3rd Specialty Conference on Disaster Prevention and Mitigation
3e Conférence spécialisée sur la prévention et la mitigation des désastres naturels

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Supply Chain Pre- and Post-Disaster Management Using Visual Analytics: The Case of Canada-U.S. Border Crossings

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Abstract: In the wake of 9/11 terrorist attacks, the high sensitivity of supply chain to traffic disruptions and its vulnerability to total collapse has evolved to one of the main concerns of manufacturing industries. Major traffic disruption could be caused by internal (e.g. labor strike) or external (e.g. storm) risks. External risks can in turn be categorized into manmade (e.g. terrorist attacks) and natural (e.g. earthquake or hurricane) risks. Visual analytics is an agile decision method widely used as a pre- and post-disaster management tool that helps mitigate risks and manage emergencies before, during and after disasters. Using this method, managers can better identify bottlenecks and congestions in supply chain systems and, thus, reduce disaster impacts on the performance of the supply chain. This paper investigates the potentials of visual analytics as a robust solution for pre- and post-supply chain disaster management and for mitigating supply chain disruptions. Several examples related to Canada-U.S. border crossings are used to illustrate the proposed approach.

1 Introduction

Supply chain management (SCM) is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores. Merchandises are produced and distributed with the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements (Simchi-Levi & Kaminsky, 2008).

SCM is sensitive to uncertainty factors, which can collapse the industry that the supply chain is servicing. Hazards in supply chains can be categorized into internal and external hazards. Internal hazards are hazards related to and caused by market environment. Uncertainties in the market result in internal hazards. Shortage in row materials, the market demand fluctuation, competitors' strategies, large-scale network problems, labor strikes and Bullwhip effect are major internal hazards of the supply chain systems. In addition, uncertainty in supply chains has other reasons that are not related to the market. These types of causes are called external hazards. Natural disasters, terrorist attacks, political decision-making can be categorized as external hazards. Although external hazards are much rarer than internal hazards, their financial loss can be much more severe.

Supply chain disruptions are costly, and it is important to understand how a disruption affects a supply chain in order to develop appropriate strategies to reduce impacts. A disruption is defined as an event that interrupts the material flows in the supply chain, resulting in an abrupt cessation of the movement of goods (Wilson, 2007). There are many examples of disruptions in supply chain systems.
Although supply chain security has always been one of the main concerns of companies, interest in designing disaster-resilient supply chains has increased since September 11, 2001. Literature reviews show that despite the considerable amount of attention that many companies have paid to the design of hazard-resilient supply chain systems, the impact of external hazards has not been considered in detail compared to that of internal hazards.

Visual analytics is the science of analytical reasoning facilitated by visual interactive interfaces (Thomas, 2006). Visual analytics or visual data mining can be used as a tool for reducing supply chain managers' response time to disasters and accelerating their reaction in emergency cases by providing better data visualization of the causes and effects of disruptions. Visual analytics not only helps in the immediate decision-making, but also it plays an important role in pre-disaster planning by analyzing available data to understand patterns and bottlenecks for mitigating risks and potential conflicts.

The current paper investigates the application of visual analytics for supply chain emergency management with the following objectives: (1) identifying the vulnerabilities of supply chain systems, (2) minimizing the cost loss of the supply chain by designing disaster-prepared supply chains, and (3) considering the alternatives for supply chain post-disaster management.

2 Literature Review

2.1 Disaster management

Most of the research on disaster management is outside the supply chain area. Many research papers in the area of disaster management are related to public services in terms of disasters' loss and response time of government and insurance companies (Kunreuther, 1996).

Some research has been done on specific disasters such as hurricanes, earthquakes, floods and fires (e.g. Iakovou and Douligeris, 2001; Witt, 1997; Warwick, 1995; McHugh, 1995). Iakovou and Douligeris (2001) have presented the development of IMASH, an Information Management System for Hurricane disasters. The developed system can offer support for a wide range of hurricane-related activities, i.e. activities during or just before a hurricane strikes, and post-disaster response and restoration activities.

