.327713	0.327713
Adjust Pro	0.325	0.325	0.325	0.325	0.325	0.325	0.325
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.025	0.180	0.025	0.318	0.025	0.025	0.025
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.26	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.24	0.24	0.24	0.24	0.24	0.24	0.18
AidRestoreFraction	0.42	0.42	0.42	0.42	0.42	0.42	0.42
AidUnofficialFraction	0.200004	0.070446	0.064435	0.042332	0.020000	0.020000	0.200004
CollabInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
D EconFactor2	0.73	0.73	0.73	0.73	0.73	0.73	0.73
D EnvirFactor2	0.58	0.58	0.58	0.58	0.58	0.58	0.58
D PhysicalFactor2	0.78	0.78	0.78	0.78	0.78	0.78	0.78
D SocialFactor2	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.15637	0.15637	0.15637	0.15637	0.16365	0.15637	0.15637
DevelPhysInit	0.19972	0.19972	0.19972	0.19971	0.19972	0.19972	0.19972
Fraction	0.39366	0.39366	0.39366	0.39366	0.45366	0.45366	0.45366
InitialAid	5.37533	5.37533	5.08767	5.37533	5.08767	5.08767	5.08767
Prep Param1	0.40513	0.38444	0.33506	0.34503	0.35415	0.35533	0.37224
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
PrepProgramsInit	4.3	4.3	4.3	4.3	3.5	3.5	4.3
ProcurementInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
TrainingInit	3.5	3.5	3.5	3.5	4.3	4.3	3.5
Restoration	94.20	103.34	0.0001	0.0011	77.00	87.29	91.34

Table 63: 50 Generated Alternatives (continued)

Number	V	CC	U	DD	I	HH	H
Rank	29	30	31	32	33	34	35
Closeness	0.56887	0.53608	0.53490	0.50016	0.49610	0.49097	0.46960
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.327713	0.259100	0.259100	0.327713	0.327713	0.259100	0.327713
Adjust Pro	0.325	0.325	0.325	0.325	0.325	0.692	0.325
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.025	0.025	0.025	0.025	0.384	0.025	0.025
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.26	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.18	0.18	0.18	0.24	0.18	0.24	0.24
AidRestoreFraction	0.42	0.42	0.42	0.42	0.42	0.48	0.42
AidUnofficialFraction	0.020000	0.020000	0.020000	0.064166	0.020000	0.200004	0.020000
CollabInit	2.7375	2.7375	2.7375	2.7375	2.7375	3.6250	2.7375
D EconFactor2	0.73	0.73	0.73	0.72	0.57	0.73	0.73
D EnvirFactor2	0.58	0.58	0.58	0.73	0.58	0.73	0.58
D PhysicalFactor2	0.78	0.78	0.78	0.78	0.78	0.78	0.76
D SocialFactor2	0.78	0.78	0.62	0.62	0.78	0.62	0.78
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.16365	0.15637	0.16365	0.15637	0.15637	0.16365	0.16365
DevelPhysInit	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972
Fraction	0.45366	0.39366	0.45366	0.45366	0.45366	0.39366	0.39366
InitialAid	5.08767	5.08767	5.08767	5.37533	5.08767	5.37533	5.08767
Prep Param1	0.36348	0.40513	0.40513	0.36744	0.33770	0.40513	0.35675
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
PrepProgramsInit	4.3	4.3	4.3	3.5	4.3	3.5	3.5
ProcurementInit	2.7375	2.7375	2.7375	3.6250	2.7375	2.7375	3.6250
TrainingInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Restoration	108.56	213.71	247.42	0.00024	213.94	0.00003	0.01762

Table 64: 50 Generated Alternatives (continued)

Number	XX	Q	T	JJ	TT	G	S
Rank	36	37	38	39	40	41	42
Closeness	0.46323	0.45311	0.44859	0.44415	0.44143	0.43985	0.43867
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.327713	0.327713	0.259100	0.327713	0.327713	0.327713	0.327713
Adjust Pro	0.325	0.325	0.325	0.325	0.325	0.325	0.763
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.201	0.025	0.025	0.318	0.025	0.025	0.025
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226	0.004226
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.26	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.24	0.18	0.24	0.24	0.24	0.18	0.18
AidRestoreFraction	0.42	0.42	0.42	0.42	0.42	0.42	0.42
AidUnofficialFraction	0.046809	0.200004	0.200004	0.028688	0.020000	0.020000	0.200004
CollabInit	2.7375	3.6250	3.6250	3.6250	3.6250	2.7375	3.6250
D EconFactor2	0.73	0.73	0.73	0.73	0.57	0.73	0.73
D EnvirFactor2	0.58	0.58	0.73	0.58	0.58	0.58	0.73
D PhysicalFactor2	0.78	0.78	0.78	0.78	0.78	0.78	0.78
D SocialFactor2	0.62	0.62	0.62	0.62	0.62	0.78	0.78
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.15637	0.15637	0.15637	0.16365	0.15637	0.15637	0.15637
DevelPhysInit	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972
Fraction	0.39366	0.39366	0.39366	0.45366	0.45366	0.45366	0.39366
InitialAid	5.08767	5.08767	5.08767	5.08767	5.08767	5.08767	5.08767
Prep Param1	0.32114	0.36472	0.40513	0.30841	0.37145	0.36533	0.40513
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	3.6250	2.7375
PrepProgramsInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
ProcurementInit	3.6250	2.7375	2.7375	2.7375	2.7375	2.7375	2.7375
TrainingInit	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Restoration	0.00783	67.59	30.96	0.00118	171.00	123.33	38.96

Table 65: 50 Generated Alternatives (continued)

Number	II	Y	BB	RR	GG	E	X
Rank	43	44	45	46	47	48	49
Closeness	0.43566	0.39300	0.39268	0.25812	0.24977	0.20471	0.17850
AD Econ	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Envir	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Phys	0.62	0.62	0.62	0.62	0.62	0.62	0.62
AD Soc	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Adjust Preparedness	0.2591	0.3277	0.3277	0.3277	0.3277	0.3277	0.2591
Adjust Pro	0.325	0.325	0.325	0.497	0.325	0.325	0.325
Adjustment DSD	1	1	1	1	1	1	1
Adjustment flowExt	0.025	0.284	0.025	0.025	0.025	0.025	0.025
Adjustment flowRes	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Adjustment flowRest	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042
Adjustment flowUn	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625
Aid Param1	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683	0.16683
AidDelayAdjust	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
AidExternalFraction	0.26	0.26	0.26	0.26	0.26	0.26	0.26
AidResponseFraction	0.24	0.18	0.18	0.24	0.24	0.18	0.24
AidRestoreFraction	0.42	0.42	0.42	0.48	0.42	0.42	0.42
AidUnofficialFraction	0.02000	0.02000	0.20000	0.05811	0.02000	0.20000	0.02000
CollabInit	3.6250	3.6250	2.7375	3.6250	3.6250	3.6250	2.7375
D EconFactor2	0.73	0.57	0.73	0.73	0.73	0.73	0.73
D EnvirFactor2	0.58	0.73	0.58	0.73	0.58	0.58	0.58
D PhysicalFactor2	0.78	0.78	0.78	0.75	0.78	0.78	0.78
D SocialFactor2	0.62	0.62	0.62	0.62	0.62	0.62	0.78
Devel EconInit	0.1223	0.1223	0.1223	0.1223	0.1535	0.1223	0.1223
Devel EnvirInit	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Devel SocialInit	0.16365	0.15637	0.16365	0.15637	0.15637	0.15637	0.15637
DevelPhysInit	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972	0.19972
Fraction	0.45366	0.39366	0.39366	0.45366	0.39366	0.39366	0.45366
InitialAid	5.08767	5.08767	5.37533	5.08767	5.37533	5.08767	5.08767
Prep Param1	0.40513	0.40513	0.36200	0.38862	0.34387	0.36684	0.40513
PrepositionInit	2.7375	2.7375	2.7375	2.7375	2.7375	3.6250	3.6250
PrepProgramsInit	3.5	3.5	4.3	3.5	3.5	3.5	3.5
ProcurementInit	2.7375	2.7375	2.7375	3.6250	3.6250	2.7375	3.6250
TrainingInit	3.5	3.5	4.3	3.5	3.5	3.5	3.5
Restoration	138.92	226.19	109.61	0.00217	37.78	83.36	125.53

Table 66: 50 Generated Alternatives (continued)

Number	NN
Rank	50
Closeness	0.16598
AD Econ	0.62
AD Envir	0.62
AD Phys	0.62
AD Soc	0.62
Adjust Preparedness	0.3277
Adjust Pro	0.325
Adjustment DSD	1
Adjustment flowExt	0.025
Adjustment flowRes	0.0625
Adjustment flowRest	0.0042
Adjustment flowUn	0.0625
Aid Param1	0.16683
AidDelayAdjust	0.00025
AidExternalFraction	0.26
AidResponseFraction	0.24
AidRestoreFraction	0.42
AidUnofficialFraction	0.02000
CollabInit	3.6250
D EconFactor2	0.73
D EnvirFactor2	0.58
D PhysicalFactor2	0.78
D SocialFactor2	0.62
Devel EconInit	0.1223
Devel EnvirInit	0.125
Devel SocialInit	0.15637
DevelPhysInit	0.19972
Fraction	0.45366
InitialAid	5.08767
Prep Param1	0.36081
PrepositionInit	2.7375
PrepProgramsInit	4.3
ProcurementInit	3.6250
TrainingInit	3.5
Restoration	48.69

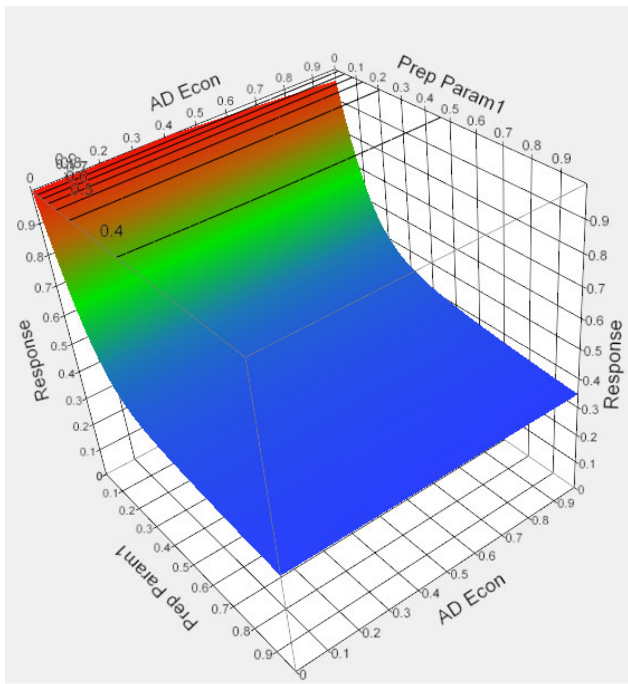
Table 67: Sensitivity Analysis Data for System Model Parameters

