

# Development of a Web-Based 3-D Visualization and Cluster Computing System for Disaster Management

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## Abstract

Natural disasters can cause huge loss of life and enormous property damage to local communities. Although it is impossible to avoid the natural disasters, human suffering can be reduced by adopting information technologies to the disaster response missions. In this paper, a Web-based 3-D visualization and cluster computing system was developed to facilitate and expedite the resource distribution process during a disaster. Our disaster management system utilizes state-of-the-art computing cluster with 16 nodes of Intel Xeon-E5 processors (16 cores per node) to process the emergency supply requests from the disaster victims and calculate the optimal resource distribution routes, while considering damaged transportation infrastructures. The optimized resource distribution problem was solved with distributed all-pair shortest path algorithm and the vehicle routing algorithm. The Web-based 3-D visualization system was developed with the Google Earth engine to display the disaster areas, affected households, and resource distribution routes. The computation result from the cluster was automatically uploaded to the Web-based 3-D visualization system, enabling users to immediately see the optimal resource distribution routes in a virtual 3-D environment. The visualization system is flexible and can be easily adapted to a Google earth enabled mobile devices, desktop monitors as well as a cave automatic virtual environment (CAVE). Historical disaster data from the Northwest Indiana was used to demonstrate the functionalities of the developed system.

## Introduction

The sights and sounds of disasters and expectation of rapid response is putting increasing pressures on governments and other institutions to move ever more quickly, whether it be in disaster relief endeavors such as the 2004 Asian tsunami, the Katrina hurricane along the Gulf Coast of the United States in 2005, the earthquake in Haiti in 2010, or the most recent earthquake and tsunami in Japan. From the White House report on Hurricane Katrina, the state and local government should develop modern, flexible, and transparent logistic system for stockpiling commodities and supplies during the emergency [1]. Improvements in emergency management information and decisions will have a positive impact on those most affected by the disaster: the population. The affected population, however, can create difficulties for the decision maker. Each has varying disaster-caused or exacerbated needs and varied demands for services from the response organizations. With a general perception of lack of planning and coordination on both federal and state levels, the question arose as to the preparedness of local government programs.

Indiana townships are part of state and local government systems, which supply indigent populations with needed services. Research has shown that, at present, many systems lack an emergency plan capable of meeting immediate needs such as basic shelter, food, clothing, and medical services for a large number of people in a short amount of time [2-6]. Better information and decision support to the manager can provide more accurate focus and priority to balance the emergency response. geospatial information system (GIS) based risk assessment and loss estimation tool has been widely used in federal and local government level. The Federal Emergency Management Agency (FEMA) has distributed HAZUS loss estimation tool on top of the integrated geographic information system platform ArcGIS (ESRI). It has been used to estimate the damages made by earthquakes and flooding [7, 8]. Based on lesson-learned research from Hurricane Katrina, federal, state, and local agencies need to maintain locally accurate GIS data that will enhance effective implementation of geospatial technologies for disaster management.

High performance computing has been utilized for a variety of damage estimation and simulation in disaster management applications. Akhter et al. extended open source GRASS (geographic resources analysis support system) library with MPI and OpenMP framework to perform distributed processing of satellite images for rapid damage severity and extent estimation [9, 10]. Roy et al. indicated that in the emergency management of the real-time data, it is important to adopt distributed geo-data processing methodology for effective decision-making [11]. Luis et al. reviewed numerous articles in disaster relief routing and suggested to utilize high performance computing approach for disaster relief routing [12]. Recently, Lecron et al. and Cruz-Chávez et al. exploited a grid computing method in solving vehicle routing problems [13, 14].