Other studies look at the disaster management from sociological perspective. As an example, Drabek and McEntire (2003) have provided a comprehensive literature review about disaster sociology. They have also emphasized the importance of human behavior during disasters.

Many studies suggest plans, guidelines or policies for disaster management (Fischer, 2000; Perry and Lindell, 2003). For instance, Perry and Lindell (2003) have reviewed the concepts of community preparedness and emergency planning, and their relationships with training, exercises and written plans. They have provided a series of 10 planning process guidelines that can be applied to natural and technological disaster preparedness and any environmental threats.

2.2 Supply chain between Canada and U.S.

Emergency management of Canada-U.S. border crossings is extremely important in the case of natural or man-made disasters. In a report about Canada-U.S. relations prepared by Congressional Research Service (Ek, 2007), the issue of the ability of the transportation infrastructure to cope with increased safety and security measures has been raised. This report also emphasized the need for better emergency management for border crossings. Therefore, collaboration between emergency preparedness planners and responders on both sides of the border should be coordinated to insure minimal interruption of traffic and secure and safe operations of the crossings. While this would have different impacts for various crossings, in all cases, it would have an impact on lives, bordering economies, trade and social services, as well as the public's confidence in road infrastructure. The report by Canada Senate Committee on National Security and Defence (CSCNSD, 2005) mentioned that Canada Border Services Agency (CBSA) needs a streamlined system that links all unconnected border posts with real-time access to the customs mainframe. Therefore, communication and collaboration management among all these stakeholders is essential.

International bridges and tunnels have a giant role in the logistics of supply chains. These crossings have proven to be significantly important to the economic ties between Canada and the U.S. There are 33 international bridges and tunnels between Canada and the U.S. with various governance regimes (Crown corporations, federal/state/provincial agencies, joint authorities, private companies). These different regimes do not necessarily have obligations to report on operations and maintenance to the Government of Canada. For example, the Ambassador Bridge, the Blue Water Bridge and the Peace Bridge altogether carry approximately 50% of all the truck traffic (36,000 trucks) at Canada-U.S. land and bridge-tunnel border crossings. Over 30% of passenger and other vehicle traffic make use of the Ambassador Bridge, the Peace Bridge, the Detroit-Windsor Tunnel and the Blue Water Bridge. Traffic volumes at other international bridge and tunnel crossings are not as significant; however, the necessity of having an international link in some of the smaller or remote communities is of great importance for the local economy (Canada Gazette, 2008). Figure 1 shows traffic volumes during 2006 to 2008 for some international bridges between Canada and the U.S. The number of trucks crossing the border at these ports illustrates their importance, which implies giant negative impacts on supply chain systems in case of natural disasters or terrorist attacks.

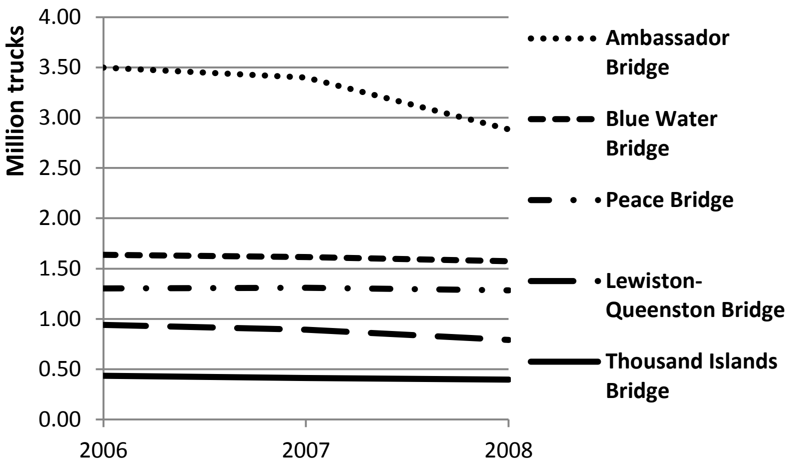


Figure 1. Annual Traffic Volumes (Trucks), Public Border Operators (PBOA, 2013)

Figure 2. Auto Industrial Region near the Crossings between Ontario and Michigan/ New York States

Industry groups have stated that, in the event that a crossing is compromised, in a matter of several hours, production lines would begin to stop in various parts of Canada and the U.S. The free flow of goods through international bridges also significantly affects exporters, importers and consumers because of the strong economic ties between Canada and the U.S. For example, commercial traffic between Ontario and Michigan/New York is mainly serving the auto industry Just-in-Time (JIT) supply chain. Figure 2 shows one of the important areas near the border, which has many auto manufacturers near the crossings. Hence, if one port of entry (PoE) is barred due to a disaster, many auto manufacturers will face logistics problems in their SCM.