Parameter	Contrast	Length	Individual P-value
Prep Param1	-0.110545	-30.38	¡.0001
Aid Param1	0.078895	21.68	¡.0001
Adjust Preparedness	-0.076211	-20.94	¡.0001
Adjust Pro	-0.063662	-17.5	¡.0001
AD Phys	-0.050648	-13.92	¡.0001
Adjustment flowRes	0.032378	8.9	¡.0001
AD Soc	-0.027599	-7.58	¡.0001
D EnvirFactor2	-0.025134	-6.91	¡.0001
AD Envir	-0.021592	-5.93	¡.0001
D PhysicalFactor2	-0.021302	-5.85	¡.0001
Devel EnvirInit	-0.017441	-4.79	¡.0001
DevelPhysInit	-0.01736	-4.77	¡.0001
Devel SocialInit	-0.016215	-4.46	¡.0001
Devel EconInit	-0.01451	-3.99	0.0001
D EconFactor2	-0.014368	-3.95	0.0001
DevelThrottle	0.011469	3.15	0.0015
D SocialFactor2	-0.009753	-2.68	0.0074
PrepositionInit	-0.006963	-1.91	0.0578
AidUnofficialFraction	-0.007058	-1.94	0.0545
ProcurementInit	0.006357	1.75	0.081
Adjustment DSD	-0.005724	-1.57	0.1169
CollabInit	0.004488	1.23	0.2158
Severity	-0.004344	-1.19	0.2298
TrainingInit	-0.004263	-1.17	0.2385
AidExternalFraction	-0.003554	-0.98	0.3223
PrepProgramsInit	0.002897	0.8	0.4216
AD Econ	-0.002849	-0.78	0.4292
Adjustment flowUn	0.002376	0.65	0.5095
AidResponseFraction	-0.001449	-0.4	0.6844
World State	-0.001324	-0.36	0.7111
Fraction	-0.001124	-0.31	0.7548
AidDelayAdjust	-0.000852	-0.23	0.8122
Adjustment flowRest	0.00077	0.21	0.8303
InitialAid	0.000553	0.15	0.8765
Adjustment flowExt	0.000517	0.14	0.8846
AidRestoreFraction	-0.000255	-0.07	0.9383

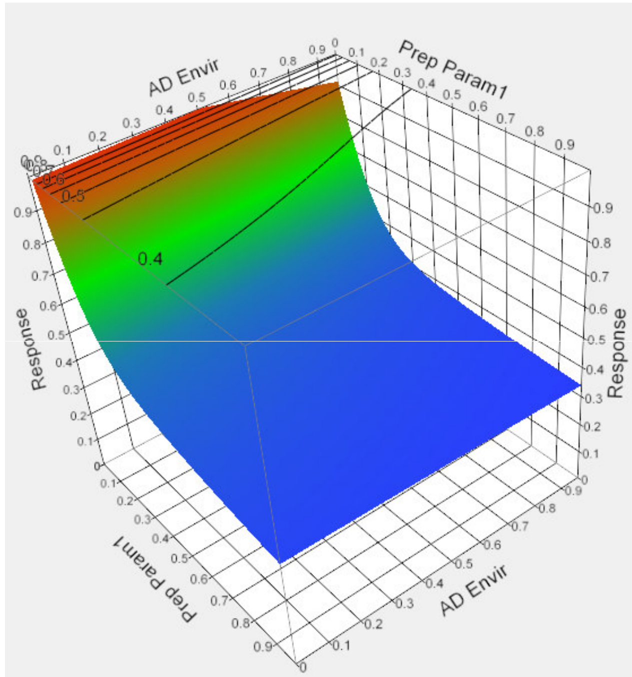
APPENDIX D

FIGURES

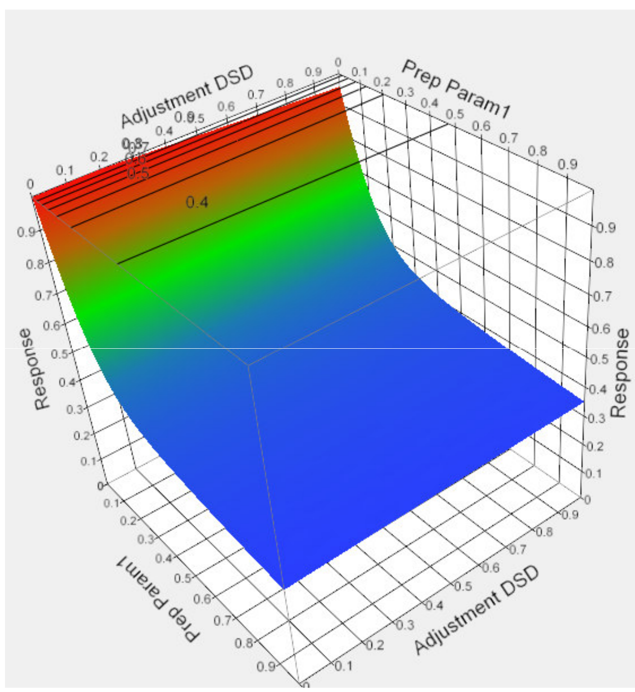
D.1 Second Order Effects



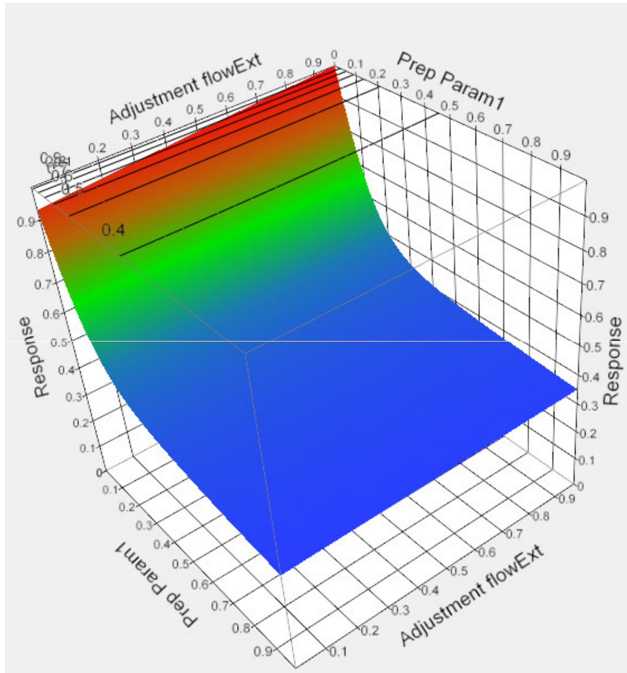
Prep Param1 & AD Econ 2 factor effect on Restoration time



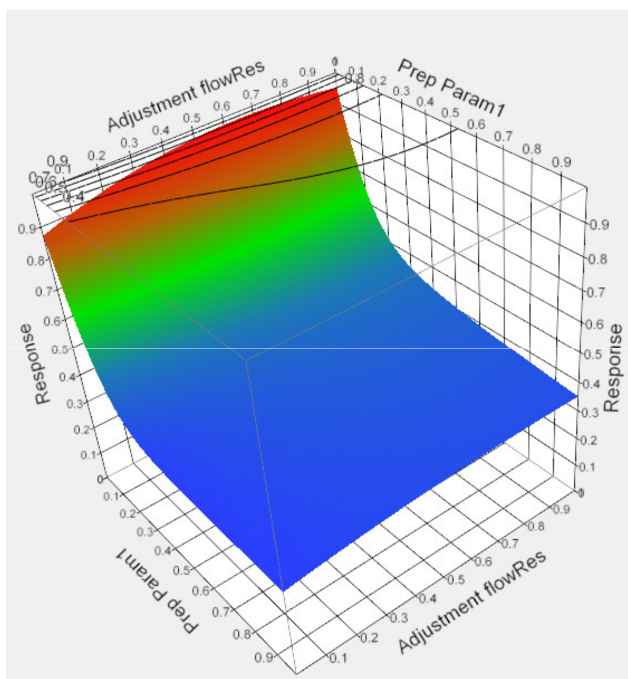
Prep Param1 & AD Envir 2 factor effect on Restoration time



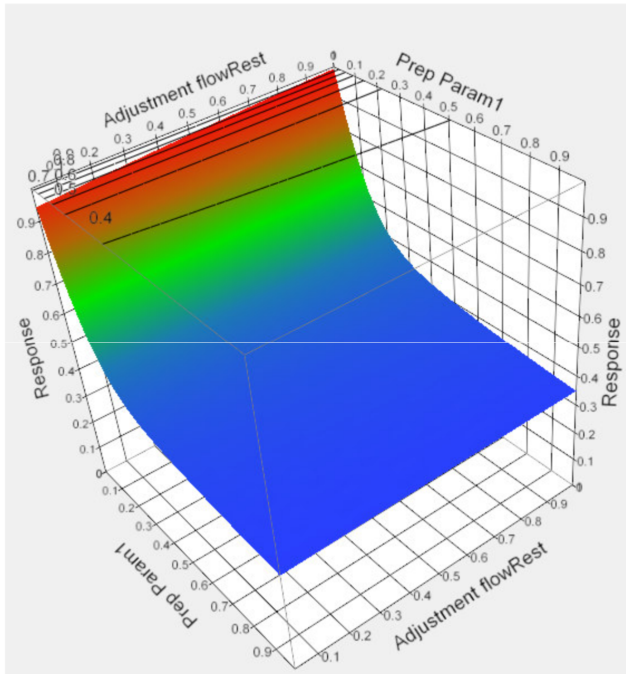
Prep Param1 & AdjustmentDSD 2 factor effect on Restoration time



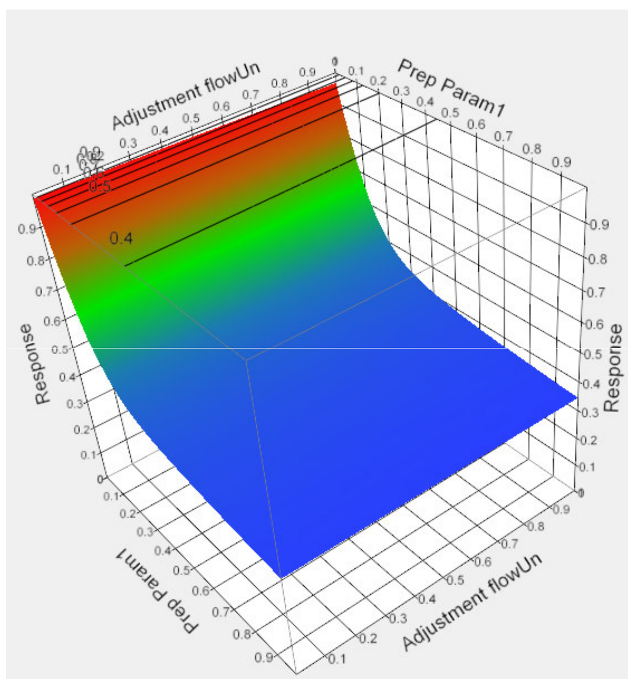
Prep Param1 & Adjustment FlowExt 2 factor effect on Restoration time



