Impact Analysis of Natural Calamities on Infrastructure and Industries

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Abstract

Hurricane Katrina was recorded as the most destructive natural calamity in U.S. history. It has exposed significant flaws in Federal, State, and local preparedness with $96Billion of the estimated loss upon overall industry areas such as housing, food, oil, electricity, communication, health care, retail, entertainment etc. Many reports say that this tragedy was mainly caused by overlooking the impact of Katrina and inappropriate reactions of related emergency agencies. More fundamentally, with respect to the nature of impacts, there was lack of both understanding of the natural disaster impacts and preparedness of public agencies and industries. Therefore research is needed to understand, the direct and indirect impacts of hurricane or other natural calamities on infrastructure and industries.
This paper presents the analysis of disaster impacts and inter-relations on infrastructure and associated industries. Disaster impact mechanism and inter-relations based on critical function of industries derived from the extensive literature review and case studies. To develop the framework, service factor was chosen to measure the level of inter-relations and proper weights for each inter-relation between infrastructure and associated industries were obtained by surveying experts in the area of disaster mitigation, emergency organizations, and infrastructure management.

Keywords: Disaster, Impact, Inter-relation, Infrastructure, and Industry

1. Introduction

Hurricane Katrina was recorded as the most destructive natural calamity in U.S. history. It has exposed significant flaws in Federal, State, and local preparedness with $96Billion of the estimated loss upon overall industry areas such as housing, food, oil, electricity, communication, health care, retail, entertainment, etc (Homeland Security and Counterterrorism 2006).

Many articles and reports say that this catastrophe was mainly caused by overlooking the impact of Katrina and inappropriate reactions of related emergency agencies. They had plans in place, had practiced, and were ready for the disaster in their view. However, after the landfall of Katrina, they felt

they overlooked its impacts. One of the officers in a key position of responsibility confessed, “We thought we were prepared, but early on we knew we were not prepared for something like this! We also thought that the feds would save us if something of this magnitude would befall us. We didn’t realize they wouldn’t be able to get to us” (Natural Hazard Center 2006)
It implies that the emergency agencies and industries had few critical problems such as:

- The magnitude of Katrina was misunderstood. They overlooked the impacts of Katrina because they did not fully understand how great Katrina’s impacts were. It is not too much to say that the disaster mechanism including the characteristics of natural calamity impacts was not defined.
- There was lack of preparedness. Emergency agencies and industries thought they were prepared but they found they were not equipped at Katrina’s landfall. Finally there was the loss of communication, equipment, and ability to respond.
- The disaster mitigation plans before natural calamities were not sufficient. The emergency agencies did not have effective cooperation system and critical infrastructure like bridges, roads and communication network were disconnected.
- And there were no proper post-activities for mitigating the impacts of natural calamities in terms of both timing and technical supports.

In fact, these problems have a root cause. That is, fundamentally saying, there was lack of understanding of both the nature of disaster impacts and the inter-relations of affected infrastructure, sectors (community and industries) and organizations. Therefore there is a need to provide proper and holistic disaster information such as disaster mechanism, characteristics of impacts, inter-relations of infrastructure and associated industries, and impact diffusion pathway on affected infrastructure and associated industries.

2. Research methods

1) Needs and Objectives

For the reasons, stated above, it is important to understand more about the disaster itself and its impacts on infrastructure and industries to mitigate the impact of the next possible natural disaster such as hurricane, flood, earthquake, tornado, etc.

We need to understand:

- What are the mechanism of disaster and its impacts
- How the impacts spread out on infrastructure and industries
- How big is the impact on affected industries due to damaged infrastructure

Therefore, the purpose of this research is to develop a Disaster Impact Analysis Model as a framework to support more understanding of natural disaster events with respect to inter-relation of infrastructure and associated industries.

The objectives are:

- To define characteristics of disaster (ex, hurricane events)
- To define Inter-relations of infrastructure and associated Industries
- To define factors to measure both the level of inter-relation and the magnitude of disaster impacts
- To suggest a framework of a Disaster Impact Analysis Model to determine the impact of disaster events on infrastructure and associated industries

2) Type of Disaster

Various types of natural disasters occur all over the world such as earthquake, hurricane, tornado, blizzard, forest fire, etc. Therefore it is important to develop disaster impact analysis models for all the types of disasters. This paper focuses on the impact analysis of hurricane type disaster for the following reasons:

- Hurricane has complex impact components such as torrential rain, strong wind, flood, fire, outage, etc. So it is not easy to analyze those impacts but this type of disaster shows the impact diffusion pathway with continuous chain events in the course of time.
- It is rather easy to obtain the basic information because extensive meteorological researches for the hurricane itself are readily available.
- Impact analysis researches of big hurricanes like Katrina and Ivan are now reported in terms of social and economic aspects. Those results would be helpful to define impact factors on infrastructure and industries that this research is aiming to obtain.