The Border Information Flow Architecture (BIFA) has been a collaborative effort in involving stakeholders from both sides of the border from both the public and private sectors. BIFA has been leaded by Transport Canada and U.S. Department of Transportation (The Canada-United States Transportation Border Working Group, 2005). The main role of BIFA is to provide policies, protocols and a system for different organizations, which are involved during emergencies.

3 Methodology

This paper proposes a visual analytics approach for supporting supply chain disaster management decision making. The investigated model collects real-time and historical data, applies visual analytics methods and graphical interaction methods with the system to visualize the results in a Geographical Information System (GIS). The model has three main components as shown in Figure 3:

(1) Data collection and management is a preliminary part in which the required data from different sources are gathered in a database. More details about the data sources and databases can be found in Section 4.

(2) Visual analytics toolbox: The second step is using visual analytics methods to create cause and effect relationships among the collected data. These relationships cannot be recognized from the raw data stored in databases without using data analysis. Visual analytics is used in this research due to its user-friendliness, quick response time and agility. The main purpose of this toolbox is to use a set of common data analysis tools to visualize the results of queries in a combined temporal and spatial manner, so the users who are not specialized in data analysis can make real-time decisions in emergency situations. Visual analytics can be categorized in statistical and algorithmic methods. The statistical methods such as factor correlation, regression analysis and design of experiment aim to find relationships and explain the impact of internal and external risks on the SCM.

(3) Intuitive graphical user interface (GUI): The results of the previous component can be shown in this step. Using dynamic time based charts and visual clustering are some examples of visualizing the results of the analysis. Another example is interactively defining paths and barriers, which can facilitate finding the shortest path and rerouting.

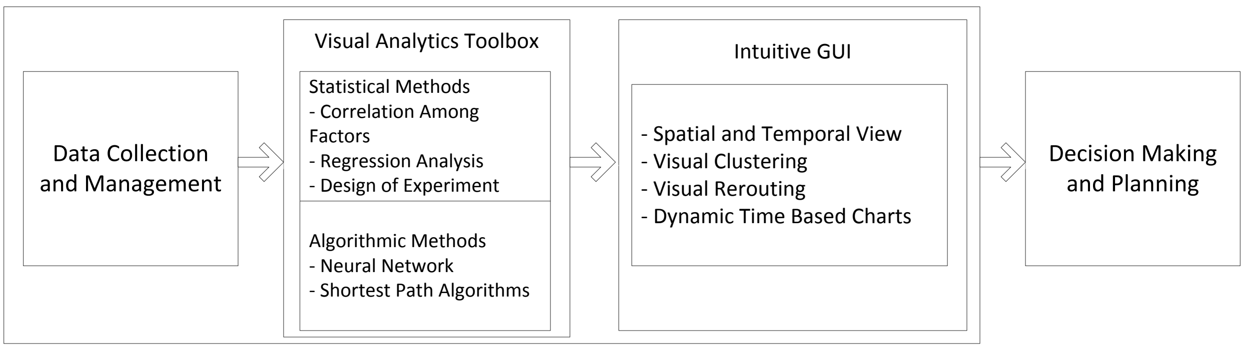


Figure 3. Proposed Methodology

4 Implementation

4.1 System Architecture

Figure 4 shows the proposed system architecture, which has three main parts: the client, the GIS server and the graphical user interface (GUI). The client is a web browser to connect to the server. The proposed system should be accessible without any extra application installation. Therefore, due to the server-side implementation, users can connect to the system with any browser after authorization. The data is secured and its accessibility is limited to authorized users. The main part of implementation is on the server side to query the database using the GUI and to visualize the results on the client. Based on the user request, the system connects to the server, applies the database query, and visualizes the results.

