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# 2008 Midwest Floods Impact Analysis on Critical Infrastructure, Associated Industries, and Communities

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**Abstract:** Conducting in-depth case studies in the flood-affected regions is very important to obtain the ephemeral data with respect to the affected infrastructure. The ephemeral data include locations and circumstances of damaged infrastructure, the level of damage, and duration of service failure right after the occurrence of a natural disaster and its impact on the functions of affected industries and communities. This data can be collected in terms of social, economic, and technical impacts of floods on the industries and communities and then can be reinterpreted into criticality, vulnerability, and severity, which are useful to enhance the plans and mitigation strategies according to the disaster response.

## 1. 2008 Midwest Floods and Preparedness of Critical Infrastructure

The impact of natural disasters includes not only people and property but also the services and activities of industries and communities. Recently, the worst flooding in the Midwest in 15 years has swamped vast areas of the U.S. and has killed 24 people and injured about 150 people causing widespread damage in cities and towns in Iowa, Illinois, Missouri, and Indiana. It has damaged huge farm belts in the affected areas, adding to over a billion dollar in losses and feeding global food inflation fears. While massive floods were triggered by heavy rains, many experts say that the fundamental reason for the widespread damage was infrastructure failures, such as broken levees along the rivers and the railroad bridge in Cedar Rapids (Figure 1). The Midwest levees, roads, water and transport systems have proven vulnerable to natural disasters on several occasions (ASCE 2005 Report Card for America’s Infrastructure). Therefore, the impact of the recent disaster could have been mitigated if infrastructure were a top priority all along (People's Weekly World Newspaper, June 19, 2008) and were reinforced to withstand its vulnerability to the flood impacts.

A break in the Pin Oak levee in Winfield, Mo (2008) Failed Old Railroad Bridge in Cedar Rapids, IA (2008)

**Figure 1: Infrastructure Failures due to the Midwest Floods** *(Courtesy: Anthony Souffle (AP) and Clark Westfield)*

The affected areas have been historically vulnerable with respect to floods. However, it became apparent that the critical infrastructure were not sufficiently fortified and maintained to resist the impact of floods. This was also an issue after the landfall of Hurricane

Katrina. The emergency agencies and industries had failed to sustain their roles properly due to the damaged infrastructure (Hastak and Oh 2008). For example, at Katrina's landfall, the critical infrastructure such as the levee system, the communication system, the nation's energy supply, chemical-production capacity, and fuel pipelines in New Orleans and the areas of Gulf Coast were in serious jeopardy (Committee on Homeland Security and Governmental Affairs 2006). A common observation of the analyses of these disaster events is the inadequate preparedness of critical infrastructure to withstand the forces of natural calamities and the lack of mitigation strategies under these circumstances on the part of emergency-related organizations, industries, and communities.

## 2. Previous Research of Natural Disaster Impact Analysis

As discussed above, critical infrastructure play significant roles during the occurrence of natural disasters, preparedness and mitigation strategies therefore should include identifying and fortifying vulnerable infrastructure based on their interrelationship with the associated industries and communities. Oh et al. (2008) proposed a technical approach to understand how the impacts of natural calamities transfer to related industries and communities through affected infrastructure. A natural disaster primarily affects the infrastructure with physical power resulting into damage to vulnerable infrastructure. The damaged infrastructure in turn transfers its impact on the associated industries and communities according to their inter-relationships as illustrated in (Figure 2). However, to sufficiently understand how the three components, critical infrastructure, industries, and communities, are inter-related, varied factors should be considered in terms of not only technical aspect, but also the social and economic aspects.