3) Methodology

In the first phase a disaster impact mechanism was defined to establish the fundamental of the disaster impact analysis model. An extensive literature review helped to derive this mechanism with few case studies such as hurricane Katrina and Ivan. Thereafter the inter-relations of infrastructure and associated industries were defined. Main components of this phase are critical infrastructure, associated industries, and the inter-relationship based on the analyses of its critical functions. In the third phase the factors for measuring the level of inter-relations and the magnitude of disaster impact were defined. Finally a new approach for structuring the disaster impact analysis model has been suggested. To develop the framework, proper weights for each inter-relation between infrastructure and associated industries were obtained by surveying experts in the area of disaster mitigation, emergency organizations, and infrastructure management through a questionnaire survey.

3. Research results

Based on the results of the literature review and the analyses of big hurricane events, the flow of development of hurricane events, from the initial stage of formation to the recovery of normal business and life after the disaster was defined and a basic cell model that explains the mechanism of hurricane events was suggested.

1) Anatomy of Disaster: Hurricane

Hurricanes initially form on the tropical ocean as a tropical storm around the Atlantic Ocean, Caribbean Sea, or Gulf of Mexico. As hurricanes move ashore, they bring direct impacts such as a storm surge of ocean water, high winds, torrential rains, flooding, hail, as well as tornadoes. The general flow of development of hurricanes and impact on infrastructure, industries, and communities is shown in Fig. 1.

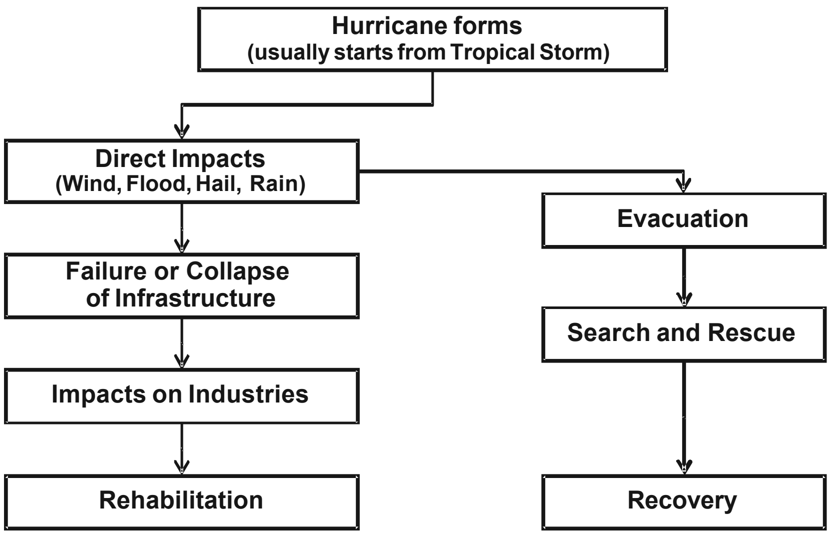

Fig. 1. Development of Hurricane and Impact Flow on Infrastructure and Industries/communities

According to the warnings of emergency agencies or the weather information forecasting by mass media, people start evacuating from their communities as the hurricane approaches or during the hurricane event. In the meantime, vulnerable infrastructure such as electricity facilities, communication systems, deteriorated bridges and roads, etc, are damaged or collapsed by the power of hurricane. During Hurricane Katrina, for example, significant levee failures occurred on the 17th Street Canal, the Industrial Canal, and the London Avenue Canal. Approximately 80 percent of the city was flooded. Towns and cities, small and large, were destroyed or heavily damaged up and down the Gulf Coast and miles inland (Homeland Security and Counterterrorism 2006).

Right after the landfall of hurricane, the search and rescue efforts by the emergency agencies start. During Hurricane Katrina about 8 percent of the affected population in the Gulf Coast of Mississippi, Louisiana, and Alabama were not able to (or did not) evacuate and about 1,330 were killed or reported missing (Homeland Security and Counterterrorism 2006).

The impact of hurricane affects people's ordinary lives and businesses in long and short term periods. For example, it took two years for recovery of the total revenues from sales, hotels, and motor vehicles in New Orleans to 94 percent of pre-storm levels. Environmental and socio-psychological problems, for example, still remain in the Gulf Area as long-term impacts. Thereafter recovery of damaged infrastructure and rehabilitation of affected lives follow.