Four types of data are used for visualization: (1) GIS data represent the base maps for the visualization and spatial processing; (2) Historical data provided by governmental organizations are stored on the server; (3) Various web services provide different types of real-time or semi-real-time data that are useful for managers; and (4) At every PoE, some cameras are installed to observe current traffic conditions. Users can connect to those cameras through the GUI and observe the PoE in real time.
All functions are designed on top of the ArcGIS platform. For the software implementation, ArcGIS server (ESRI, 2013) offers three web Application Development Interfaces (APIs) with similar functionalities: JavaScript, Flex and Silverlight. We chose Silverlight as the development API because of its better compatibility with the widely available Windows operating system. The steps of the implementation are shown in the Figure 5.

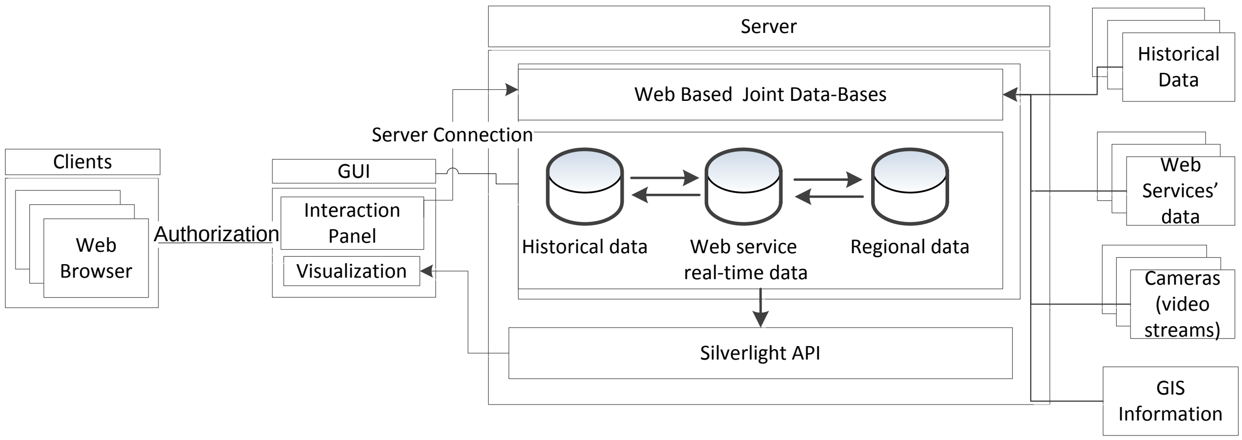


Figure 4. System Architecture

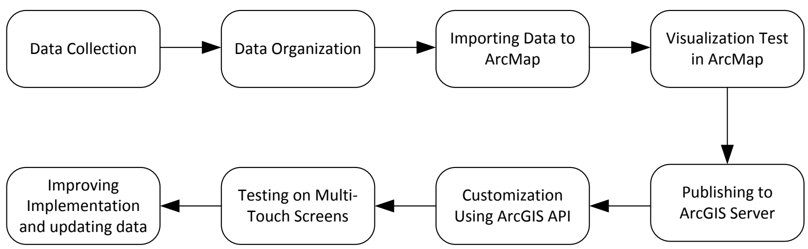


Figure 5. Steps of the Implementation

4.2 Databases

The required data can be categorized into two types: static and dynamic data which are described in following.

4.2.1 Static data

(1) Information of PoEs including land, air and marine ports (Locations and names, hours of operation, phone numbers, etc.) which are useful during emergency cases for the responsible departments to contact each other in an acceptable time period.

(2) Land traffic data (disaggregated by the PoE and the month duration)

- Canada Side: Statics Canada (CANSIM, 2012): These data are available starting from 1972 and include all the vehicles entering Canada (i.e., U.S. vehicles, Canadian vehicles) based on the mode of transportation (i.e., automobiles, trucks, others) and the length of stay (i.e., same day, one night, two or more nights).
- U.S. Side: Research and Innovative Technology Administration (RITA, 2012): These data are available starting from 1995 and include all the vehicles entering the U.S. based on the mode of transportation (i.e., personal vehicles, personal vehicle passengers, trucks, loaded/empty truck containers, trains, loaded/empty rail containers, train passengers, buses, bus passengers, pedestrians).