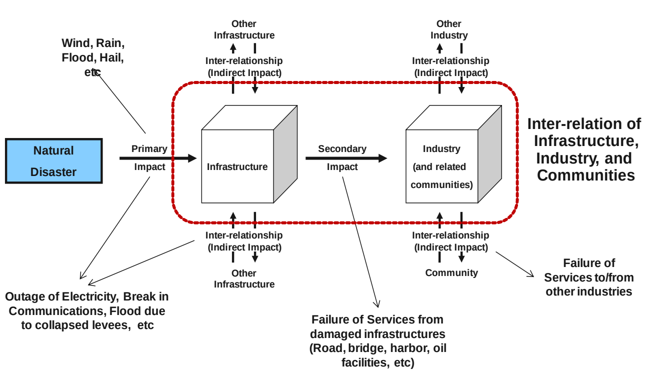


**Figure 2: Disaster Impact Mechanism (Basic Cell Model) (*Oh and Hastak 2008*)**

Rinaldi et al. (2001), McDaniels et al. (2007), and Oh et al. (2008) contributed to improving the methodology of disaster impact analysis by applying statistical and empirical approach focusing on the technical aspect in terms of interdependency or inter-relationship of infrastructure. Lindell et al. (2003) emphasized social impacts on communities focusing on preparedness and hazard mitigation practices. Recently, Picou et al. (2006) and Farroqui et al. (2008) added the socio-psychological and socio-economic approaches to the body of knowledge. In terms of economic aspect, Burrus et al. (2002) and Lian et al. (2007) applied business interruption and interdependency of companies to measure the cumulative impact due to natural disasters. Ross et al. (2007) established economic factors to measure the impact of natural disasters. Besides, Chang et al. (2002) and An et al. (2004) added economic approaches on technical aspects using physical infrastructure systems and the urban economy. Chang (2003) also evaluated societal impacts combining with the life cycle cost analysis in disaster context.

While the contributions of previous research are significant, it would be better if there is an effort to properly combine major features (technical, social, and economic) to structure the disaster impact models. To realistically understand and analyze the impacts of natural disaster, flood data should be collected from the affected site and people in terms of the technical, social, and economic aspects. In addition, models that analyze and forecast the impacts of disasters should be detailed enough to reflect all relevant factors and sufficient information about damages, such as ephemeral data of floods including the height of the crest water, how long the flood waters remained in an area, the mental distress that people experienced, etc. If these intangible characteristics are reflected on the structuring the disaster impact analysis models, the result will be more practical for field agencies and experts to apply into their practices.

## 3. Needs and Objectives

To analyze the impacts of floods in the various spectrums as mentioned above, it is required to collect varied data from the affected areas. Also it is important to capture the data without losing the feature of its characteristics. For example, Hastak and Oh (2008) have indicated that the relevant data is best collected soon after the occurrence of disasters. As the floodwaters recede and rehabilitation commences, a lot of evidence of destruction and damage is removed making it difficult to establish the extent of impact and inter-relationship between infrastructure, industries, and communities (Figure 3).


**Figure 3: An example of ephemeral data: Flooded Road in Oakville, Iowa** *(Courtesy: Chicagotribune.com 2008)*

Based on this need, data collection trips to Cedar Rapids, Iowa; Gulfport, Illinois, and other affected cities in the Midwest areas have already been conducted as a part of the National Science Foundation supported project (SGER: A Short-term Site Investigation of the 2008 Midwest Floods). The objective of this short-term exploratory research is to conduct in-depth case studies in the regions affected by the 2008 Midwest Floods to obtain the ephemeral data with respect to the affected infrastructure and related industries and communities. Such data would include locations and circumstances of damaged infrastructure, the level of damage, and duration of service failure right after the occurrence of a natural disaster and its impact on the functions of affected industries and communities. The data are also collected considering social, economic, and technical point of views as emphasized above.

## 4. Data Collection Method

The ephemeral data available from the flood damaged infrastructure in the affected areas and the resulting impact on industries and communities would be very useful in establishing the relationships between the critical infrastructure and the associated industries/communities. Therefore, early site investigation is important to gather the ephemeral data that in the end would support the development of a more robust disaster impact analysis model. Such a model would facilitate the identification of vulnerable infrastructure and its impact on related industries and communities as well as in developing relevant mitigation strategies.

***Three modes of data collection are used in this research***: interviews, site investigations, and questionnaire survey with respect to technical, social, and economic impacts. Travels to the affected areas are divided into two stages: primary and secondary data collections. The primary data collection is for obtaining ephemeral and detailed information of damaged infrastructure from the sites and for conducting interviews of affected parties, including public agencies, industries, and communities to determine the technical, social, and economic impacts of the floods. The secondary data collection includes a follow-up questionnaire survey to gather additional data that focuses on social and economic impacts of the damaged infrastructure and fills the gaps from stage one data collection. The research targets the same affected areas and survey public agencies and the affected industries and communities.