2) Disaster Impact Mechanism

The flow of impact by a natural disaster can be divided into two stages: the primary impact and the secondary impact. Primary impact means direct impact from a natural disaster itself on infrastructure with physical damages and losses. For example, a hurricane brings few destructive powers such as winds, rain, flood, hail, tornado, etc. Infrastructure in the influenced territory would get damaged or collapse directly due to the impact of the hurricane. The results could be outage of electricity, break in communications, collapse of buildings, roads and bridges, etc. After these direct impacts or during the disaster impact on infrastructure, secondary impact will be on the services of associated industries. These service failures occur due to damaged infrastructure.

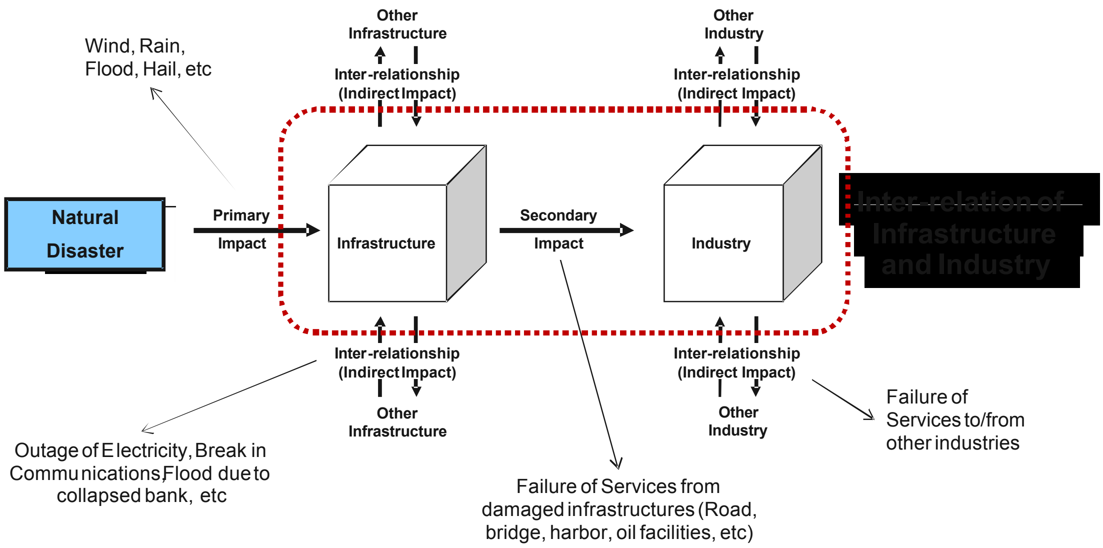

Fig. 2. Disaster Impact Mechanism (Basic Cell Model)

Inter-relations of infrastructure and associated industries are the key component to establish a disaster impact mechanism. A natural disaster primary impacts the infrastructure with physical power and some vulnerable infrastructure may get damaged. Then the damaged infrastructure secondarily transfers its impact to associated industries according to their inter-relation.

Fig. 3 shows the flow of the impact from a natural disaster to associated industries through damaged infrastructure for the representative case, Hurricane Katrina. Few critical infrastructure and associated industries are chosen as examples to show the impact flow and how they are inter-related. In this context, critical infrastructure in the area of the Gulf Coast are buildings, road and rail facilities including traffic signals, electricity facilities, levees and embankments, bridges, communication facilities, and oil facilities (infrastructure for various services such as banking, government service, health care, etc, were excluded to simplify the example). Associated industries are health and hospital, food, agriculture, transportation, communication, oil and refinery, and retail.