This paper introduces a GIS-based disaster data management, cluster computing, and 3-D visualization system that focuses on Northwest Indiana region. The Web-based disaster data management and communication system can provide communication between local authorities and indigent population affected by the disaster. The high performance computing

cluster will provide expedited disaster management plans for decision makers. The cluster computing system gathers the data during a disaster and disburses that information to the administrators who must make critical decisions to provide emergency food, water, medical and rescue distribution. The 3-D geospatial information visualization system provides situational awareness and a common operating picture of local disaster areas. The local government agencies can visually acquire disaster-related information and make appropriate decisions based on the proposed disaster management and decision support system. The visualization system is flexible and can be easily adapted to a Google Earth enabled mobile devices, desktop monitors as well as a cave automatic virtual environment (CAVE). Although the proposed research focuses on the Northwest Indiana region, the generality of the proposed methods and developed prototype system can be easily applied to other regional government agencies across the nation. The optimized resource distribution and route planning algorithm is based on USGS road network data in Arcview Shapefile format, which is open to the general public. The optimal route calculation algorithm utilizes open source VRPH (vehicle route planning heuristics) library and is implemented in C++ for single CPU and in C++/MPI for the computing cluster. The Web-based 3-D visualization system adopts open source PostgreSQL server with 3-D Google Earth plugin and is implemented in PHP/Javascript. These software tools and programs are available for the regional government agencies across the nation to develop their own disaster management and visualization system.

### **Web-Based Disaster Management and Communication System**

The disaster management and communication module consists of a software/hardware solution. The software consists of a SQL server database and user interface built on the ASP.NET framework. It contains modules for collecting client information and resource information for services such as housing, transportation, emergency assistance, clothing, etc. The resource inventory data can be used by the Homeland Security incident commander in charge of providing support to the affected disaster area. The networking and hardware portion of this system consists of wireless handheld devices or laptops, which can be brought to a disaster site to collect indigent demographic information. This information is then added to the SQL database through a wireless network system.

Built on a Windows server platform, this system was implemented on both portable computers and workstations, which can be easily transported if necessary. The enhanced entity relationship model describes the relationships between the agency, resources, clients, and service providers during emergencies. The DMCS system was setup as a two tier application with application screens and class objects residing on a Web server and the data being stored in a separate SQL server database. The Web server uses HTTPS security protocol to encrypt the data communication between the client computer and Web server. The application requires a login ID and password validated through the database to get access to the application. The communication between the DMCS and the database was setup with one connection setup in the Web.cfg file. The security of the data is also enhanced by the use of SQL stored procedures that reside on the database for getting and sending data to the Web application from the database.

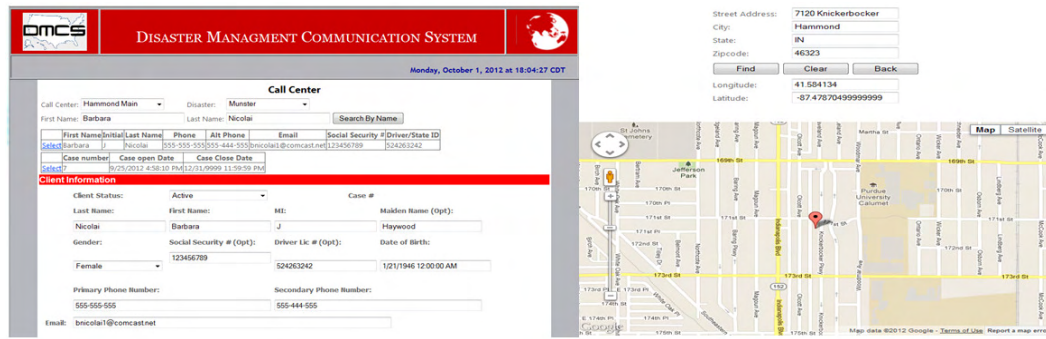


Figure 1. Web-based DMCS interface and geo-location API

Figure 1 displays the Web-based DMCS system described above. Once the disaster manager is assigned to the operation, s/he begins to collect information about the event in order to inform their actions. Another feature of DMCS system is a GIS module, which could be used to display geographic conditions. To obtain the latitude and longitude values of an entered address the system uses a Web service provided by “Yahoo PlaceFinder.” This service can convert an address such as “1600 Pennsylvania Avenue, Washington, DC” into geographic coordinates (latitude 38.898717, longitude 77.035974). The geospatial information is part of the situational awareness needed to develop the common operating picture.

### Automated Data Transmission between the Web-Based DMCS and Computing Cluster

The automated data transmission subsystem was developed to create a secure channel that connects the database to the remote computing cluster. The subsystem is located at the DMCS database server and runs synchronous operations to search new requests from the customers. When the new requests matched, the subsystem extracts and collects the data through SQL scripts and automatically connects to the Linux-based supercomputing cluster using SFTP and SSH protocols. Figure 2 shows a data flow diagram of automatic data transmission between the Web-based DMCS and computing cluster, optimal route computation inside computing cluster and the Web-based 3-D visualization system.