***Interviews:*** Data types that are collected by interviews are identification of critical infrastructure, industrial functions and services, and brief information of the damaged infrastructure. Critical infrastructure are roads, bridges, office buildings, hospitals, manufacturing plants, wastewater treatment plants, etc. The main functions and services that are disrupted for specific industries in the affected area are indentified during the interviews. An industrial zoning map can be developed to understand the range of influence of critical infrastructure and associated industries. In addition, information of the affected infrastructure, such as locations, reported damages, adjacent facilities, industrial activities or services that rely on the affected infrastructure, etc., can be identified.

Interview areas include affected regions in Cedar Rapids (Iowa), Gulfport (Illinois), and other Midwest areas. Related public and private organizations were identified for interviews including: (1) governmental organizations at the federal, state, and local level, such as FEMA, DHS, Counties, and Cities, which are responsible for building, operating, and maintaining critical infrastructure and emergency situations; (2) private organizations, such as major companies and industrial associations in the affected areas; and (3) affected communities and non-profit organizations (i.e., Red Cross).

***Site Investigations and Questionnaire Survey:*** Data collected through site investigations include detailed information and the circumstances surrounding the affected infrastructure including the level-of-service of damaged infrastructure and the impact on related industries and communities. In addition, questionnaire survey is conducted to measure social and economical impacts on industries and communities with the help of sociologists on our multi-disciplinary team. The data include demographical information (i.e., population, gender, employment, income, etc), mental distress, duration of service failure (i.e., hours, days, weeks, months, and years), etc. In addition, detailed information of damaged infrastructure and its circumstances (i.e., adjacent facilities and commercial services around the affected roads) are being investigated (Oh 2008). Sites to be investigated are identified through internet or Mass Media (i.e., the reported 350 flood damaged infrastructure in Cedar Rapids) as well as those identified by the interviewees and governing agencies.

## 5. Case Study: Cedar Rapids, Iowa

### 5.1 Data collection efforts in the Midwest area

From August 2008 to February 2009, the research team conducted six data collection trips to Cedar Rapids, Iowa (Aug. and Nov. 2008, Jan 2009), Terre Haute, Indiana (Oct. 2008), and Gulfport and Des Plaines, Illinois (Oct. 2008). Eighteen interviews in total have been conducted during the data collection trips: fourteen interviews in Cedar Rapids (the city departments (8), industrial parties (3), community parties (3)); and four interviews in other cities (Terre Haute (1), Des Plaines (1), and Gulfport (2)). Two severely affected communities (Czech and Time Check Villages) and downtown area were investigated for the ephemeral data, the extent of damage, and duration, etc. Besides, 40 complete questionnaires to affected residents were collected from Cedar Rapids. In this paper, Cedar Rapids was analyzed as a case study because the flood damage was the most severe when compared to other cities.

### 5.2 Introduction to Cedar Rapids

Cedar Rapids is the second largest city in Iowa and lies on both banks of the Cedar River. Interstate Highway I-380 is one of the most important roads that connects both sides of the city. Downtown area is located on the east side of the river where major employers, such as Mercy Medical Center, Alliant Energy, Quaker Oats, etc., are located. Most communities, including old villages such as Time Check and Czech villages, are sitting on the west part of the city. Cedar Rapids is an economic hub of the state and is called the manufacturing capital of Iowa. It is also a flourishing center for arts and theatre in Eastern Iowa. The population of the city is 126,396 and the average income is $46,734 in 2007. (Source: The City of Cedar Rapids from www.cedarrapids.org).

As a flood protection system, the levees on both sides of Cedar River protect near communities and industries, including the area of 100 and 500 Year Flood Plains. For example, historical districts of Cedar Rapids (Time Check and Czech Village) and downtown area are depending on the levee systems to secure their safety from floods. Likewise, as Figure 4 shows, the communities and industries (i.e., Quaker Oates, Penfold, Mercy Medical Center, Diamond V, etc) are depending on the two power plants, 6th St. Power Plant and Prairie Power Plant, to sustain (or operate) their activities and services. The wastewater treatment plant, located in the south, supports the entire area of Linn County and Cedar Rapids. Thus, it is the most critical infrastructure to the food and