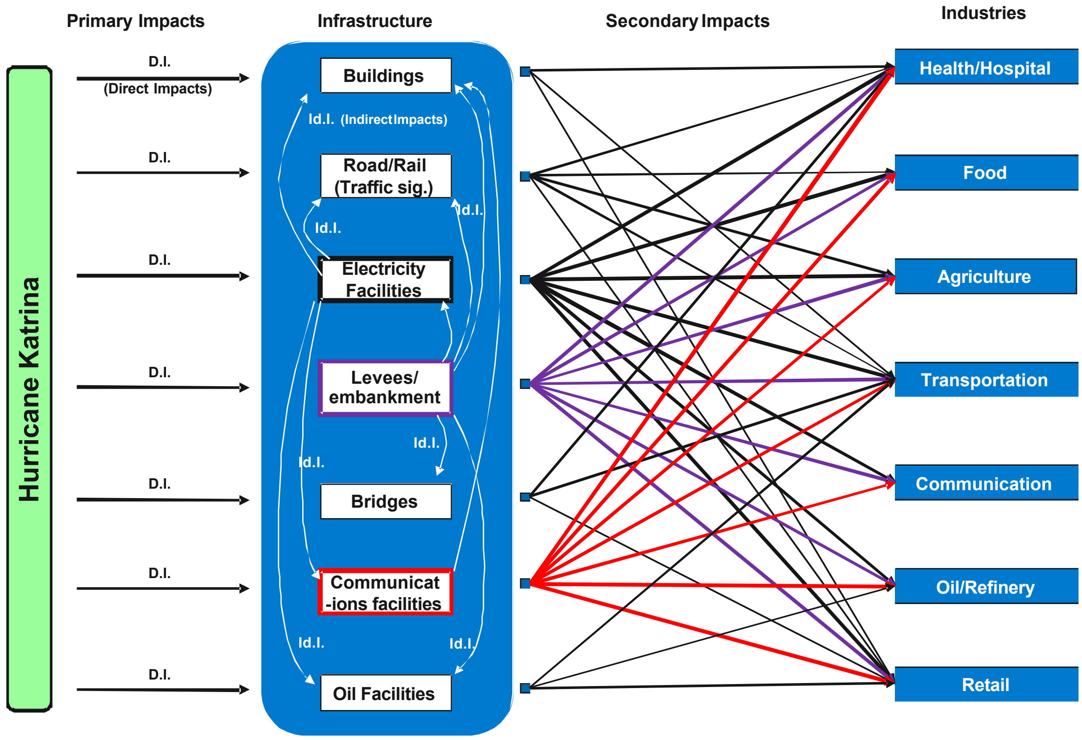

Fig. 3. Impacts on Infrastructure and Industries (Hurricane Katrina)

In fact, the entire infrastructure in the Gulf Area was damaged or collapsed. However, we can find there are few critical infrastructure that affect other adjacent infrastructure. Electricity facilities, levees and embankments, and communication facilities are some of the critical ones in terms of their impact on other facilities. Those critical facilities indirectly impact on other related facilities as shown in Fig. 3.

The impacts originally caused due to Hurricane Katrina get transferred to main industries through damaged facilities in the second impact stage. Especially the three infrastructure, electricity, levees, and communications, affected many industries in addition to the adjacent infrastructure in the primary impact stage.

3) Inter-relations of Infrastructure and Associated Industries

As defined in the disaster impact mechanism, there are many relations such as between infrastructure, between industries, and between infrastructure and industries. It is important to define all these inter-relations to establish the disaster impact mechanism and to structure the disaster impact analysis model. This paper is focused on defining the inter-relation of infrastructure and its associated industries.
The main components of establishing inter-relations of infrastructure and associated industries are critical infrastructure, associated industries, and the inter-relationship based on the analyses of critical functions in each industry.

Critical Infrastructure

The President’s Commission on Critical Infrastructure Protection in the United States has defined the term *infrastructure* as “a network of independent, mostly privately-owned, man-made systems and processes that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and services” (1997). The Commission narrowly focused on eight critical infrastructure “whose incapacity or destruction would have a debilitating impact on our defense and economic security.” Those are telecommunications, electric power systems, natural gas and oil, transportation, water supply systems, banking and finance, government services, and emergency services (including medical, police, fire and rescue systems).

This definition of infrastructure has been broadened and redefined by the Critical Infrastructure Assurance Office (CIAO) as “the framework of interdependent networks and systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services essential to the defense and economic security of the United States, the smooth functioning of governments at all levels, and society as a whole.” In this wider perspective, Rinaldi et al (2003) categorized five additional infrastructure as critical for sustaining industries and communities. These additional infrastructure are food & agriculture (including production, storage, and distribution), space, numerous commodities (including iron and steel, aluminium, finished goods, etc.), the health care industry, and the educational system.

Critical infrastructure are also lifeline facilities to support industries and communities as life support networks (Benoît et al 2006). And in the broadened viewpoint as redefined by CIAO, the critical infrastructure included in this research would be thirteen including PCCIP’s eight critical infrastructure and CIAO’s five additional infrastructure.

Associated Industries

Standard Industrial Classification (SIC) Code provides 99 industries for North American Industrial Sector. Burrus et all (2002), however, aggregated 51 industries using IMPLANT model to conduct a survey for determining business interruption times due to hurricanes. This research is focused on defining inter-relations of infrastructure and associated industries. The main industries in this context should relate to the critical infrastructure. The main industries are primarily related with lifeline/essential services and the related infrastructure systems. After analyzing the aggregated 51 industries, the main industries could be divided into two groups, supporting and affected industries.