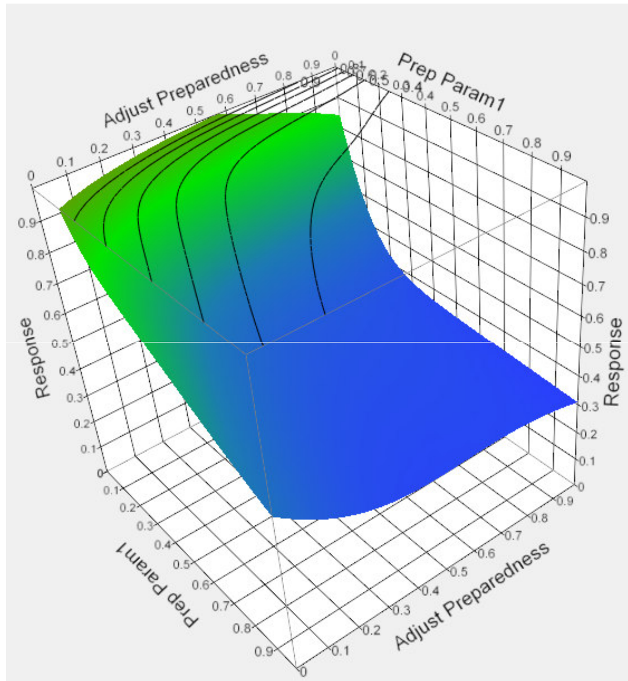
Prep Param1 & Adjustment FlowRes 2 factor effect on Restoration time



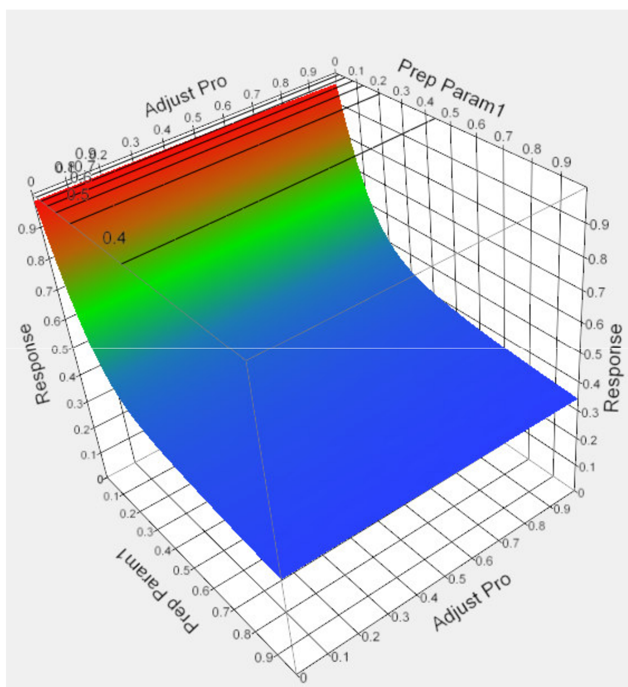
Prep Param1 & Adjustment FlowRest 2 factor effect on Restoration time



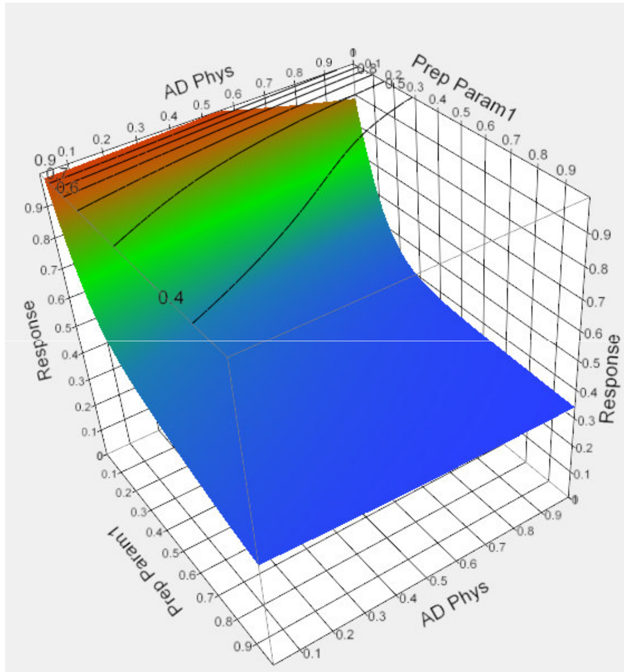
Prep Param1 & Adjustment FlowUn 2 factor effect on Restoration time



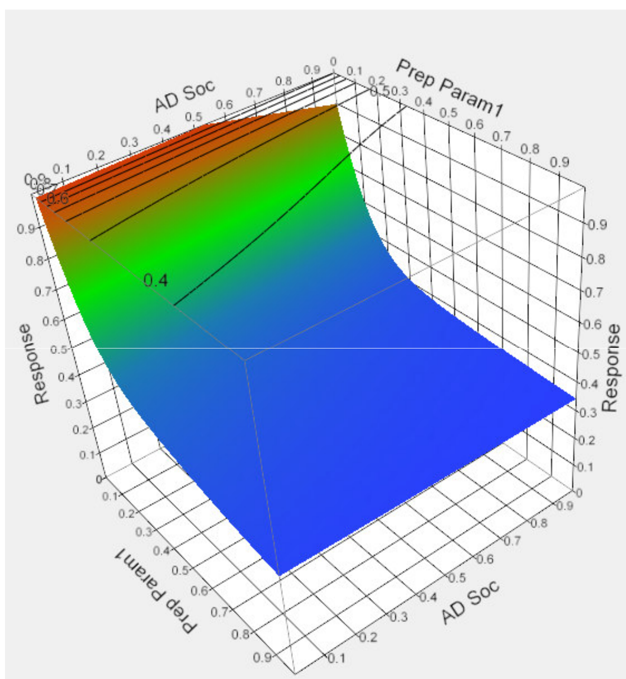
Prep Param1 & AdjustPreparedness 2 factor effect on Restoration time



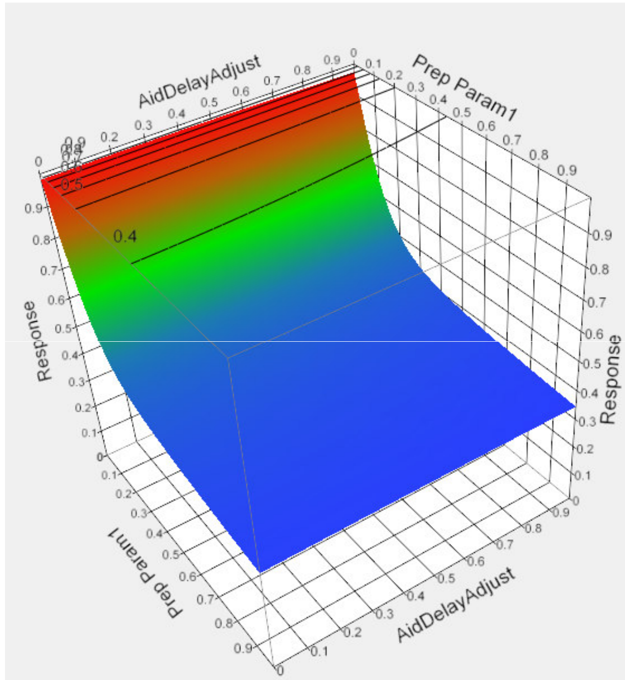
Prep Param1 & AdjustPro 2 factor effect on Restoration time



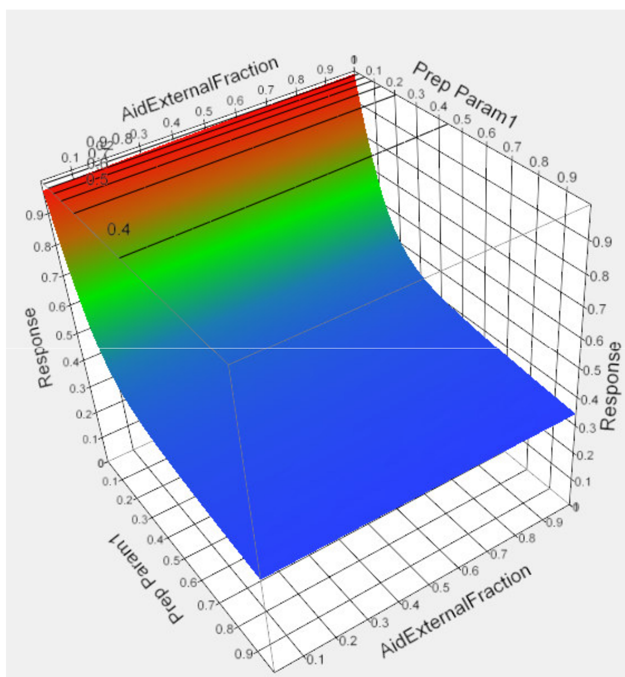
Prep Param1 & AD Phys 2 factor effect on Restoration time



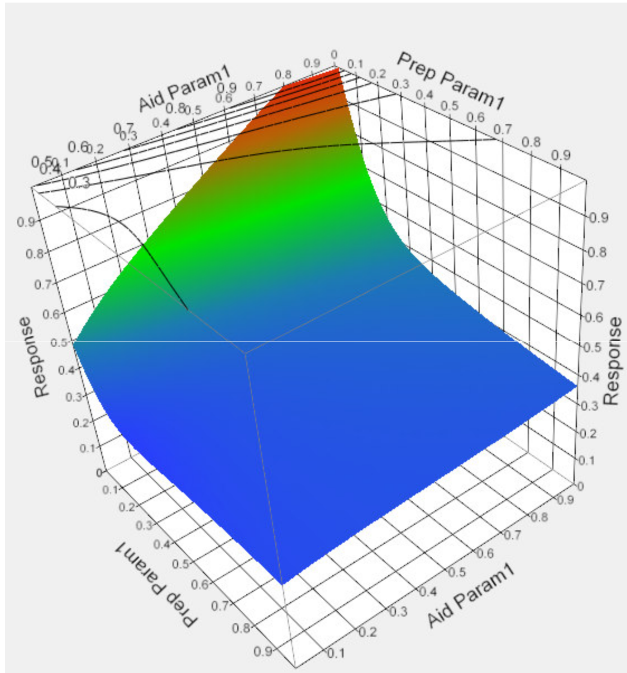
Prep Param1 & AD Soc 2 factor effect on Restoration time