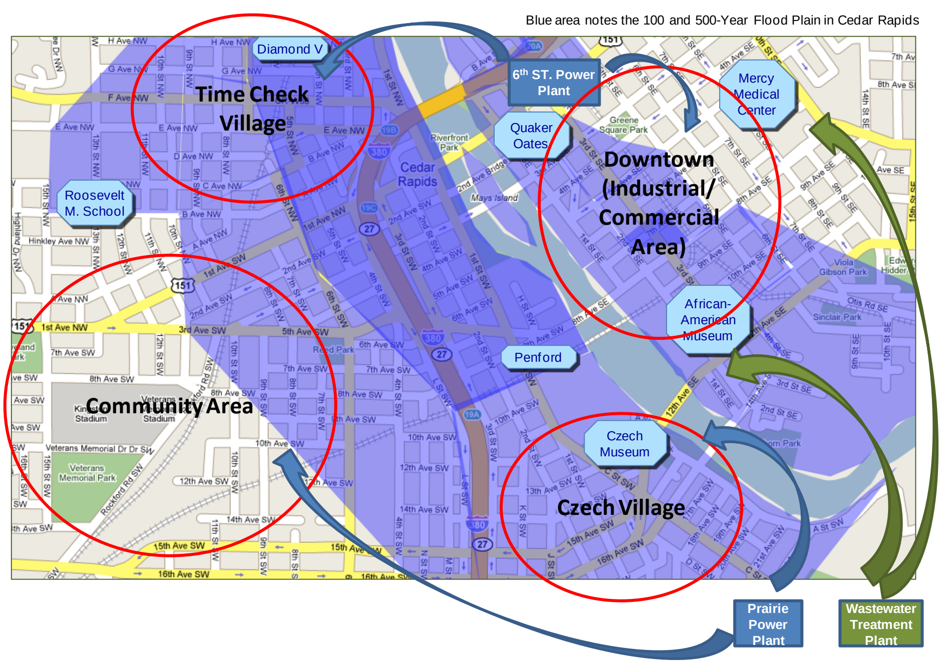


**Figure 4: Inter-relationships of Infrastructure, Industries, and Communities in Cedar Rapids, Iowa**

manufacturing industries such as Quaker Oates, Diamond V, and Amana Refrigeration Products. In addition, the industries depend on highways and main routes to transport their goods and materials.

There are critical inter-relationships between infrastructure, industries, and communities and they interact with each other through these inter-relationships. Therefore, a critical infrastructure fails or collapses, then associated industries and communities will be affected significantly.

### 5.3 Flood Impact on Critical Infrastructure

Cedar Rapids was affected severely by the Midwest Floods from around June 8, 2008 until about July 1, 2008. Historical flood heights until then were 20 ft. in 1929 (maximum) and 19.3 ft. in 1993, however, a new crest of 31.12 ft. was recorded in this 2008 Midwest floods. The estimated loss was over $1.5 Billion, including residential, commercial, and industrial properties.

All bridges and routes near the Cedar River, except I-380, were totally closed; and around 5,000 houses (900 in downtown area) were inundated. The Midwest Floods caused enormous and varied impacts on critical infrastructure in Cedar Rapids. Ten square miles, or 14%, of the city was inundated by the floods. Over 500 houses were severely damaged and were issued purple and red labels after inspections, which meant they had significant structural damage and were unsafe to enter under any circumstance. I-380, the most critical route in Cedar Rapids, sustained the floods while other bridges were inundated or closed due to the flood water. The Cedar Rapids and Iowa City Railway (CRANDIC) Bridge collapsed during the floods and affected CRANDIC and other local industries such as Penford. Only one well out of 50 was operational and protected by Coast Guard.

Lack of water to the affected people was a significant issue soon after the floods and most industries were directly or indirectly impacted. All flood-impacted city departments had to be relocated and made operational within five days. The entire area of Linn County could not treat wastewater for 4 weeks due to the failure of the Wastewater Treatment Plant in Cedar Rapids and had to be released into the Cedar River (Figure 5). As an aftermath of the floods, 150 million pounds (75,000 tons) of debris was collected and removed to landfills.

**Figure 5: Flooded Wastewater Treatment Plant in Cedar Rapids, Iowa (June 2008)**

### 5.4 Flood Impact on Associated Industries

The industries of Cedar Rapids have traditionally been based in the manufacturing and processing of agricultural and food products, steel fabricating, tool and die making, and radios and electronics. Cedar Rapids is in the center of the Midwest area and provides an effective environment for operating and developing industries such as advanced research and development laboratories and an educated and productive labor force. Due to the Midwest floods, 9,000 people working in downtown area were displaced and 450 downtown businesses were impacted.