Supporting Industries are mainly related with lifeline infrastructure systems such as communications, transportation, electricity, gas and oil, and water supply system. Supporting industries are also the Industries that have major responsibility to support, operate, and maintain lifeline/essential infrastructure. Affected Industries indicate the primary industries that provide essential services such as government services, emergency services, banking and finance, food, and educational system and are affected by the condition of the critical infrastructure. Fig. 4 shows how the main industries were derived from the thirteen (13) critical infrastructure identified through this research and how they correspond to the industries identified in the IMPLANT model (Burrus et all 2002).

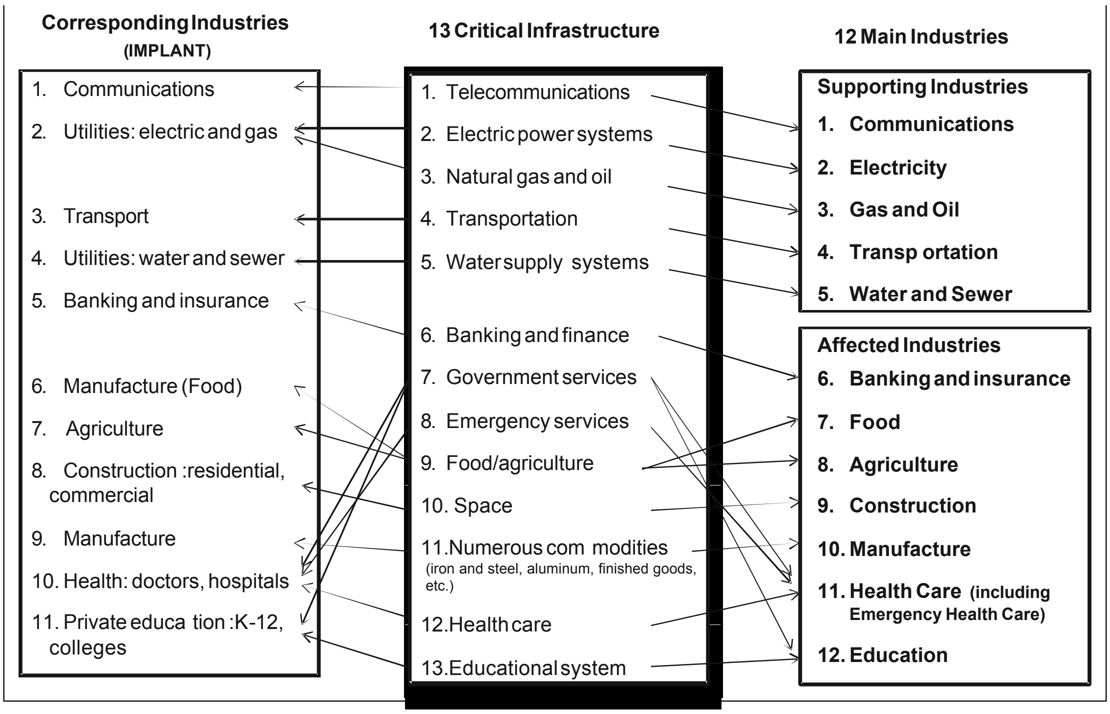

Fig. 4. Critical Infrastructure and Main Industries (Supporting and Affected)

Finally five supporting industries and seven affected industries were derived. Supporting industries are communications, electricity, gas and oil, transportation, and water and sewer; and affected industries are banking & insurance, food, agriculture, construction, manufacture, health care (including emergency health care), and education.

Inter-relations of infrastructure and associated industries

Inter-relation of infrastructure and associated industries can be defined based on analysis of critical functions of industries. The critical functions are the functions that an industry has within its own business such as telecommunication service and broadcasting services for communication industry. Based on the critical functions found above, related infrastructure can be selected. In the health care industry, for example, critical functions would be medical services, hospitalization services, and emergency services (including emergency medical service, emergency transport service, etc). The related infrastructure are space (main clinic building, ward, ER, etc), electric power system (emergency power generator, distribution networks, poles, etc), natural gas and oil (fuel station, pipelines, heating system, etc), communications (telecommunication equipment, internet line, etc), water supply system (water pipe, sewage system, watertank, etc), and transportation (facilities on routes, road, bridge, etc).

These inter-relations can be illustrated for a sample town as shown in Fig. 5 and Fig. 6. Fig. 6 shows the level of inter-relation and how the infrastructure and industries are related to each other.