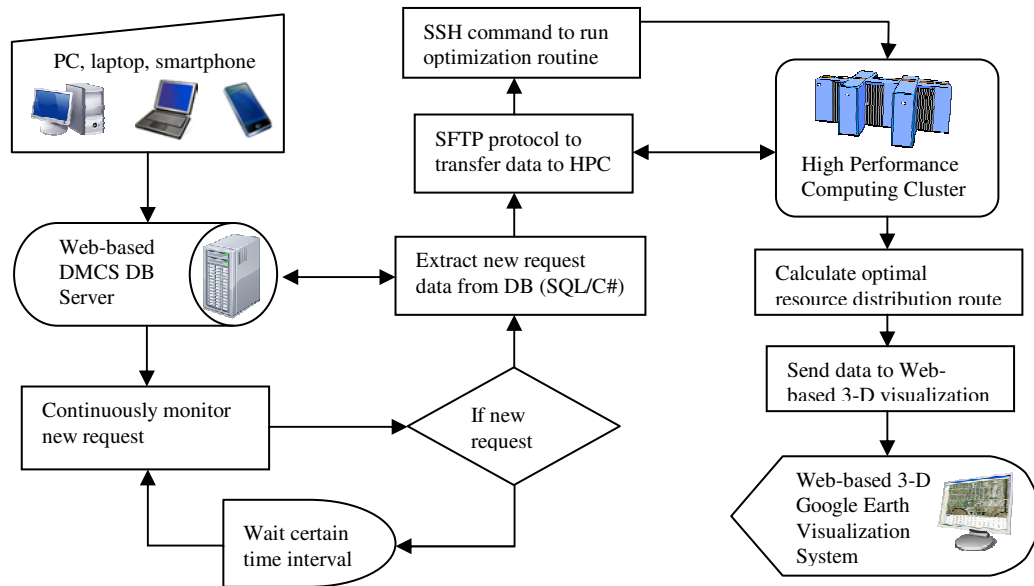


Figure 2. Data flow of automatic data transmission, route planning, and visualization

### Optimized Resource Distribution Route Computation Using Computing Cluster

It is essential to provide efficient resource distribution strategy to the decision makers after a disaster impact. A resource distribution center has certain capacities of resources including food, water, clothes, emergency medicines, and transportation units. An affected household has certain requests with food, water, clothes, and emergency medicines. With the assumption that the amount of resource is sufficient to serve all the affected population, minimizing the resource distribution time is equivalent to minimize the sum of the distance between the resource center and household locations. Therefore, the problem becomes minimizing sum of traveling distance between resource centers to household locations. Minimizing sum of traveling distance with the constraint of the capacity is a vehicle routing problem and can be solved by all-pair shortest path algorithm and vehicle routing algorithm. Both all-pair shortest path and vehicle routing problem are fundamentally graph problems. In this paper, the graph being processed is the road network structure in Northwest Indiana region. The GIS road network data were acquired from the US Census Bureau. Unfortunately, these data are only a collection of line segments that do not provide any connectivity information. To solve this problem, a scan conversion algorithm was implemented to rasterize the GIS road data and recreated adjacent graph structure. The scan conversion algorithm rasterizes unique road color codes for road segments and identifies intersection points (Figure 3). This rasterizer is used to generate an adjacency road network graph to calculate all-pair shortest path and vehicle routing problem.