Twenty seven companies were impacted by the flood and 6,167 employees in the companies were affected (4,137 employees due to eighteen companies that were directly impacted; and 2,030 employees due to nine companies that were indirectly impacted). Twenty five companies have committed to rebuild in Cedar Rapids. The major companies that were affected are as below: Quaker Oats (Food), Alliant Energy (Electricity and steam), Penford Products (Ethanol), Diamond V and Red Star Yeast (Yeast), etc. Red Star Yeast had to shut down operation during the floods (although they were not directly impacted by the floods) due to lack of water as well as due to lack of steam that they procure from ADM– one of the largest agricultural producers. Alliant Energy, for example, lost two power plants (6th St. Power Plant and Prairie Creek Power Plant), transmission centers, electricity networks, communication system and IT system, etc (Figure 6). They still couldn't recover the long lasting damage as of November 2008 and bring the electricity for Cedar Rapids from a nuclear power plant in Palo City, which is 10 miles away from Cedar Rapids to the north. Due to the course of the floods, over 100,000 customers were without power at some point and

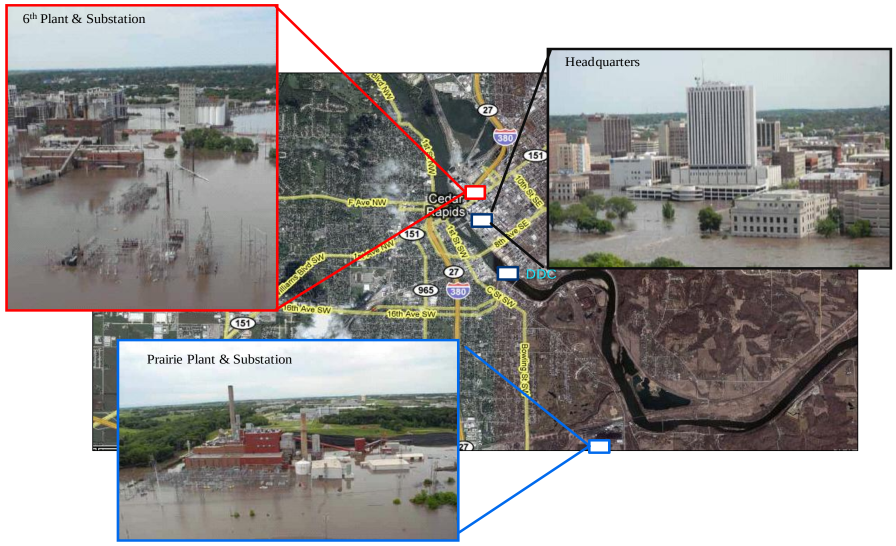


**Figure 6: Flooded Power Plants and Facilities of Alliant Energy in Cedar Rapids (2008)** *(Courtesy: Alliant Energy)*

over 30,000 customers were without power right after the floods.

### 5.5 Flood Impact on Communities

The Midwest Floods exceeded over the 500-year flood plain, thus, all residential areas in the 100 and 500-year flood plains were flooded and the southwest area was included in the new flood plain. Two residential areas with low income houses and elderly people were severely affected, which are the Czech village (C Street and A Avenue) and Time Check village (NW part of Cedar Rapids). The displaced people totaled almost 22,000 and most of them are still striving to return to their homes as of November 2008 (Figure 7). In addition, six school districts were severely damaged. The damage to the school districts was estimated at $25 million and 180 staff members of these organizations were displaced. The city also lost a few famous cultural assets, such as Czech & Slovak National Museum & Library and African American Historical Museum & Cultural Center.


**Figure 7: Damaged Houses after the floods in Cedar Rapids, Iowa (August 2008)**

### 5.6 Survey Result

Survey results indicate that residents of the devastated communities at Cedar Rapids were badly affected by the failure of various infrastructure and their disruption of service for some time. It is evident that failed infrastructure have a socio-economic impact on the residents of the affected region. The social impact which affected most of the survey participants was increased travel time. They also had limited or no access to friends and family. In addition, participants selected road and bridge as the most critical infrastructure for the community to survive and electricity as the most important utility service for daily activities. Respondents were asked to identify the infrastructure that got damaged and affected the community most. The water supply service was found as the most damaged infrastructure that affected the community most, while transportation services and electricity supply were rated the secondary damaged ones (Figure 8). It is observed that electricity was rated the most important "Very High" infrastructure among all the listed utility services for sustaining communities.