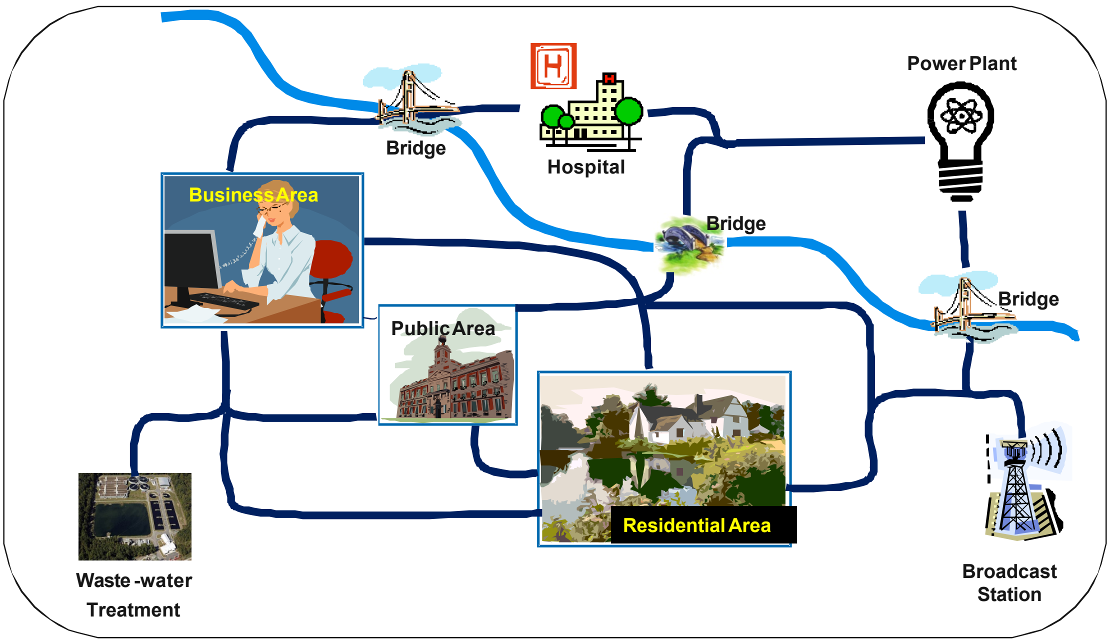

Fig. 5. Application of Inter-relations to a Sample Town

The infrastructure in the sample town are mapped with all industries that the town might have. It is worth noting that the key factor of this map is the level of inter-relation, depicted as very high (5), high (4), medium (3), low (2), and very low (1).

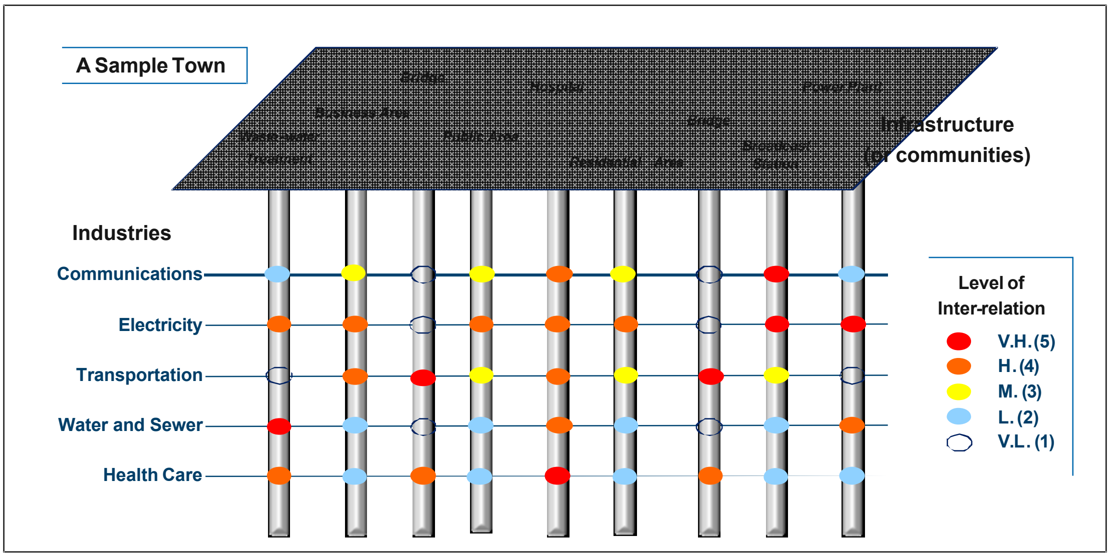

Fig. 6. A Sample of Inter-relations of Infrastructure and Associated Industries

4) Measurement Factors

To develop the framework of the disaster impact model, we need proper factors to measure not only the level of inter-relations of infrastructure and associated industries, but also the level of impact (or the magnitude of impact) of disaster. The backbone of the framework is the inter-relation of infrastructure and industries, therefore, the factors should be suitable to reflect the characteristics of infrastructure and industries.