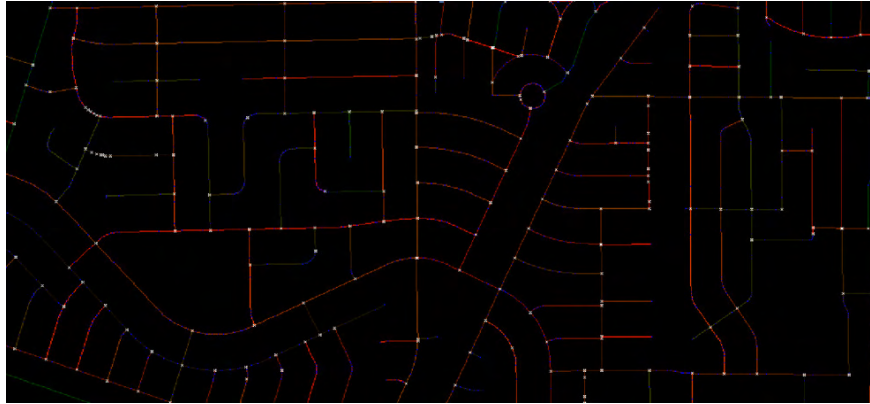


Figure 3. Conversion algorithm to generate road network graph

All-pair shortest path algorithm is a graph analysis algorithm to find the shortest paths between any two nodes in a weighted graph. The original Floyd-Warshall algorithm is a dynamic programming algorithm that finds the summed weights of the shortest paths between all-pairs of vertices, but it does not provide the transition route [15]. In this paper, a distributed Floyd-Warshall algorithm was implemented to provide transition route information inside 16-node computing cluster.

The distributed all-pair shortest path algorithm works as follows: each cluster node will obtain a part of the adjacency graph matrix. The shortest path computation will perform in row-first order. Each node will choose the row that will be shared by multiple nodes, and broadcast it to other nodes. These are candidate transition route that if the cumulated distance of passing this graph vertex is shorter than current cumulated distance, then replace the shortest path, and put the transition graph vertex into the precedence matrix P.

The vehicle routing problem (VRP) is to construct a minimum cost set of routes that meets all customer demand while minimizing the total distance of transition routes. Because of the difficulty in solving the VRP and additional constraints, a VRP problem of realistic size was typically solved via heuristic methods. In this project, an open source C++ package (VRPH) was adopted to solve the vehicle routing problem. VRPH was developed by Chris Groer and provides a modular, well-documented library of local search heuristics for generating solutions to the VRP [16]. The all-pair shortest path matrix will be used as an input to the VRPH software, and it will generate optimized resource distribution route. The optimal distribution route starts from the command center, follow the shortest path to the affected household and resource distribution locations and return back to command center. Different colors indicate the multiple resource distribution routes based on the numbers and capacities of the mobile unit. Figure 4 shows a visualization of the computed resource distribution route in a Web-based 3-D visualization system.

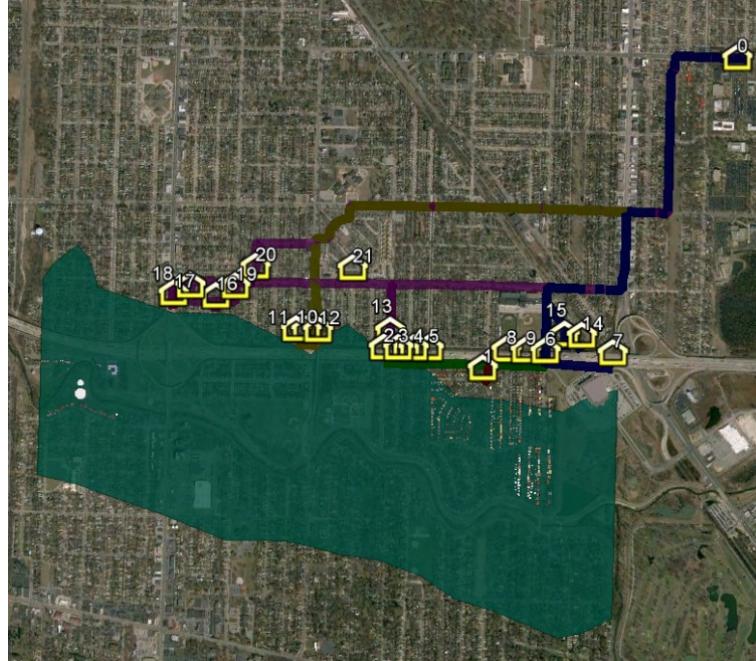


Figure 4. Optimal route calculation using VRPH method

The optimal resource distribution route computation utilizes state-of-the-art computing cluster with 16 nodes of Intel Xeon-E5 processors to process the emergency supply requests from the disaster victims, and calculate the optimal resource distribution routes with the consideration of the damaged transportation infrastructures. For Munster and Hammond, the HPC can update the optimal route in less than a minute. Considering the flooded area in Lake County, Indiana, the route computation took 15 minutes inside the high performance computing cluster.

