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# Improving supply chain disaster preparedness

Supply chain  
disaster  
preparedness

## A decision process for secure site location

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195

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### Abstract

**Purpose** – Terrorist attacks, natural disasters, and regional power outages from the past several years have all highlighted the low levels of disaster preparedness that exist at many firms. Supply chain disruptions caused by external events can have a significant financial and operational impact on firms not properly prepared. Therefore, improving disaster preparedness in supply chains is critical. One critical component of disaster management planning in supply chains is the storage of emergency supplies, equipment, and vital documents that will be needed in times of crisis. The goal of this paper is propose a decision process for establishing an efficient network of secure storage facilities that can effectively support multiple supply chain facilities.

**Design/methodology/approach** – The authors use the five-stage disaster management process for supply chains as the framework for a proposed decision process for secure site locations. The decision process combines recommendations from FEMA's *Disaster Management Guide* with a set cover location model from the location sciences field to help establish a network of secure site locations.

**Findings** – Storing emergency supplies at every supply chain facility can be cost-prohibitive. In addition, gaining access to emergency supplies that are stored at each facility may be prevented by some external events, such as fires or hurricanes, because items stored on-site are destroyed or are inaccessible. Therefore, the proposed secure site selection process can balance operational effectiveness and cost-efficiency by identifying the minimum number and possible locations of off-site storage facilities.

**Originality/value** – One important contribution of the paper is that it combines recent recommendations for disaster preparedness in supply chains with established models in location sciences research to create an interdisciplinary solution to an important supply chain issue. Even though the storage of important documents, equipment, and materials is only one small part of disaster management planning, it is hoped that this model will do its share in helping supply chains become better prepared for the next emergency.

**Keywords** Supply chain management, Contingency planning, Storage, Disasters, Emergency measures

**Paper type** Research paper

### Introduction

Interest in supply chain security has never been higher since the terrorist attacks of September 11th, 2001. This is evidenced by the increased resources that industry and government have been committing to cargo security (e.g. the Container Security Initiative (CSI)), tracking and routing of materials (hazardous or otherwise), import/export precautions, and risk management (e.g. newly-devised programs such as C-TPAT, FAST, and BASC). However, supply chain disruptions can occur from many other non-terrorist related events as well, including labor strikes, natural disasters, and power grid outages. Ripple effects from these external events on supply chain operations can be significant. For example, federal spending on ten separate



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natural disasters in the late 1990s ranged from over \$600 million to \$7 billion per event (Helferich and Cook, 2002), and these figures do not include the costs to companies affected by the disasters. And while the post September 11th era has justifiably led to increased attention on securing the supply chain, events that can significantly disrupt the continuity of supply chains will never be completely eliminated.

The most important lesson from the past few years of terrorist attacks, dock strikes, regional blackouts, and natural disasters may be that firms finally realize the need to develop effective emergency response strategies within their supply chains to react and recover from inevitable supply chain disruptions. In the past, firm performance on disaster preparedness was poor, as noted by Helferich and Cook (2002, p. 2):

The typical large US corporation has given disaster preparedness a low priority because of competing business issues, the lack of recognition of the true level of disaster vulnerability, and an assumption that the service and government sectors are responsible for disaster response. The threat of more terrorist attacks, increasing global unrest, and higher occurrence of major natural disasters creates a powerful motivation for management to explore the processes to secure the performance of the commercial supply chain.

As firms begin to pay more attention to supply chain security and the development of comprehensive disaster management processes, little help can be found in the logistics and supply chain management literature. Instead, logistics managers must rely upon existing planning models in the disaster management literature and emergency preparedness advice offered by federal and state government agencies, adapting the information to fit supply chain settings (Helferich and Cook, 2002). And while much of the recent attention in the business and trade press has been spent on securing the supply chain against future terrorist attacks or other internal security threats, it is also critical that firms become more proactive in their disaster planning and work at developing the coping and recovery skills that will be required to maintain supply chain continuity during future, inevitable times of crisis (Helferich and Cook, 2002).

For example, one important recommendation made by the Federal Emergency Management Association (FEMA) in their *Emergency Management Guide for Business and Industry* is that firms should store critical documents, emergency supplies and equipment, satellite phones, medical equipment, water, clean-up supplies, portable lights, inventory and equipment records, and generators, in a safe and secure location (Helferich and Cook, 2002). However, storing a set of these items at every distribution center, manufacturing facility, transportation hub, and office within in the supply chain can be cost prohibitive. In addition, gaining access to these items during an emergency may be prevented in some instances because of the nature of some external events (e.g. fires, explosions, hurricanes) that could destroy the emergency supplies stored at the facilities directly affected by the disaster.

Given these cost and risk constraints, the goal of this paper is to provide a site selection model for emergency resources that can be utilized by logistics managers and supply chain continuity teams to determine the appropriate number and locations of storage areas for critical emergency equipment and supplies. The importance of balancing cost efficiency with operational effectiveness in emergency planning and response has been demonstrated in previous research. Charles (1995) argued that projecting costs for disaster planning and response scenarios and working to make these costs more efficient was a critical aspect of effective disaster planning to ensure

that available resources matched the requirements of the disaster plan. An application of this philosophy is sought in the model proposed in this research. The proposed model for secure site locations will enable firms to provide each facility in their supply chain with quick access to the emergency materials and equipment needed for effective disaster response, while minimizing the total cost for the supply chain.