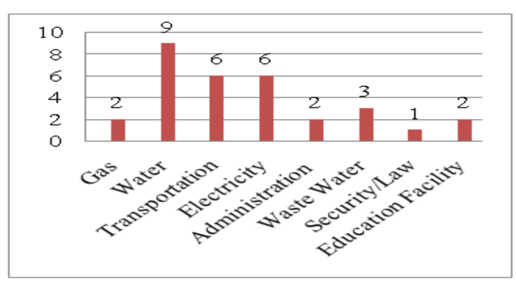


**Figure 8: Damaged infrastructure that affect the community most**

## 6. Significance

### 6.1 Measurement Factors (Metrics)

After data collection is complete, then, using the data, varied levels of plans and mitigation strategies for reducing the impact from natural disasters can be generated by city managers, emergency management agencies, industries, and communities according to their purposes. However, the information that they need to prepare the plans and strategies will be similar and it can be derived based on the analyses of the collected data. For example, the purpose of disaster preparedness for a city manager, who is in charge of planning, design, construction, and maintenance of public infrastructure, can be protecting entire communities and industries so that he or she may want to know the critical or vulnerable infrastructure from the viewpoint of the whole city. Similarly, emergency managers in private companies also need to know what critical or vulnerable infrastructure they have inside and outside the companies, even though their viewpoints are smaller than the city engineer. Therefore, the information that should be identified for developing the mitigation plans and strategies would be:

- Identification of critical infrastructure for industries and communities in terms of the technical, social, and economic aspects (criticality)
- Identification of vulnerable infrastructure or vulnerable parts and sections of the critical infrastructure (vulnerability)
- Establishment of priority to retrofit vulnerable infrastructure
- Impacts on industries and communities if vulnerable infrastructure fail during a disaster (severity or level of impact).
- Mitigation plans to protect industries and communities.

Therefore, the data for the technical, social, and economic aspects can be interpreted in terms of criticality, vulnerability, and severity to identify the inter-relationships based on the characteristics. Criticality implies, for example, how much a company is critically depending its productivity on critical infrastructure. Vulnerability addresses the threats or real hazards to industries or communities in disaster situations and can vary according to the condition of infrastructure. Severity implies the extent of damage or impact when a disaster occurs in communities or near industries. Therefore, criticality, vulnerability, and severity can be key metrics to understand how critical infrastructure, industries, and communities are inter-related in terms of the impacts of natural disasters and how the natural impact can be measured (Figure 9).

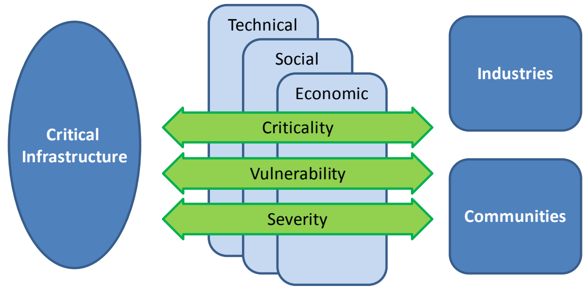


**Figure 9: Metrics of Inter-relationships**

A generic framework of the decision support system can be developed for facilitating the decision-making of the local emergency agencies and industries to develop better plans and strategies. The model at least should consist of the major metrics, criticality, vulnerability, and severity, and reflect the nature of flood impacts and the flow of impacts based on social, economic, and technical understanding. Thus, the collected data in terms of technical, social, and economic aspects can be converted into the three metrics in the decision support system (DSS) as shown in Figure 10. For example, criticality can be explained by three factors of inter-relationships (technical, social, and economic). It will depend on the inter-relationships of the infrastructure and communities or industries; and there can be two kinds of dependencies: dependency of sustaining the security of industries or communities (i.e., levee to protect a company or a village) and dependency of sustaining the functions and services of industries and communities (i.e., electricity to provide the power for production).