The disaster management and communication module consists of a software/hardware solution. The software consists of a SQL server database and user interface built on the ASP.NET framework. It contains modules for collecting client information and resource information for services such as housing, transportation, emergency assistance, clothing, etc. The resource inventory data can be used by the Homeland Security incident commander in charge of providing support to the affected disaster area. The networking and hardware portion of this system consists of wireless handheld devices or laptops that can be brought to a disaster site to collect indigent demographic information. This information is then added to the SQL database through a wireless network system. Built on a Windows server platform, this system was implemented on both portable computers and workstations, which can be easily transported if necessary. The enhanced entity relationship model describes the relationships between the agency, resources, clients, and service providers during emergencies. The DMCS system was setup as a two tier application with application screens and class objects residing on a Web server and the data being stored in a separate SQL server database. The Web server uses HTTPS security protocol to encrypt the data communication between the client computer and Web server. The application requires a login ID and password validated through the database to access the application. The communication

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### **3-D Visualization of the Optimal Resource Distribution Route and Disaster Area**

The computation result from the computing cluster is automatically uploaded to a Google-Earth based 3-D visualization system. This approach enables the users to immediately see the computation result from a Web based visualization system. The Google Earth software package was chosen, as it was both a freely available and reasonably capable GIS suite. Initial testing indicated that selective culling of models would be necessary within the displayed area to insure program responsiveness. Google Earth supports a large subset of the KML (keyhole markup language) specification. A significant feature of the KML specification used in this visualization system is the network link element. A KML network link allows a Google Earth context to be updated periodically from a remote server. The visualization interface initially loads all possible categories of displayable elements as network links. The response files are dynamically generated using PHP and a database backend to reflect the current state of the emergency scenario. Objects that are dynamically generated from database for display includes emergency relief packages sources (EMS centers) as KML models, emergency relief package destinations as KML placemarks, extent of flooded water bodies as KML polygons, calculated optimal package delivery routes as KML lines and observer photographs inserted as geo-located KML PhotoOverlays. The Web-based 3-D visualization system provides monoscopic and stereoscopic page, which facilitates the usage of both regular monitor and the stereoscopic displays such as 3-D monitor and CAVE virtual environment (Figure 5).



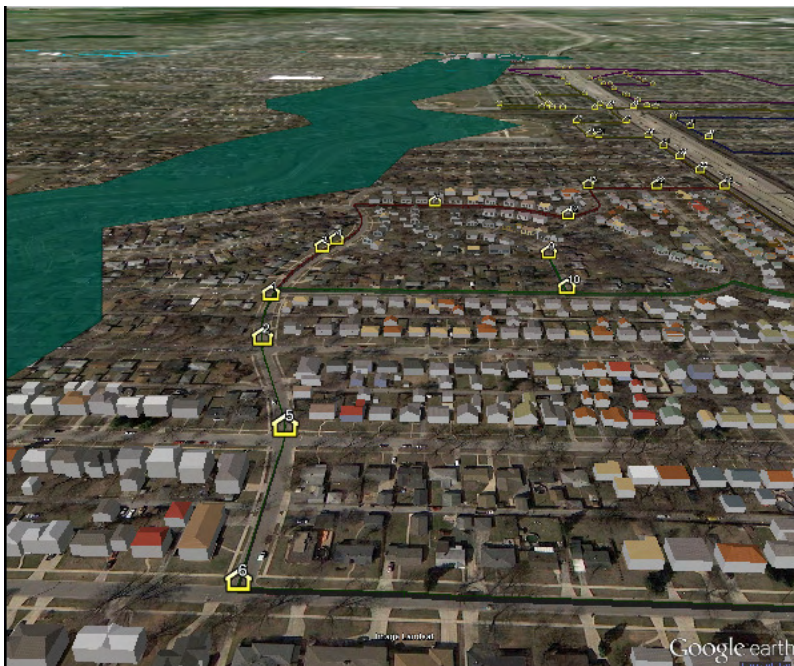


Figure 5. 3-D Visualization of 2008 flood data in Munster, Indiana

During the disaster, users can upload the photos of disaster areas using mobile and handheld devices. Users can take a photo in the field with mobile device. The picture info and data could be acquired from phone instrumentation. The photo and geospatial information was uploaded to server, and pictures will be automatically updated and placed within the Google Earth interface (Figure 6), which is dynamically updated or populated with delivery targets, routes, and road obstruction visual indicators via a remote database and computing cluster backed Web server.