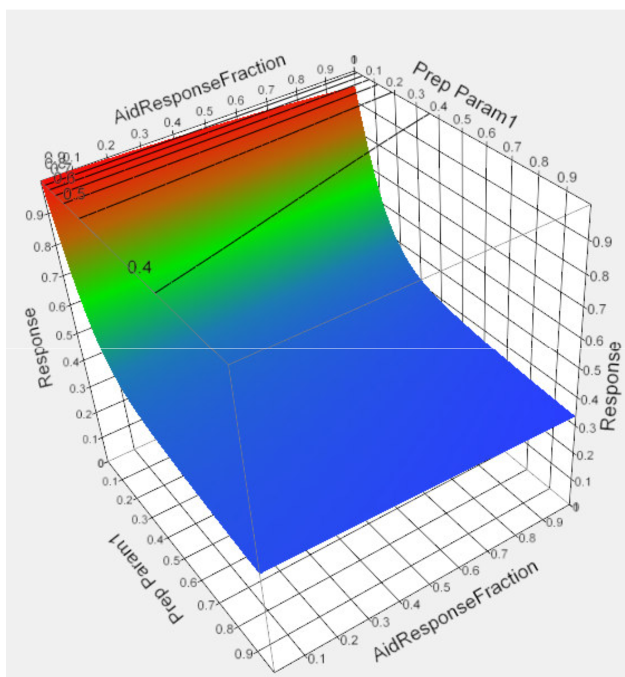
Prep Param1 & DelayAdjust 2 factor effect on Restoration time



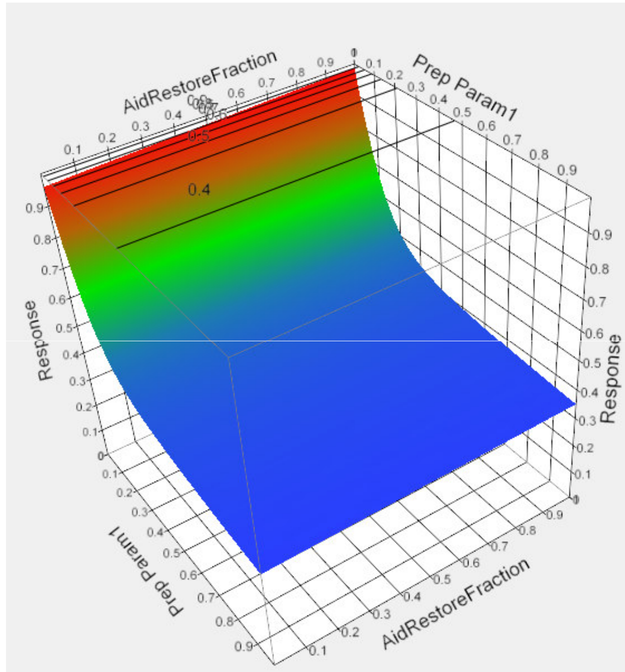
Prep Param1 & ExternalFraction 2 factor effect on Restoration time



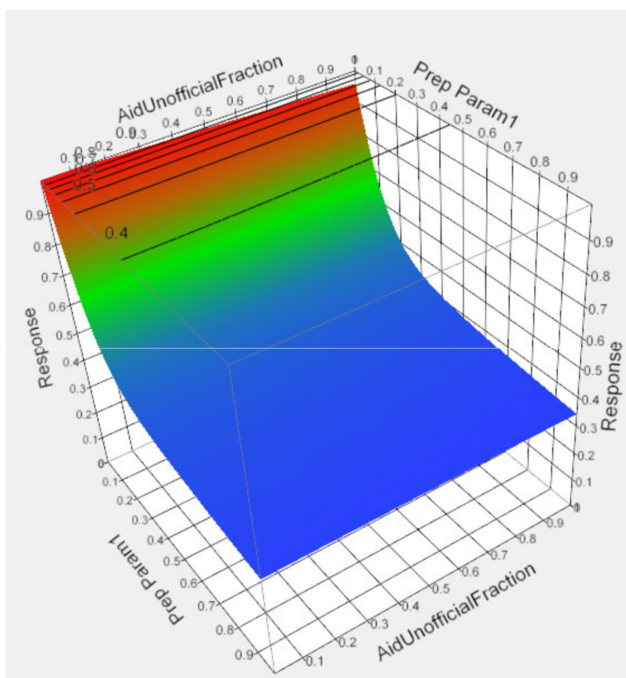
Prep Param1 & AidParam1 2 factor effect on Restoration time



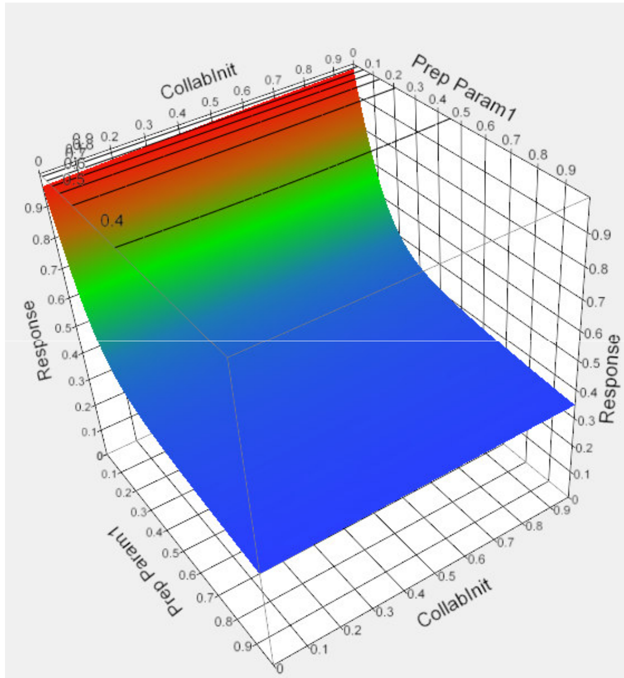
Prep Param1 & AidResponseFraction 2 factor effect on Restoration time



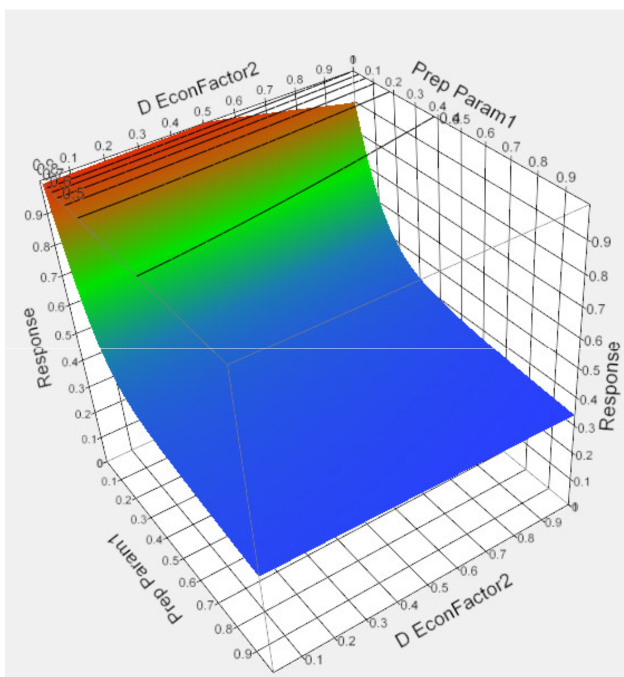
Prep Param1 & AidRestoreFraction 2 factor effect on Restoration time



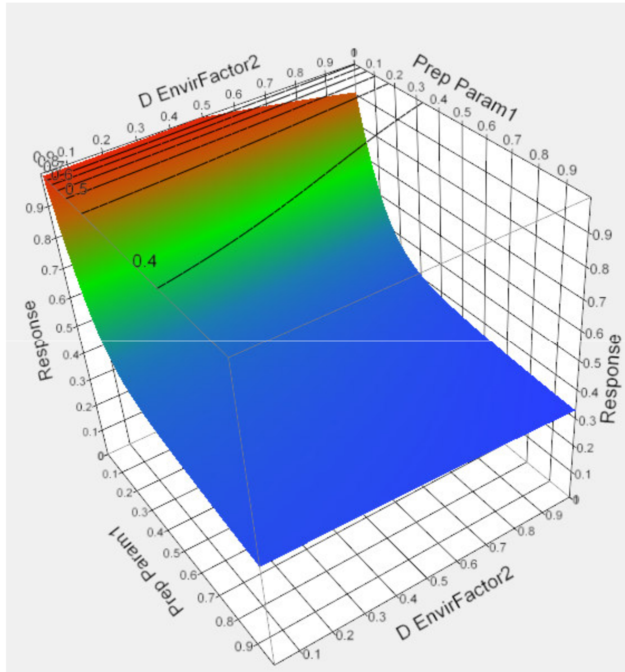
Prep Param1 & AidUnofficialFraction 2 factor effect on Restoration time



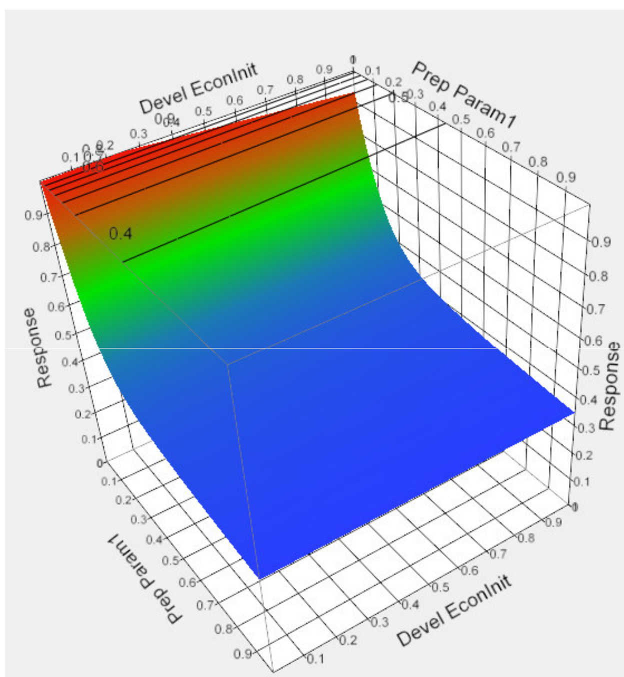
Prep Param1 & CollabInit 2 factor effect on Restoration time



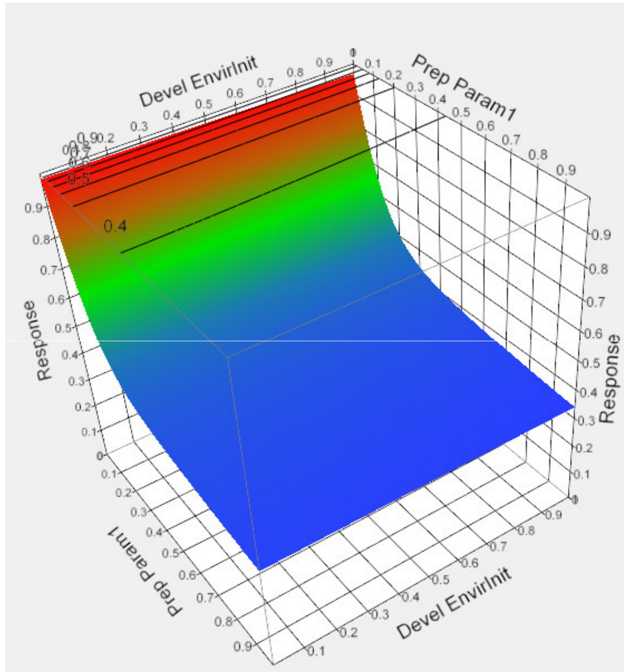
Prep Param1 & D EconFactor2 2 factor effect on Restoration time