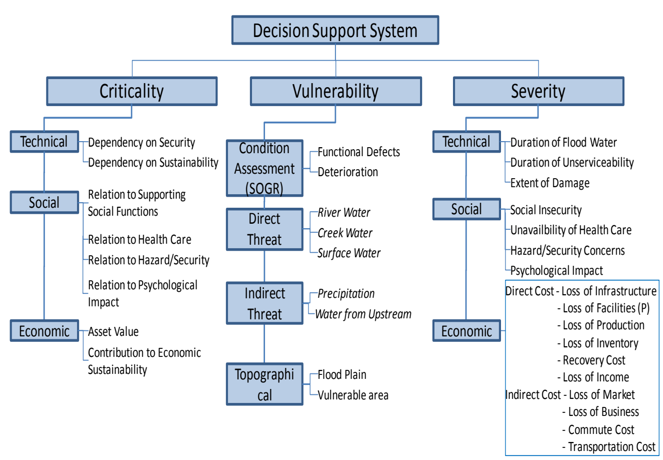


**Figure 10: Metrics of Inter-relationship and Measurement Factors (Example)**

Public infrastructure sustain the social functions and activities of communities, such as shopping and purchasing, visiting families and friends, etc. In addition, the infrastructure has a critical role to provide health care service and security of communities, as well as psychological stability of affected people. The infrastructure that is damaged by natural disasters also affect the income of people or the revenues of companies. Vulnerability can be determined by physical conditions of infrastructure itself and surrounding factors, such as the state of good repair (SOGR, i.e., functional defects and deterioration), direct threats (i.e., river water, creek water, and surface water), indirect threats (i.e., precipitation), and topographical conditions (i.e., the flood plain, vulnerable areas). Severity can be also measured by technical (i.e., duration of flooding, duration of unserviceability, and extent of damage), social (i.e., social insecurity, unavailability of healthcare, hazard/security concerns, and psychological impact), and economic factors (i.e., direct and indirect), similar to measuring Criticality.

### 6.2 Modeling Approach to develop the Decision Support System (DSS)

The purpose of DSS is to assist decision-makers prepare better plans and mitigation strategies for reducing the impact from natural disasters. Thus, the model should be able to express the nature of the disaster impacts, which are inter-related to main entities, such as critical infrastructure, associate industries, and communities. The flow of natural disaster impacts, however, must be described and simulated in a simple manner within the system of DSS. Also the model needs to provide a way to represent the feedback mechanism to handle counterintuitive processes and provide the ability to test different policy or management scenarios for better decision making (Amin et al. 2005). In this research, the System Dynamics simulation approach applied to express complex inter-relationships between main entities. The entities and factors can be structured in a simulation model using variables in System Dynamics Method, such as box variables (stocks and levels), flows, variables (constant, auxiliary, and data), causal loop that describe the behavior of the system. Figure 11 shows how the flood water impacts related infrastructure and community. River water (an auxiliary variable) could be rising due to heavy precipitation (a constant variable) making the collected water in the river reach up to the flood stage (an auxiliary box variable) at some points. The impact of the river water will transfer to the level of vulnerability based on the given Criticality (or inter-relationship). If the river water rises up to the flood stage, then, the vulnerability of the community will be increased through the damaged levee.

### 6.3 Decision Support System and Disaster Mitigation Strategies

The main results of the DSS will be good resources to enhance the efforts of disaster response because the analyses of criticality, vulnerability, and severity will support emergency agencies and industries to prepare their mitigation strategies according to the normal process of disaster response. The Department of Homeland Security defines the three stages of disaster response: preparedness, response, and recovery (DHS, 2004). Preparedness includes wide range of activities to prevent/mitigate the impact of disasters, thus, it requires relevant data (i.e., technical, social, and economic) for hazard assessment, infrastructure assessment, planning, and training personnel. Through the DSS, we can assess the condition of critical infrastructure as well as its vulnerability to any disaster events. In the response stage, we should be able to use the critical infrastructure for immediate actions to preserve life, property, and the environment. Therefore, main routes can be examined in the criticality and vulnerability analyses ahead of disaster occurrence to provide evacuation methods during the disaster. In addition, the condition of critical infrastructure in protection plans, such as levees, flood walls, dams, etc., should be considered in the analyses because those infrastructures are critical to protect industries and communities (Figure 12).