The main issue of these data is their heterogeneous attributes and formats due to their different sources, which makes it difficult to combine the data from the related to each PoE.

(3) Mapping of ports of origin (where travelers or goods may be originating).

4.2.2 Dynamic and real-time data

(1) Border wait times: CBSA website lists wait times for selected PoEs (CBSA, 2013). Some provinces (e.g. British Columbia) have their own Web sites (U.S. Customs and Border Patrol & Canadian Border Services Agency, 2013). The U.S. Customs and Border Protection has its own site which provides the wait time for pedestrians, commercial and passenger vehicles. It also provides the number of the lanes (gates) (Border-lineups Website, 2013).
(2) Road conditions: For example, the Quebec Ministry of Transport Web page indicates road conditions and construction work in real time (Ministry of Transport of Quebec, 2013).
(3) Traffic conditions: For example, the system can connect to installed CBSA cameras at PoEs to observe current traffic via video. Similar Web application is available to observe the cameras of the Quebec Ministry of Transport (Ministry of Transport of Quebec, 2013).
(4) Weather information and weather alerts near PoEs (e.g., Weather-for-you-website, 2013)
(5) Amber alerts near PoEs (Roayal Canadian Mounted Police, 2009).
(6) Social media postings relating to PoEs.

5 Case Studies

5.1 Case study 1: Visualization of traffic historical data

Using charts can facilitate the comparison of different attributes for analysis. Figure 6 shows the number of trucks traveling from Canada to U.S. and vice versa using historical time series data. A time slider at the bottom of the figure indicates the year and the month.

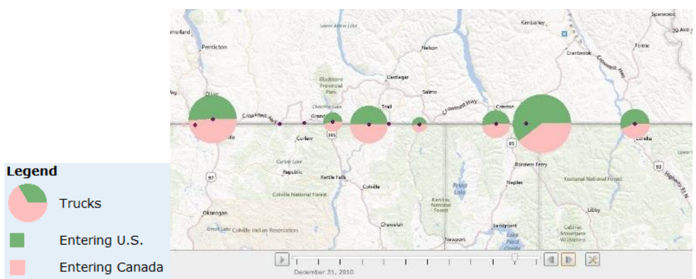
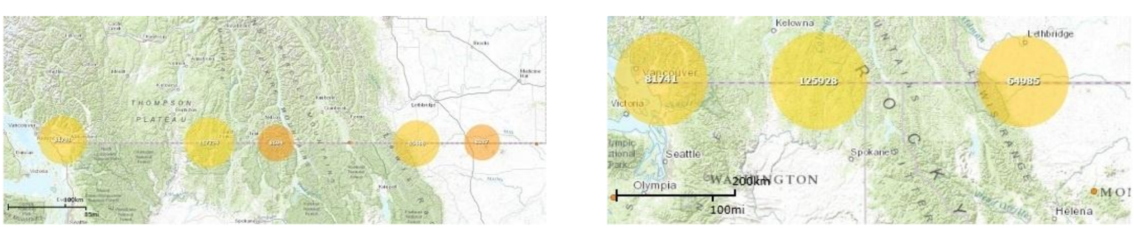


Figure 6. Number of Trucks Travelling from/to Canada to/from U.S. in December 2010

5.2 Case study 2: Clustering based on map scale

Clustering is a common technique for statistical data analysis to compare different regions according to their values. As an example, Figure 7 indicates the number of trucks that cross the border in the British Columbia and Alberta provinces. Figure 7(a) shows the pie charts representing the number of trucks that cross the border with large scale clustering. Figure 7(b) shows the same region after zooming out. The circles are clustered based on the new scale.