Factors for measuring the level of inter-relation can be decided by level of service, magnitude of service, number of services, relevance between infrastructure and associated industries, etc. These inter-relation factors are rather subjective except number of services therefore a survey was sent to experts in the area of disaster mitigation, emergency organizations, and infrastructure management. The purpose of the survey was to obtain weights for each level of inter-relation between 13 critical infrastructure and 12 associated industries including supporting and affected industries (Fig. 7). Fifteen responses were received from the survey.

The level of impact (or the magnitude of impact) can be measured usually after the disaster event. Few studies for measuring the impact of disaster have already been conducted. They, however, focused on the external aspects of disaster impacts. For example, they measured economic impact (monetary value of losses, damaged infrastructure, etc.) and social impacts (lost job, depreciated properties, socio-psychological damage, etc.), rather than the inter-relation of infrastructure and industries (Lindell et all, 2003, Mumane, 2006, Scawthorn, 2006, etc).

The disaster impact analysis model in this research is intended to provide information for decision makers who need timely and technically proper counterplan. Therefore this model should be able to measure the impact from natural disaster before, during, and after the disaster event. Most of previous studies measure the disaster impacts after its occurrence so that it is difficult to use their results for preparedness or decision making during the event. Mendonça et al (2006) investigated impacts of the 2001 World Trade Center attack on critical infrastructure systems in the New York City metropolitan area and counted the number of service downtime for three months after the attack. Their research shows the importance of using the level-of-service as a factor to measure the magnitude of disaster impact even though they only counted the number of service failures. In this research, however, the level-of-service available from a damaged infrastructure would be gathering in all stages of a disaster event and would be applied into the model to measure the impact on associated industries as shown in Fig. 8.

Level of Inter-relation between Infrastructure and Associated Industries

Instruction: Please choose the level of inter-relation
1. Please read Infrastructure in the center column first (Title: Inter-related Infrastructure).
2. Choose the level of Inter-relation between **Supporting Industries and Inter-related Infrastructure**.
3. Choose the level of Inter-relation between **Affected Industries and Inter-related Infrastructure**.
4. Please repeat "No 2 and 3" requests for each Inter-related Infrastructure (There are total 13 Inter-related Infrastructure)

Supporting Industry	Level of Inter-relation	Inter-related Infrastructure	Level of Inter-relation	Affected Industry
Communications	(Click Here)	(1) Communication System	(Click Here)	Banking & Insurance
Electricity	(Click Here)		(Click Here)	Food
Gas and Oil	(Click Here)		(Click Here)	Agriculture
Transportation	(Click Here)		(Click Here)	Construction
Water and Sewer	(Click Here)		(Click Here)	Manufacture
			(Click Here)	Health Care
			(Click Here)	Education
Communications	(Click Here)	(2) Electricity	(Click Here)	Banking & Insurance
Electricity	(Click Here)		(Click Here)	Food
Gas and Oil	(Click Here)		(Click Here)	Agriculture
Transportation	(Click Here)		(Click Here)	Construction
Water and Sewer	(Click Here)		(Click Here)	Manufacture
			(Click Here)	Health Care
			(Click Here)	Education

Fig. 7. Survey Sample to Obtain Weights of Each Level of Inter-relation

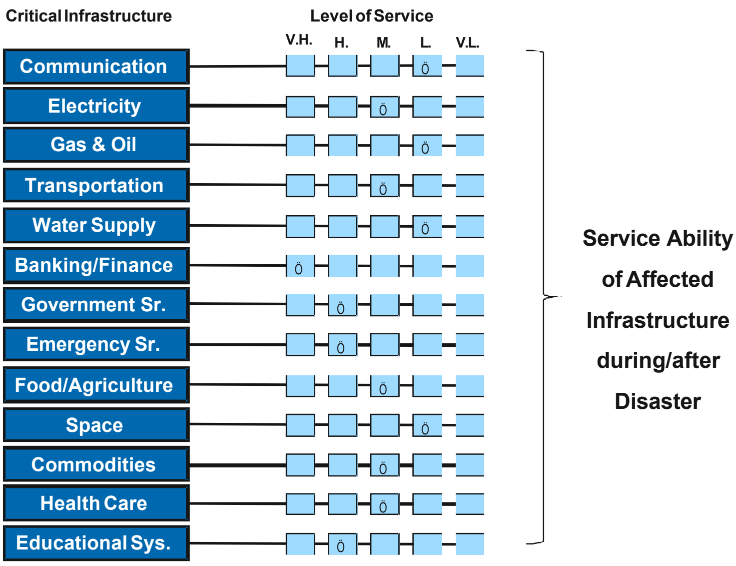

Fig. 8. Sample Sheet to Measure the Magnitude of Impact (level-of-service)

5) Framework of Disaster Impact Analysis Model

Based on the result of the literature review and the survey, a framework for the disaster impact analysis has been suggested as shown in Fig. 9. Thirteen critical infrastructure are centered as a backbone of the model and supporting and affected industries are located left and right hand sides. The level of service, i.e., the magnitude of impact gathered before/during/after a disaster event, is shown under each infrastructure, for example, level of service 2 for communication. It means that this communication facility (internet cable, telephone network, transmitting station, etc) were damaged and the service level available is only 2 which is low level. This level of service is then transferred to each supporting or affected industry according to the weights given by the survey.