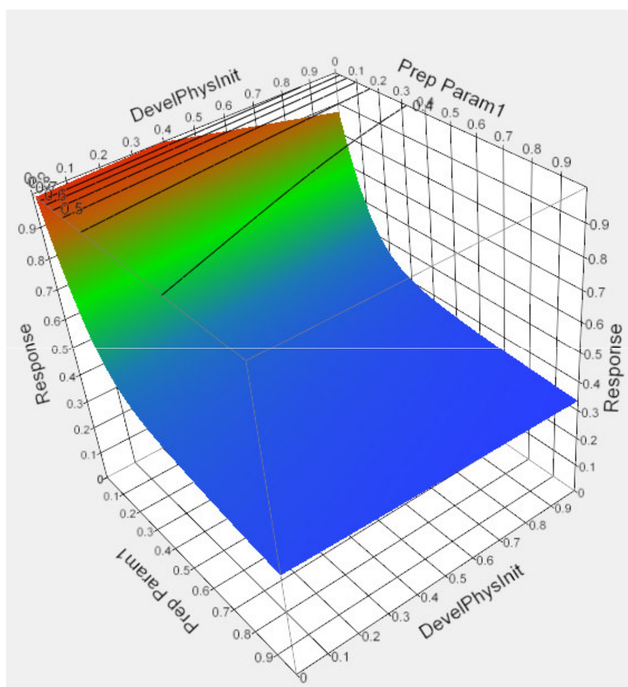
Prep Param1 & D EnvirFactor2 2 factor effect on Restoration time



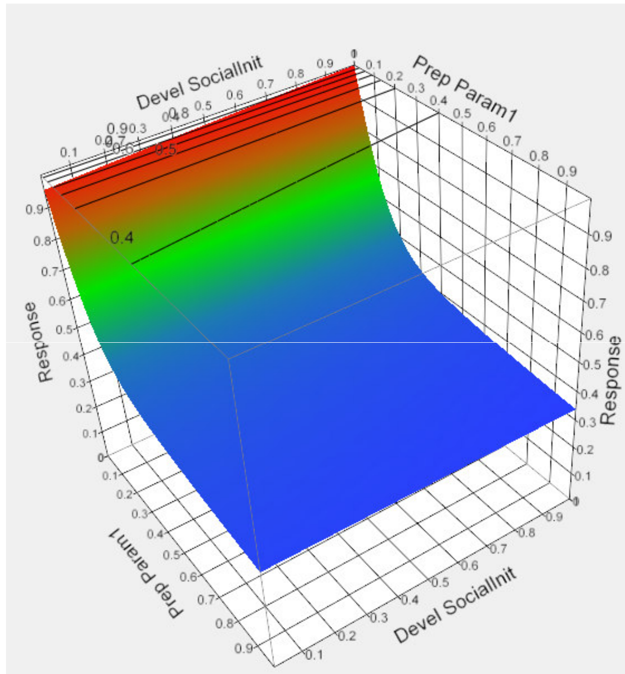
Prep Param1 & DevelEconInit 2 factor effect on Restoration time



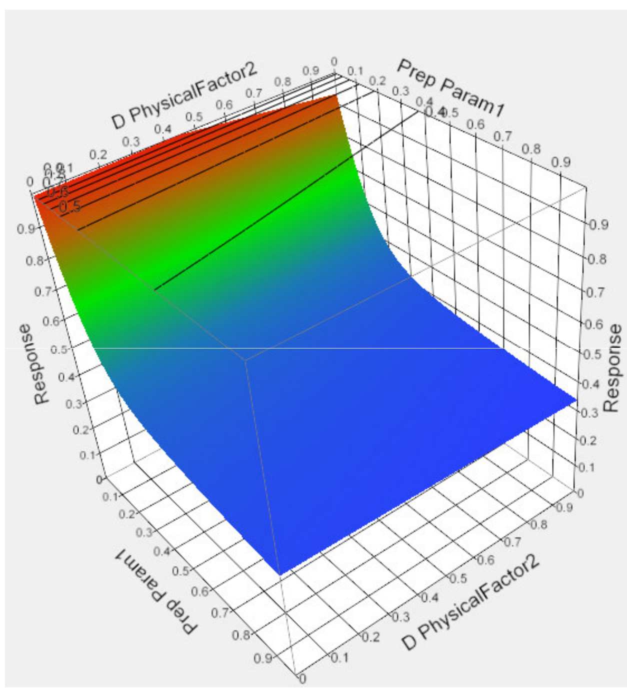
Prep Param1 & DevelEnvirInit 2 factor effect on Restoration time



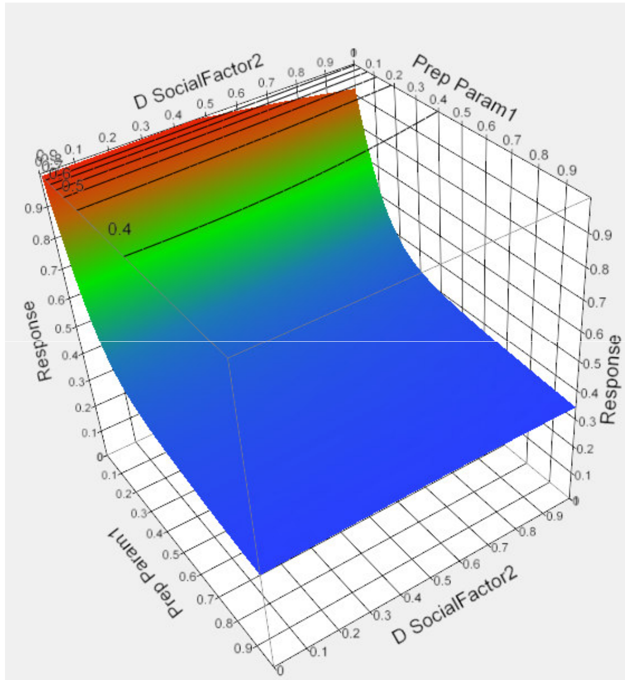
Prep Param1 & DevelPhysInit 2 factor effect on Restoration time



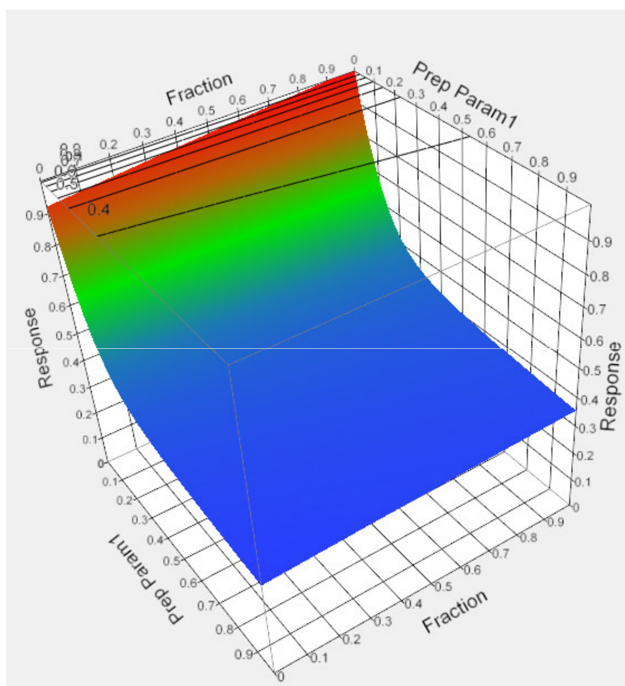
Prep Param1 & DevelSocialInit 2 factor effect on Restoration time



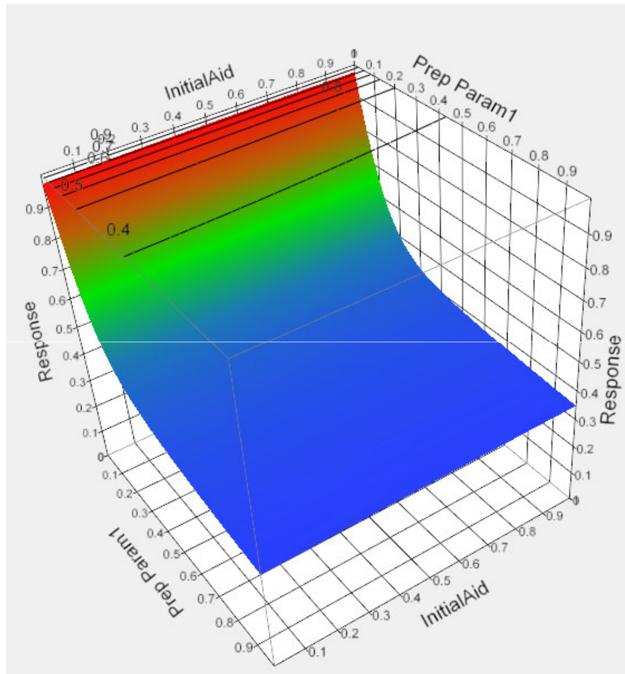
Prep Param1 & D PhysicalFactor2 2 factor effect on Restoration time



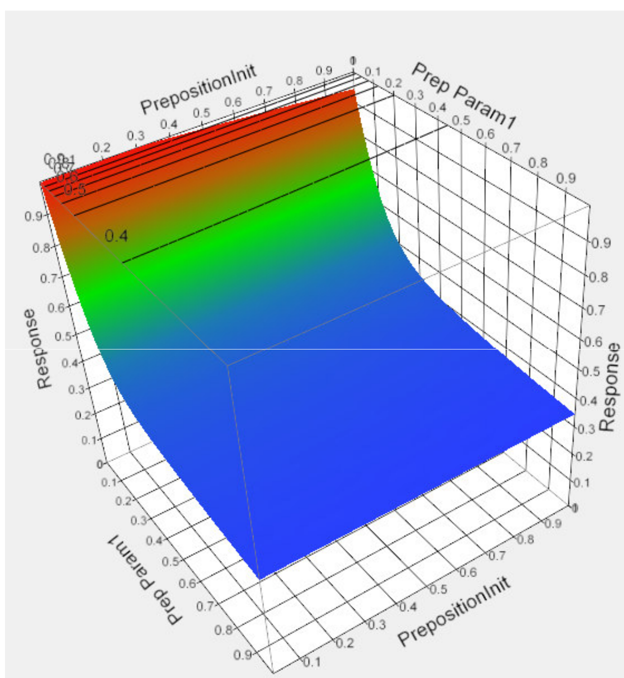
Prep Param1 & D SocialFactor2 2 factor effect on Restoration time