(a) (b)

Figure 7. Clustering the Number of Trucks Crossing the PoEs Based on Map Scale

5.3 Case study 3: Visualization of real-time data

Many governmental or non-profit organizations use web services to publish real-time data via the Internet. However, when the published data is in the format of Extensible Markup Language (XML) files, it is necessary to parse these files to extract the information. Rich Site Summary (RSS) technology is a common solution for real-time data collection, which allows updating the data frequently from web services. We used RSS to read XML published data from web services and convert them to information that can be used in our analysis and visualization.

As an example, U.S. Geological Survey's (USGS) Earthquake Hazards Program provides a web service to report earthquakes and to assess earthquake impacts and hazards. This web service publishes real-time earthquake data that can be obtained via RSS. Figure 8 shows the earthquakes that occurred during the past seven days, which are accessible via a web service that is updated every 10 minutes.

Figure 8. Earthquakes for the Past Seven Days with Magnitude more than 2.5 in Richter Scale, (USGS)

5.4 Case study 4: Rerouting

Transportation networks should have redundancy in case a link is cut. For example, the new structures proposed by CSCNSD (CSCNSD, 2005) have to be built to assure adequate separate and secure infrastructure redundancy in case of a disaster on the Ambassador Bridge at Windsor-Detroit. The Government initiated a process to examine possible alternative crossings either north of Lake St. Clair along the Ontario-Michigan border or along the Ontario-New York border.

In case of an emergency, some PoEs may be partially or fully closed so the managers need to prepare an alternative road to reroute the traffic. Figure 9 shows an example of rerouting after closing the Windsor-Detroit Tunnel and the Ambassador Bridge.

(a) (b) (c)

(a) Shortest Route between Detroit and Windsor through the Tunnel, (b) Shortest route after closing the Tunnel through Ambassador Bridge, (c) Shortest Route after Closing the Tunnel and the Bridge

Figure 9. Routing and Rerouting after Closing PoEs

5.5. Case study 5: Retrieving video from PoE cameras

There are some cameras installed at each PoE to observe traffic and other conditions. We developed an application to connect to a Sony web-based camera (SNC-ER580) and to control it over the Internet. The designed GUI is shown in Figure 10.

5.6. Case study 6: Interaction with the system with multi-touch screens

Multi-touch user interface is proposed to interact with the designed system. We are testing on four multi-touch HP LD4200tm, 42 inch screens that are synchronized for displaying information as shown in Figure 11.

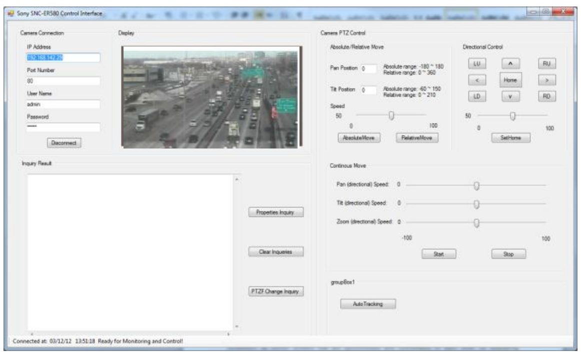


Figure 10. GUI for Controlling Cameras

Figure 11. Using Multi-touch Screens to Interact with the Developed System

6 Conclusions and Future Work

This paper proposed a new approach for supply chain pre- and post-disaster management using visual analytics and focusing on the case of Canada-U.S. border crossings. Using this approach, managers can better identify bottlenecks and congestions in supply chain systems and, thus, reduce disaster impacts on the performance of the supply chain. Several examples related to Canada-U.S. border crossings are used to illustrate the proposed approach.

Future work will continue to investigate the different visual analytics and interaction methods that can be used in the context of the current research. Additional data related to SCM (e.g. origin and destination of trucks, alternative suppliers, number of trucks) should be added to the database in order to apply the proposed method.

Acknowledgment

The authors would like to extend their thanks to Mr. Alex Guindon and David Macaulay for providing information and GIS data for the case studies. Also, the authors would like to thank Miss. Mahsa Rafiee, graduate student and research assistant at Concordia University, who developed the application for the cameras surveillance. Finally, the authors would like to thank the support from Canada Border Services Agency and the discussion with Mr. Paul Loo and Ms. Kathryn Mills.

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