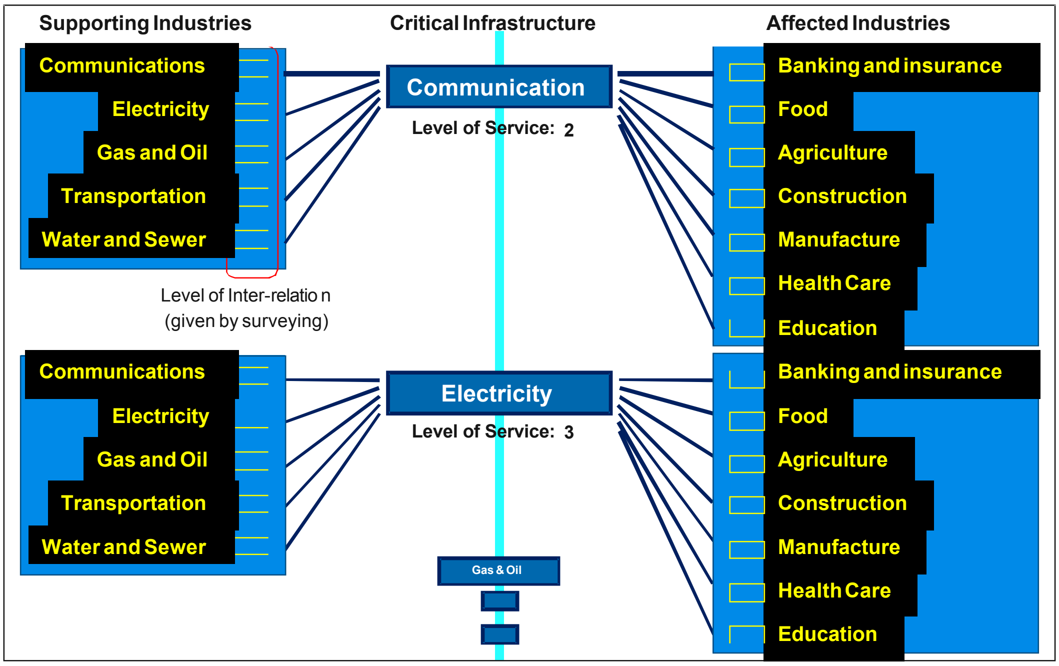

Fig. 9. A framework of the Disaster Impact Analysis Model

4. Discussion and conclusions

The research presented in this paper analyzed several important questions: what are the mechanisms of disaster and their impacts; how the impacts spread out on infrastructure and industries; and what is the magnitude of these impacts on industries due to the damaged infrastructure. To answer these questions, intensive literature review, case studies, and a survey were conducted and finally a disaster impact analysis model was suggested.

Disaster impact mechanism explains how a natural disaster impacts on infrastructure and associated industries through the primary impact and the secondary impact stages. The key component of the mechanism is the inter-relation between infrastructure and industries. Hurricane Katrina was used to illustrate its mechanism. Based on this result, inter-relations of infrastructure and associated industries were defined by providing the definition of critical infrastructure and main industries that include supporting and affected industries. In addition, a survey was conducted to obtain suitable weights for each level of inter-relation and finally a framework for a disaster impact model has been suggested.

The disaster impact mechanism may provide better understanding for people who in the area of disaster mitigation such as FEMA, DHS as well as related industries. Furthermore, this disaster impact analysis model will be a good foundation to develop a decision aid tool for government organizations when they are faced with natural disaster events such as Hurricane Katrina. This model will be fortified through case studies for applying the procedure into practice and would be developed into a decision aid tool for multi-purpose usage.

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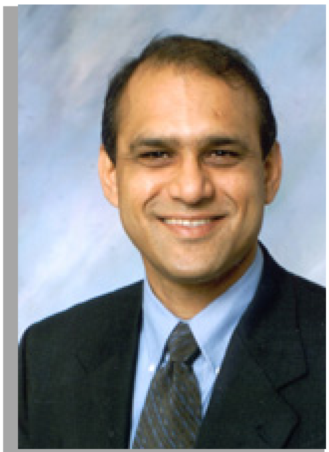
Author's Biography



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