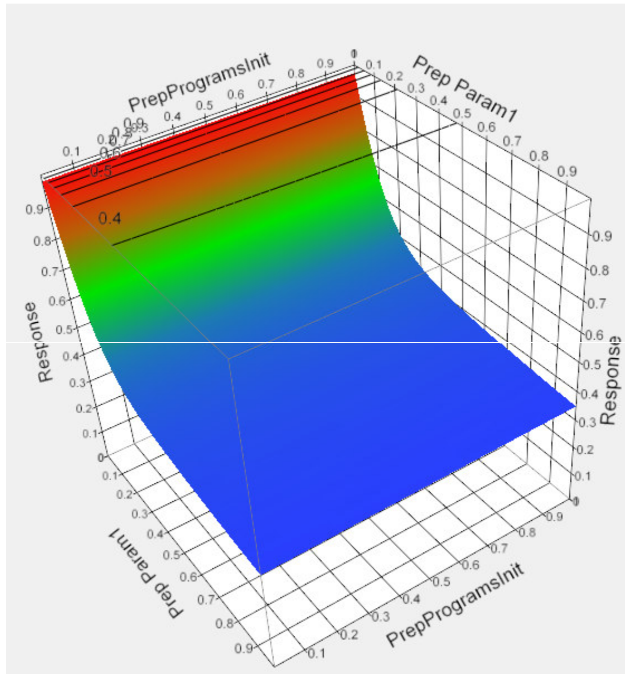
Prep Param1 & Fraction 2 factor effect on Restoration time



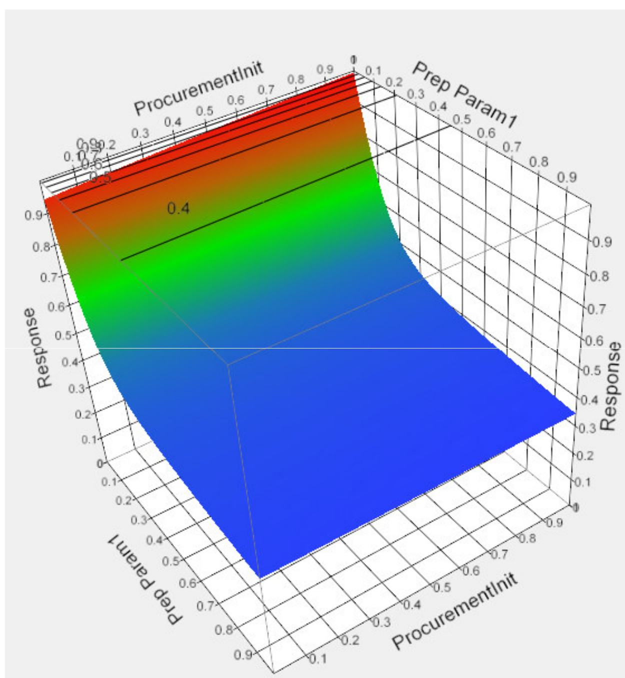
Prep Param1 & InitialAid 2 factor effect on Restoration time



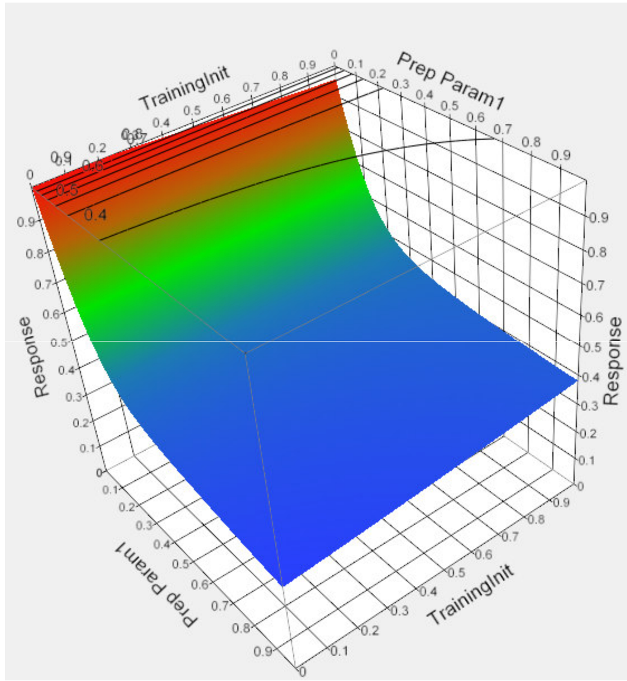
Prep Param1 & PrepositionInit 2 factor effect on Restoration time



Prep Param1 & PrepProgramsInit 2 factor effect on Restoration time



Prep Param1 & ProcurementInit 2 factor effect on Restoration time



Prep Param1 & TrainingInit 2 factor effect on Restoration time

REFERENCES

[1] "Merriam-Webster Online Dictionary." `http://www.merriam-webster.com/dictionary`.

[2] "EVI: Description of Indicators," 2004.

[3] "Sex-ratio imbalance in Asia: Trends, consequences and policy responses: Executive summary," 2007.

[4] "The SoVI Recipe," 2008.

[5] "Pacific Ring of Fire Graphic," February 2009. `http://en.wikipedia.org/wiki/File:Pacific_Ring_of_Fire.svg`.

[6] *Central United States Earthquake Consortium Operations Officers Working Group*, 2010.

[7] "Haiti Recovery Assessment: Volume 1 - Synthesis Report," tech. rep., International Federation of Red Cross and Red Crescent Societies, 2010.

[8] "The Perspectives Reader," 2010. `www.perspectives.org`.

[9] Ad Hoc Subcommittee on Disaster Recovery, "Far From Home: Deficiencies in Federal Disaster Housing Assistance After Hurricanes Katrina and Rita and Recommendations for Improvement," special report, United States Senate, S-PRT. 111-7, February 2009.

[10] Adair, B., "10 years ago, her angry plea got hurricane aid moving," *St. Petersburg Times*, 2002. `http://www.sptimes.com/2002/webspecials02/andrew/day3/story1.shtml`. Accessed August 21, 2009.

[11] Aerospace Systems Design Laboratory, "Navy t-craft functional assessment," 2010.

[12] Alberts, S., "Haiti's leaders forced to defend earthquake response." http://www.nationalpost.com/news/story.html?id=2483182.

[13] AlertNet, "Myanmar: Nargis remittances - disaster aid with a difference," *ReliefWeb Updates*, 2009.

[14] Anderson, M. B. and Woodrow, P. J., *Rising from the Ashes: Development Strategies in Times of Disaster*. Westview Press, 1989.

[15] Aviv, Y., "The Effect of Collaborative Forecasting on Supply Chain Performance," *Management Science*, vol. 47, pp. 1326–1343, October 2001.

[16] Baculinao, E., "China grapples with legacy of its missing girls: disturbing demographic imbalance spurs drive to change age-old practices." web article, September 2004.

[17] Banach, C. S. J. and Ryan, A., "The Art of Design: A Design Methodology," *Military Review*, pp. 105–115, April 2009.

[18] Bartholomees, J. B. J., ed., *Guide to National Security Issues: Volume I: Theory of War and Strategy*. U.S. Army War College, 3rd ed., June 2008.

[19] Bartholomees, J. B. J., ed., *Guide to National Security Issues: Volume II: National Security Policy and Strategy*. U.S. Army War College, 2008.

[20] BBC News, "Haiti quake aid effort hampered by blockages," *BBC News*, 2010.

[21] Beamon, B. M. and Balcik, B., "Performance measurement in humanitarian relief chains," *International Journal of Public Sector Management*, vol. 21, pp. 4–25, 2008.

[22] Biddle, S. and Friedman, J. A., *The 2006 Lebanon Campaign and the Future of Warfare: Implications for Army and Defense Policy*. Strategic Studies Institute, 2008.

[23] Briceno, S., *Game-Based Decision Support Methodology for Competitive Systems Design*. PhD thesis, Georgia Institute of Technology, 2008.

[24] Briguglio, L., "Small Island Developing States and Their Economic Vulnerabiities," *World Development*, vol. 23, no. 9, pp. 1615–1632, 1995.

[25] Briguglio, L. and Galea, W., "Updating and Augmenting the Economic Vulnerability Index," *draft of study only*, 2003.

[26] Bucco, G., "Flood of the Century: Remembering the Great Midwest Flood of 1993," 2009.

[27] Cable News Network (CNN), "Haiti was 'catastrophe waiting to happen'." CNN, 2010. http://www.cnn.com/2010/WORLD/americas/01/12/haiti.earthquake.infrastructure/index.html.

[28] Center for Disease Control, "Pandemic Severity Index." www.cdc.gov/media/pdf/MitigationSlides.pdf http://www.pandemicflu.gov/professional/community/commitigation.html.

[29] Center for Health and Humanitarian Logistics, "Health and Humanitarian Logistics Conference 2010," 2010. http://www.scl.gatech.edu/humlog2010.

[30] Central Intelligence Agency, "The World Factbook: Cuba."

[31] Central Intelligence Agency, "The World Factbook: Dominican Republic."

[32] Central Intelligence Agency, *The World Factbook*. CIA, 2010.

[33] Central Intelligence Agency, "The World Factbook: Haiti," April 2010.

[34] Chandrasekaran, B., "Designing Decision Support Systems to Help avoid Biases and Make Robust Decisions, With Examples from Army Planning," tech. rep., Department of Computer and Information Science The Ohio State University, 2008.

[35] Chuchmach, M., "FEMA Says No to Ice For Hurricane Survivors," September 2008. http://abcnews.go.com/Blotter/Story?id=5828158&page=4. Accessed August 21, 2009.

[36] Citizens for Responsibility and Ethics in Washington (CREW), "CREW's Hurricane Katrina Offers of International Assistance Matrix," July 2007.

[37] Cobb, C. W. and Rixford, C., "Lessons Learned from the History of Social Indicators,"

[38] Columbia University, "Socioeconomic Data and Applications Center," 2010. http://sedac.ciesin.columbia.edu/gateway/.

[39] Cutter, S. L., Boruff, B. J., and Shirley, W. L., "Social Vulnerability to Environmental Hazards," *Social Science Quarterly*, vol. 84, pp. 242–261, 2003.

[40] Daniel, T., Clark, L., and Rosenberg, C., "More troops, humanitarian aid coming to Haiti; mass migration to U.S. not materializing," January 2010. http://www.miamiherald.com/2010/01/18/1431558/window-closing-for-survivors-relief.html.

[41] Davidson, A. L., "Key Performance Indicators in Humanitarian Logistics," Master's thesis, Massachusetts Institute of Technology, 2006.

[42] de Boer, J., "Definition and Classification of Disasters. Introduction of a Disaster Severity Scale," *Journal of Emergency Medicine*, vol. 8, pp. 602–608, 1990.

[43] Department of Homeland Security, "About the Homeland Security Advisory Systems." FEMA, 2010.

[44] DeWald, V. L., "National Weather Service Stormspotting and Weather Safety: Thunderstorm Severity," 1999. http://www.crh.noaa.gov/lmk/spotter_reference/spotter_slideshow/slide13.php.

[45] Dieter, G. E., *Engineering Design: A Materials and Processing Approach*. McGraw Hill, 2000.

[46] Dilley, M., Chen, R. S., Diechmann, U., Lerner-Lam, Arthur, L., Arnold, M., Agwe, J., Buys, P., Kjekstad, O., Lyon, B., and Yetman, G., "Natural Disaster Hotspots: A Global Risk Analysis," 2005.