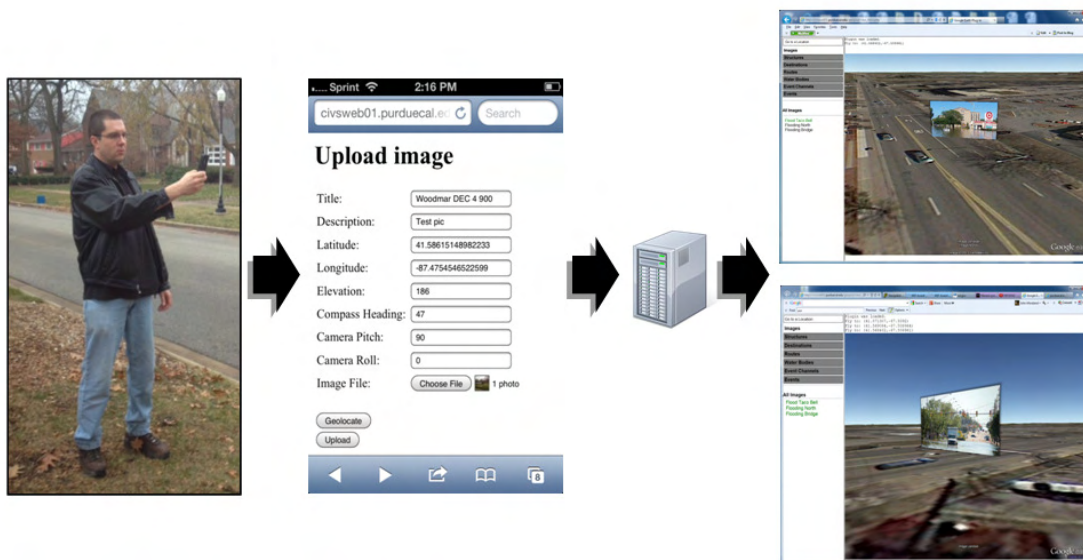


Figure 6. Real-time update of disaster-related photos from mobile devices

To test the developed DMCS system, historical flood data were acquired from the FEMA report on 2008 Northwest Indiana flood case. The blue area in the Figure 7 left image is the flooded area along the Little Calumet River in Munster. The flooded area was imported to the HPC and Web-based visualization system to compute the optimal resource distribution route.

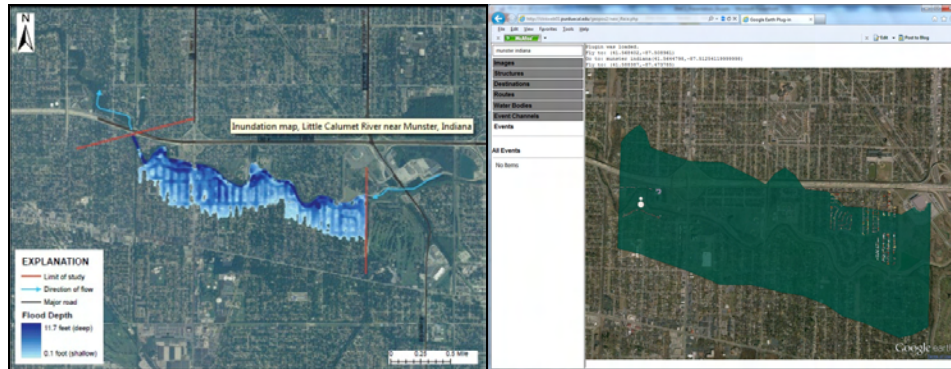


Figure 7. 2008 flood data in Munster, Indiana

The flooded area rapidly changes during a disaster. The high performance computing cluster is capable of dynamically update the optimal resource distribution route with the changes in the flooded area. Figure 8 shows the expansion of the flooded area and resource distribution routes to the affected households over the time.