During the response stage, State Coast Guard or volunteers execute the search and rescue activities as well as protecting critical infrastructure such as

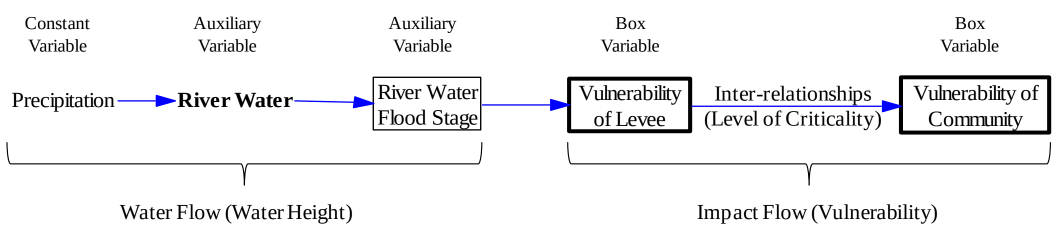


**Figure 11: Basic Flow of Flood Impacts (Vulnerability) from Precipitation to Community**

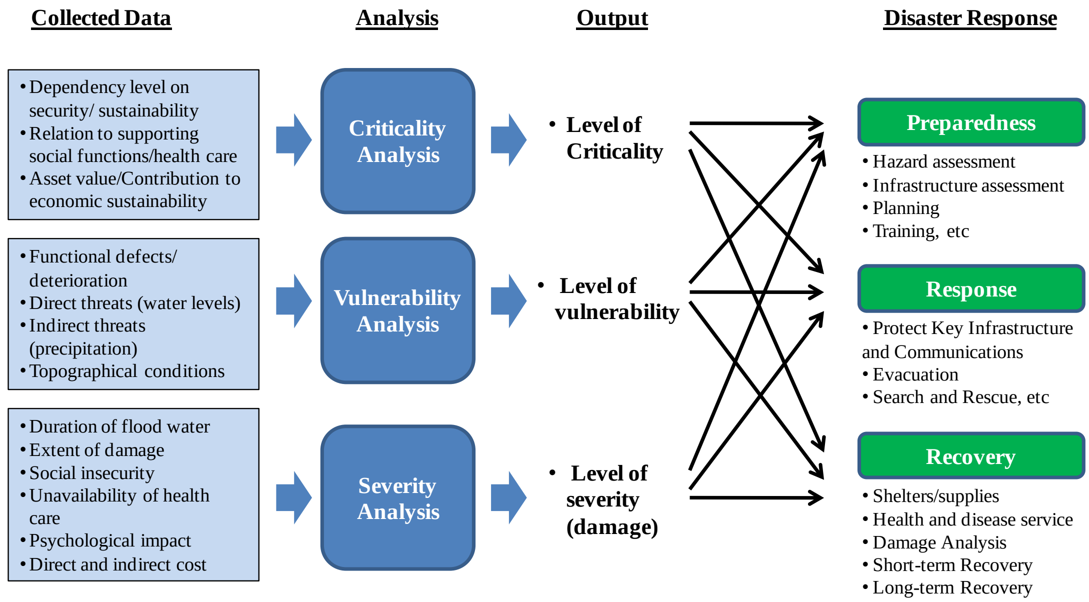


**Figure 12: Decision Support System and Disaster Mitigation Strategies in Disaster Response**

power plants, wells, wastewater treatment plants, etc. After disaster events, the efforts of recovery and rehabilitation of damaged industries/communities/ infrastructure will follow. The priority of rehabilitation of damaged infrastructure will be decided based on the result of the criticality and severity analyses that allows measuring the magnitude of impact.

## 7. Conclusion

The objective of this short-term exploratory research is to conduct in-depth case studies in the flood-affected regions in the Midwest to obtain the ephemeral data with respect to the affected infrastructure and related industries and communities. Personal interviews and questionnaire surveys are being conducted to obtain such data from affected communities, industries, and responsible public agencies. Data includes locations and circumstances of damaged infrastructure, the level of damage, and duration of service failure right after the occurrence of a natural disaster and its impact on the functions of affected industries and communities. These data are analyzed in terms of social, economic, and technical impacts of floods on the affected industries and communities. The analyses of criticality, vulnerability, and severity will give the people, who are involved in risk management, better insight to improving the functions of infrastructure in terms of the mitigation of disaster impacts. In addition, the new approach of data analysis using criticality, vulnerability, and severity will improve the methodology of disaster impact analysis and mitigation; and the disaster-related preparedness of governmental and industrial agencies will be enhanced.

## 8. Acknowledgements

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