[47] Doctors Without Borders, "Doctors Without Borders Plane with Lifesaving Medical Supplies Diverted Again from Landing in Haiti." http://www.doctorswithoutborders.org/press/release.cfm?id=4176.

[48] Dogan, F. C., "HAZUS Coastal Flood Hazard Analysis."

[49] Dolfman, M. L., Wasser, S. F., and Bergman, B., "The effects of Hurricane Katrina on the New Orleans economy," *Monthly Labor Review*, pp. 3–18, 2007.

[50] Duggan, W., "Coup d'Oeil: Strategic Intuition in Army Planning," November 2005.

[51] Dwyer, A., Zoppou, C., and Nielsen, O., *Quantifying Social Vulnerabiity: A Methodology for Identifying Those at Risk to Natural Hazards*. Geoscience Australia, 2004.

[52] Ekklesia, "Fears that final Haiti death toll is likely to exceed 250,000," February 2010. http://www.ekklesia.co.uk/node/11226.

[53] Emergency Management Accreditation Program, "Emergency Management Accreditation Program." http://www.emaponline.org.

[54] Fauske, K. M., "Example: Neural Network," 2010. http://www.texample.net/tikz/examples/neural-network/.

[55] Federal Emergency Management Agency, "Why Prepare,"

[56] Federal Emergency Management Agency, "Robert T. Stafford Disaster Relief and Emergency Assistance Act," June 1988.

[57] Federal Emergency Management Agency, *National Response Plan*. Federal Emergency Management Agency, 2004.

[58] Federal Emergency Management Agency, "National Response Framework," 2008.

[59] Federal Research Division, Library of Congress, "Country Profile: Haiti," 2006.

[60] Feng, C.-W., Liu, L., and Burns, S. A., "Using Genetic Algorithms to Solve Construction Time-Cost Trade-Off Problems," *Journal of Computing in Civil Engineering*, pp. 184–189, 1997.

[61] Ferro, G., "Assessment of Major and Minor Events that Occurred in Italy during the Last Century Using a Disaster Severity Scale Score," *Prehospital and Disaster Medicine*, vol. 20, no. 5, pp. 316–323, 2005. Accessed September 7, 2009.

[62] Ford, D. N. and Sterman, J. D., "Expert Knowledge Elicitation to Improve Mental and Formal Models," 1997.

[63] Francis, L., "Martian Chronicles: Is MARS better than Neural Networks?," *Casualty Actuarial Society Forum*, pp. 269–304, 2003.

[64] Fujita, T. T., "Tornado Background," 2003. http://www.fema.gov/news/newsrelease.fema?id=2549.

[65] Garcia, S. L., *The Impact of Natural Disasters on Economic Growth: A Study of Mexico and Central America*. PhD thesis, University of Kentucky, 2002.

[66] Georgia Insistute of Technology Aerospace Systems Design Laboratory, "Aerospace systems design laboratory."

[67] Glanz, J. and Onishi, N., "Japan's Strict Building Codes Saved Lives," *The New York Times*, March 2011.

[68] Godschalk, D. R., Beatley, T., Berke, P., Brower, D. J., and Kaiser, E. J., *Natural Hazard Mitigation: Recasting Disaster Policy and Planning*. Washington, D.C.: Island Press, 1999.

[69] Godschalk, D. R., Rose, A., Mittler, E., Porter, K., and West, C. T., "Estimating the value of foresight: aggregate analysis of natural hazard mitigation benefits and costs," *Journal of Environmental Planning and Management*, vol. 52, no. 6, pp. 739–756, 2009.

[70] Goldratt, E. M. and Cox, J., *The Goal.* North River Press, Inc., 1986.

[71] Granger, C. W. J., "Some Properties of Time Series Data and Their Use in Econometric Model Specification," *Journal of Econometrics*, vol. 16, pp. 121–130, 1981.

[72] Haas, J. E., Kates, R. W., and Bowden, M. J., eds., *Reconstruction Following Disaster.* The MIT Press, 1977.

[73] Haddow, G. D., Bullock, J. A., and Cappola, D. P., *Introduction to Emergency Management.* Elsevier, 2008.

[74] Hamann, C. and France-Presse, A., "Viva Chile! Nation rallies to help quake victims," March 2010. `http://www.abs-cbnnews.com/world/03/07/10/viva-chile-nation-rallies-help-quake-victims`.

[75] Harnden, T., "Haiti earthquake: dozens feared dead as buildings collapse," January 2010. `http://www.telegraph.co.uk/news/worldnews/centralamericaandthecaribbean/haiti/6977881/Haiti-earthquake-dozens-feared-dead-as-buildings-collapse.html`.

[76] Harrell, E., "Chile's President: Why Did Tsunami Warnings Fail?," March 2010. `http://www.time.com/time/world/article/0,8599,1969009,00.html?iid=sphere-inline-bottom`.

[77] International Human Development Indicators, "Haiti: Country profile of human development indicators," 2010.

[78] Jasper, J. B., "Quick Response Solutions: FedEx Critical Inventory Logistics Revitalized," tech. rep., FedEx, 2006.

[79] Jigyasu, R., *Reducing Disaster Vulnerability Through Local Knowledge and Capacity.* PhD thesis, Norwegian University of Science and Technology, 2002.

[80] Jimenez, H., Stults, I. C., and Mavris, D. N., "A morphological approach for proactive risk management in civil aviation security," in *47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition*, American Institute of Aeronautics and Astronautics, Inc., 2009.

[81] Kennedy, J. and Eberhart, R., "Particle Swarm Optimization," *Proceedings IEEE International Conference on Neural Networks*, vol. IV, pp. 1942–1948, 1995.

[82] Kettinger, W. J., Teng, J. T. C., and Guha, S., "Business Process Change: A Study of Methodologies, Techniques, and Tools," *MIS Quarterly*, pp. 55–80, 1997.

[83] Kettinger, W. J., Teng, J. T., and Guha, S., "Business Process Change: A Study of Methodologies, Techniques, and Tools," *MIS Quarterly*, pp. 55–80, 1997.

[84] Knabb, R. D., Rhome, J. R., and Brown, D. P., "Tropical Cyclone Report: Hurricane Katrina," tech. rep., National Hurricane Center, August 2005. cited in KatrinaLL.

[85] Knowledge Based Systems, Inc., "IDEF Website." Online. `http://www.idef.com/IDEF0.html`.

[86] Kuhne, R. and Michalopoulos, P., *Traffic Flow Theory: A State-of-the-Art Report*, ch. Five: Continuum Flow Models. Transportation Research Board, 1992.

[87] Larson, C., "UPS Supply Chain Solutions," tech. rep., UPS, 2005.

[88] Louie, J., "Modified Mercalli Scale of Earthquake Intensity," 1996. `http://www.seismo.unr.edu/ftp/pub/louie/class/100/mercalli.html`.

[89] Louie, J., "What is Richter Magnitude?," 1996. `http://www.seismo.unr.edu/ftp/pub/louie/class/100/magnitude.html`.

[90] Louisiana Weekly, "Landrieu, Cao demand FEMA shakeup," March 2009. Accessed August 21, 2009.

[91] Margesson, R. and Taft-Morales, M., "Haiti earthquake: Crisis and response," 2010.

[92] Masters, J., "Hurricanes and Haiti: A Tragic History." http://www.wunderground.com/hurricane/haiti.asp?MR=1.

[93] Mavris, D. N., "Introduction to Response Surface Methods," tech. rep., Aerospace Systems Design Laboratory at Georgia Institute of Technology, 2007.

[94] Mavris, D. N., "An Introduction to RSM and its Role in the Paradigm Shift," tech. rep., Aerospace Systems Design Laboratory at Georgia Institute of Technology, 2007.

[95] Mavris, D. and Kirby, M., "A Methodology for Technology Identification, Evaluation, and Selection for Complex Systems," 2007.

[96] Mavris, D. N., "A Paradigm Shift in Complex System Design: Enabling Technologies for Strategic Decision Making of Advanced Design Concepts," 2007.

[97] Mavris, D. N., "Multi-Criteria Decision Making (MCDM)," 2008.

[98] Media Accuracy on Latin America, "Media Analysis Guidelines: How to detect bias in news media."

[99] Min, H. S. J., Beyeler, W., Brown, T., Son, Y. J., and Jones, A., "Toward modeling and simulation of critical national infrastructure dependencies," *IIE Transaction*, vol. 39, pp. 57–71, 2007.

[100] Mitchell, J. K., ed., *Crucibles of Hazard: Mega-cities and Disasters in Transition.* United Nations University Press, 1999.

[101] Mohapatra, S., Joseph, G., and Ratha, D., "Remittances and Natural Disasters: Ex-post Response and Contribution to Ex-ante Preparedness," 2009.

[102] Murray, A. T., Matisiw, T. C., and Grubesic, T. H., "Critical network infrastructure analysis: interdiction and system flow," *Journal of Geographic Systems*, vol. 9, pp. 103–117, 2007.

[103] Murray, W., "National Security Challenges for the 21st Century," tech. rep., Strategic Studies Institute, 2003.

[104] Muthu, S., Whitman, L., and Cheraghi, S. H., "Business Process Reengineering: A Consolidated Methodology," *Proceedings of The 4th Annual International Conference on Industrial Engineering Theory, Applications, and Practice*, 1999.

[105] National Fire Protection Association (NFPA) Standards Council, "Standard on Disaster/Emergency Management and Business Continuity Programs." `http://www.nfpa.org/assets/files/pdf/nfpa1600.pdf`.

[106] National Institute of Building Sciences, *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities*. Washington, D.C.: Multihazard Mitigation Council, 2005.

[107] News, C., "Chile asks Canada for help," March 2010. `http://www.cbc.ca/world/story/2010/03/01/canada-chile-ortega.html`.

[108] Nixon, W. A. and Qiu, L., "Developing a Storm Severity Index," 2004.

[109] Oblack, R., "Hurricane Ike: Damage Reports," 2008. `http://weather.about.com/b/2008/09/14/hurricane-ike-damage-reports.htm`.

[110] of Inspector General, O., *A Performance Review of FEMA's Disaster Management Activities in Response to Hurricane Katrina*, vol. OIG-06-32. Office of Inspector General, March 2006.

[111] Office of Climate, Water, and Weather Services (OCWWS), "Heat: A Major Killer," 2010. `http://www.nws.noaa.gov/om/heat/index.shtml`.

[112] Office of the Director, Program Analysis and Evaluation, *Department of Defense Future Year Defense Program (FYDP) Structure*, April 2004.

[113] Office of the Haiti Special Coordinator, "Haiti: One Year Later," tech. rep., U.S. Department of State, January 2011.

[114] Oh, I.-S., Lee, J.-S., and Moon, B.-R., "Hybrid Genetic Algorithms for Feature Selection," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 26, pp. 1424–1437, November 2004.