Figure 8. Real-time update of rescues route with the changes in disaster area

The Web-based, 3-D visualization interface was developed in response to two specific criteria: first, that disaster resource requests and locations must be visible to users of the system, and secondly, that users of the system must have control of the type and quantity of information displayed in the user interface. The new elements of the system were designed to be backward compatible with previous system considerations. An illustration of a typical usage scenario follows: A remote user opens the visualization interface in a HTML 5 compliant Web browser. The interface presented contains the main display surface based on 3-D Google Earth. A number of sub-panels located around the main display surface allow the user to enable or disable elements visible within the Google Earth environment and view information about each element being displayed.

### **Project-Based Learning for Graduate and Undergraduate Education**

Since 2010, more than 30 PUC graduate and undergraduate students have participated in this research. The authors worked closely with graduate and undergraduate students in developing a Web-based disaster management and communication system and distributed graph partitioning algorithm in Purdue University Calumet HPC Cluster for disaster decision support. During the project, the students acquired hands-on experience in grid computing as well as interactive visualization techniques. Students developed a HPC-based disaster decision support system to compute the effective resource distribution strategy and prioritize the rescue areas by utilizing disaster specific geospatial information system. Three graduate students completed their master's theses based on this project, and more than 10 undergraduate students completed their senior design project based on this research.

### **Conclusion**

This paper described the development of a Web-based, 3-D visualization and cluster computing model for the disaster management and rescue effort. The system is portable and self-supporting with laptops or handheld devices that can be carried into a disaster area. The components of the system could be quickly and easily transported to any disaster terrain site. After deployment, the system could be operational and functional within just a few hours. In addition, utilization of freely available software packages proved effective as a low-cost solution to the problem. Disaster management systems are currently not installed as a consistent solution across the nation. This research will lay a foundation for disaster preparedness, management and decision support system for the local and federal government. Integration of 3-D geospatial visualization and middle-sized computational cluster with disaster DMCS has the potential to provide innovative disaster management solutions to the local and federal government agencies.

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## **Biographies**

GE JIN, D.Sc, is currently an assistant professor in the Department of Computer Information Technology and Graphics at the Purdue University, Calumet. He teaches computer game development, computer graphics and animation, as well as computer information technology courses at the undergraduate and graduate levels. Prior to joining Purdue University, Calumet, he was a postdoctoral research scientist at the George Washington University, Department of Computer Science. Professor Jin holds a B.S. in Computer Science from Peking University, China, and an M.S. in Computer Science from Seoul National University, South Korea. He earned his Doctor of Science degree in Computer Science with a concentration in computer graphics from the George Washington University. His research spans the fields of computer graphics, virtual reality, computer animation, medical visualization, and educational game development.

GERALD DEKKER obtained his master's degree in Computer Science from Purdue University Calumet in 2012. He currently works at the Purdue Calumet Center for Innovation through Visualization and Simulation as a post-graduate researcher in virtual reality and computer graphics.

JOHN MORELAND is senior research scientist at the Center for Innovation through Visualization and Simulation at Purdue University, Calumet. He has MS in Technology, BS in Computer Graphics Technology, and is currently working on a PhD in Technology focusing on the application of mixed reality technologies to education.

BARBARA JEAN NICOLAI is currently an associate professor in the Department of Computer Information Technology and Graphics at the Purdue University, Calumet. Her research focuses on Disaster Management Communication System that supports any natural or man-made disaster, including pandemic, flood, earthquake. Her research interests include Database modeling and architecture, specifically the study of entities and their correlation with each other, a database perspective of women in technology, and a database perspective of women and children's health care.

CHUCK WINER is currently a professor in the Department of Computer Information Technology and Graphics at the Purdue University, Calumet. His research interests lie in the shared database utility of the indigent population of the United States. Specifically, those families and individuals in Northwest Indiana and how they can best be serviced in their needs. Of continuing interest is how heterogeneous and homogenous database data may be

utilized by both private non-profit organizations and government agencies. He has published and presented papers on this subject at national and international conferences.