[115] Oregon State University (ORST), "BAR Scale." http://www.transboundarywaters.orst.edu/database/event_bar_scale.html.

[116] Orihuela, R. and Attwood, J., "Chile's San Antonio Port Returns to 80% Capacity," March 2010. http://www.bloomberg.com/apps/news?pid=20601086&sid=aW.tGFQaicJs.

[117] Palmer, W., "Drought Severity Index by Division," 2010. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif.

[118] Papadopoulos, G. A. and Imamura, F., "A proposal for a new tsunami intensity scale," in *ITS 2001 Proceedings Session 5 Number 5-1*, 2001.

[119] Pelling, M. and Uitto, J. I., "Small island developing states: natural disaster vulnerability and global change," *Global Environmental Change Part B: Environmental Hazards*, vol. 3, pp. 49–62, June 2001.

[120] Perez, J. O. and Pena, A. C., "Multi-agent based interrelationship modeling and forecasting of macroeconomic variables," tech. rep., Departamento de Sistemas de Informacin CUCEA Universidad de Guadalajara, 2009.

[121] Pesonen, E., Eskelinen, M., and Juhola, M., "Treatment of missing data values in a neural network based decision support system for acute abdominal pain," *Artificial Intelligence in Medicine*, vol. 13, pp. 139–146, 1998.

[122] Pielke Jr., R. A., Gratz, J., Landsea, C. W., Collins, D., Saunders, M. A., and Musulin, R., "Normalized Hurricane Damages in the United States: 1900-2005," 2006.

[123] Poli, R., Kennedy, J., and Blackwell, T., "Particle Swarm Optimization: an overview," *Swarm Intelligence*, vol. 1, pp. 33–57, August 2007.

[124] Priddy, K. L. and Keller, P. E., *Artificial Neural Networks: An Introduction.* The International Society for Optical Engineering, 2005.

[125] Puente, S., *Crucibles of Hazard: Mega-Cities and Disasters in Transition*, ch. 9, pp. 295–334. United Nations University Press, 1999.

[126] Reynolds, K., *Defense Transformation: To What, For What?* Strategic Studies Institute, 2006.

[127] Ross, A. M., Rhodes, D. M., and Hastings, D. E., "Defining Changeability: Reconciling Flexibility, Adaptability, Scalability, Modifiability, and Robustness for Maintaining System Life Cycle Value," *Systems Engineering*, vol. 11, no. 3, pp. 246–262, 2008.

[128] Rothery, R. W., *Traffic Flow Theory: A State-of-the-Art Report*, ch. Four: Car Following Models. http://www.tfhrc.gov/its/tft/tft.htm: Transportation Research Board, 1992.

[129] Rowlett, R., "Volcanic Explosivity Index," 2003. `http://www.unc.edu/~rowlett/units/scales/VEI.html`.

[130] Roy, D. P., Boschetti, L., and Trigg, S. N., "Remote Sensing of Fire Severity: Assessing the Performance of the Normalized Burn Ratio," *IEEE Geoscience and Remote Sensing Letters*, vol. 3, pp. 112–116, 2006.

[131] Sack, K. and Williams, T., "Government's Disaster Response Wins Praise," *The New York Times*, 2011.

[132] Sadeh, N. M., Hildum, D. W., Kjenstad, D., and Tseng, A., "MASCOT: an agent-based architecture for dynamic supply chain creation and coordination in the internet economy," *Production Planning and Control*, vol. 12, no. 3, pp. 212–223, 2001.

[133] Schott, T., Landsea, C., Hafele, G., Lorens, J., Taylor, A., Thurm, H., Ward, B., Willis, M., and Zaleski, W., "The Saffir-Simpson Hurricane Wind

Scale," tech. rep., National Hurricane Center in the National Weather Service and National Oceanic and Atmospheric Administration, 2010.

[134] Schrage, D. P. and Gordon, M. A., "Defining The Problem Continued: Quality Function Deployment." Lecture.

[135] Sellar, R. S., Batill, S. M., and Renaud, J., "Response Surface Based, Concurrent Subspace Optimization for Multidisciplinary System Design," *AIAA*, 1996.

[136] Shankar, A. U., "Discrete-Event Simulation," 1991.

[137] Shields, G., "Report Outlines FEMA Storm Failings," February 2009. http://www.2theadvocate.com/news/politics/40333512.html?showAll=y&c=y. Accessed August 21, 2009.

[138] Shrage, D. P., "Modern Systems Engineering - The Integration of Key Elements for Product Life-Cycle Engineering."

[139] Sieberg, A. and Ambraseys, N., "Sieberg-Ambraseys Tsunami Intensity Scale." http://geology.about.com/library/bl/bltsunamiscaleold.htm.

[140] Simpson, D. M. and Katirai, M., "Indicator Issues and Proposed Framework for a Disaster Preparedness index (dpi)," 2006.

[141] Smalltree, H., "Supply chain management best practices from Wal-Mart take center stage at CSCMP." online, September 2009. http://searchmanufacturingerp.techtarget.com/news/article/0,289142,sid193_gci1369066,00.html.

[142] Sommez, H. and Gokceoglu, C., "A liquiefaction severity index suggested for engineering practice," *Environmental Geology*, vol. 48, pp. 81–91, 2005.

[143] Soukup, T. and Davidson, I., *Visual Data Mining: Techniques and Tools for Data Visualization and Mining*. Wiley Publishing, Inc., 2002.

[144] Sterman, J. D., *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw Hill/Irwin, 2000.

[145] Stonefield, R. and Jackson, J., "Flash Flood and Flood c[limatology for the wfo blackburg, virginia county warning area." http://www.erh.noaa.gov/rnk/Newsletter/Spring_2009/flash_flood_climatology/Flash_Flood_Climatology.html.

[146] Stowers, D. and Doyle, W. R., "Workshop Discussions 2009 Conference on Humanitarian Logistics," February 2009.

[147] Stults, I. C., *A multi-fidelity analysis selection method using a constrained discrete optimization formulation*. PhD thesis, Georgia Institute of Technology, 2009.

[148] Suburban Emergency Management Project (SEMP), "The Loess Soil Problem beneath Memphis, Tennessee," February 2006.

[149] Survey, U. G., "Natural Hazards Gateway," April 2010. http://www.usgs.gov/hazards/.

[150] Talluri, S., Narasimhan, R., and Nair, A., "Vendor Performance with Supply Risk: A Chance-Constrained DEA Approach," *International Journal of Production Economics*, vol. 100, pp. 212–222, 2006.

[151] The Urban Child Institute, "The Implications of Teen Parenting in Shelby County, Tennessee," April 2009.

[152] Thomas, A., "Humanitarian Logistics: Enabling Disaster Response," tech. rep., Fritz Institute, 2003.

[153] Townsend, F. F., "The Federal Response to Hurricane Katrina: Lessons Learned," tech. rep., United States Federal Government, February 2006.

[154] Tuchman, G. and Redman, J., "Haiti government working on quake recovery, prime minister says," January 2010. http://www.cnn.com/2010/WORLD/americas/01/19/haiti.earthquake.government/index.html.

[155] United Nations, New York, *Handbook on Social Indicators*, 1989.

[156] United Nations Development Programme(UNDP), "Technical Note 1: Calculating the Human Development Indices," *Human Development Report*, 2008.

[157] United Nations Educational, Scientific and Cultural Organization (UNESCO), "3c Social Development: Literacy, education and social development," in *Workshops held at the Fifth International Conference on Adult Education*, 1997.

[158] United Nations Environment Programme and South Pacific Applied Geosciences Commission (SOPAC), "Building Resilience in SIDS: The Environmental Vulnerability Index."

[159] United Nations International Strategy for Disaster Reduction (UNISDR), "United Nations International Strategy for Disaster Reduction." http://www.unisdr.org/disaster-statistics/introduction.htm.

[160] United Nations Statistics Division (UNSTATS), "Social Indicators."

[161] United States Coast Guard, "United States Coast Guard Website." http://www.uscg.mil.

[162] United States Coast Guard, "DPD GIS Viewer," 2010. Last Accessed: June 18, 2011.

[163] United States Congress, *To authorize the Secretary of Agriculture to provide assistance to the Government of Haiti to end within 5 years the deforestation in Haiti and restore within 30 years the extent of tropical forest cover in existence in Haiti in 1990, and for other purposes., S.1183, 111th Cong., 1st Sess.*, 2009.

[164] U.S. Census Bureau, "Tennessee Census Tracts by County," 2001.

[165] U.S. Geological Survey, "Documentation for the 2008 Update of the United States National Seismic Hazard Maps," tech. rep., U.S. Department of the Interior, 2008.

[166] U.S. Geological Survey, "NOAA Watch: NOAA's All Hazard Monitor," May 2010. http://www.noaawatch.gov/.

[167] U.S. Geological Survey, "U.S. Geological Survey Haiti Earthquake," 2010. http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2010rja6.php.

[168] U.S. Geological Survey (USGS), "2008 United States National Seismic Hazard Maps,"

[169] U.S. Geological Survey (USGS), "U.S. Geological Survey Chile Earthquake." http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/us2010tfan.php.

[170] Welch, W. M., Vergano, D., and Hawley, C., "Chilean earthquake hints at dangers of 'Big One' for USA," March 2010. http://www.usatoday.com/tech/science/2010-03-01-chile-quake-lessons_N.htm.

[171] Wheeler, R. L., Omdahl, E. M., Dart, R. L., Wilkerson, G. D., and Bradford, R. H., "Earthquakes in the Central United States-1699-2002," Tech. Rep. OFR-03-232, United States Geological Survey, 2003.

[172] Wilensky, U., "Netlogo," 2010. http://ccl.northwestern.edu/netlogo/.

[173] Williams, J. C., *Traffic Flow Theory: A State-of-the-Art Report*, ch. Six: Macroscopic Flow Models. Transportation Research Board, 1992.

[174] Wilmot, C. G. and Mei, B., "Comparison of Alternative Trip Generation Models for Hurricane Evacuation," *Natural Hazards Review*, vol. 5, pp. 170–178, November 2004.

[175] Xinhua, "Aid pours into Chile as aftershocks still threaten," March 2010. http://news.xinhuanet.com/english2010/world/2010-03/04/c_13197550.htm.

[176] Yang, I.-T., "Utility-based decision support system for schedule optimization," *Decision Support Systems*, vol. 44, pp. 595–605, 2008.

[177] Yoon, S., Velasquez, J., Partridge, B., and S.Y., N., "Transportation security decision support system for emergency response: A training prototype," *Decision Support Systems*, vol. 46, pp. 139–148, 2008.

VITA

Stephanie Weiya Mma was born in Minneapolis, Minnesota in 1982. She graduated cum laude with a Bachelor of Aerospace Engineering and Mechanics degree from the University of Minnesota (Twin Cities campus) in 2005. She began her Ph.D. program in Aerospace Engineering at the Georgia Institute of Technology in 2005 and became an Air Force recruit for the Science, Mathematics, And Research for Transformation (SMART) Scholarship Program in 2008. Her research interests include aircraft systems design, parametric systems design, and humanitarian logistics.