This paper will begin with a review of recent research in the disaster management academic literature and at disaster research centers. After a review of the scant academic research in the logistics literature on securing the supply chain and disaster management planning, a model will be proposed for secure site location of critical documents, equipment, and materials recommended by FEMA for effective disaster preparation by businesses. In addition, the viability of the proposed secure site selection process will be demonstrated using a hypothetical example.

## Background

### *Review of disaster planning literature*

As expected, most of the academic research on disaster management and emergency preparedness can be found outside the logistics and supply chain arena. Much of the research in the disaster management field is targeted to public servants, government agencies, and insurance firms charged with responding in times of crisis and has traditionally focused on crises such as hurricanes, earthquakes, flooding, and fires (e.g. Iakovou and Douligeris, 2001; Witt, 1997; Warwick, 1995; McHugh, 1995). However, the models and guidelines in this research field can easily, and appropriately, be applied to disaster management planning by firms within supply chains that have been awakened by recent world events and confronted with new government regulations on supply chain security (Helferich and Cook, 2002).

One recent study used a comprehensive literature review to evaluate the sociological aspects of the disaster literature. Drabek and McEntire (2003) conducted a literature review to evaluate the impact of emergent phenomena in disasters and the coordination of multiple organizations responding to crises. They concluded that much of the theory posited by pioneers of disaster research have been supported by research in the past 15 years. In addition, research has found that humans behave in a compassionate manner during disasters without much panic or anti-social behavior immediately after the crisis (e.g. Fischer 2002). The authors also reinforce the importance of examining human behavior during disasters and the need to conduct more sociological research in this area because human behaviors are critical to any successful response to future disasters (Drabek and McEntire, 2003).

Several studies in the disaster literature offer models, guidelines, and planning procedures for the development of effective disaster plans. A representative, but not complete, review of relevant research in this area for logistics managers includes a study by Joseph and Couturier (1993) where seven management activities are proposed as necessary to support effective disaster planning. These activities included arranging in advance with outside organizations necessary agreements and developing contingency plans for each part of the disaster process. In a survey of local and city governments, Kartez and Lindell (1987) found a positive relationship between the amount of disaster preparedness meetings by city officials and the adoption of sound disaster practices. Fischer (2000) provided a thorough review of mitigation and response planning for bio-terrorism. Dalhammer and D'Souza (1997)

identified the keystones of disaster preparedness for businesses. And finally, several recent efforts have looked at the interactions between disasters and disaster response groups (e.g. Harrald *et al.*, 2002; Webb *et al.*, 2000).

One research stream in the disaster literature focuses on improvements to disaster training, preparation, and planning. For example, Paton (2003) recently recommended the inclusion of stress risk management in the training of managers to improve the effectiveness of performance during all phases of disasters. Because actual opportunities for managers to acquire disaster training experience from real events are rare, Paton and Jackson (2002) recommend the use of assessment centers that simulate disaster scenarios so that emergency response personnel and managers develop the critical decision-making and team skills needed to perform effectively during disasters. Finally, in response to the growth of new emergency response and disaster training programs, Alexander (2003) recently proposed the development of standards for disaster training so that minimum standards of quality are achieved.

#### *Disaster research centers and logistics trade organizations*

Since September 11th, university research centers and logistics trade organizations have responded with workshops and conferences on supply chain security and natural disaster mitigation, preparedness, and the associated response and recovery mechanisms. Until recently, the intended target audience for much of this research has been local and state governments and those agencies called into action at times of crisis (Helferich and Cook, 2002). However, there has been an understandable increase in the attention paid to disaster management by logistics managers based on lessons learned from the September 11th attacks and regional power outages in 2003.

After studying the aftermath at ground zero for several months, Tricia Wachtendorf of the Disaster Research Center (DRC) at the University of Delaware re-stated the importance of planning, adaptability, and improvisation in disaster management, especially for first responders (Wachtendorf 2002). Even before the recent terrorist attacks, Michael Lindell of the Hazard Reduction and Recovery Center (HRRC) at Texas A&M University cited an increased need for "hazard mitigation, emergency preparedness, and disaster recovery" (Lindell, 1999). The Center for Supply Chain Research at Penn State University sponsored a supply chain contingency workshop in December 2001. The workshop focused on emergency management and how various companies (including UPS, Boeing, Toyota, USPS, General Motors, Ford, and Oracle) dealt with the aftermath of September 11th. The workshop emphasized how these same companies have now reengineered their supply chains because of the increased need for emergency management planning. The Columbia-Wharton/Penn Roundtable on "Risk Management Strategies in an Uncertain World" took place in April 2002. The roundtable brought together white papers (participant notes) on the management of extreme events. The Council of Logistics Management (CLM) recently commissioned a study on securing the supply chain (Helferich and Cook, 2002) and has co-sponsored seminars on supply chain security and the need for better emergency response planning. The common theme from all of these efforts is that planning for extreme events and natural disasters is not only good practice but an absolute necessity.

### *Research on supply chain security and disaster planning in logistics*

Research on disaster planning within the logistics and supply chain literature is scarce. One study by Richardson (1994) discussed the need for carriers to develop redundancy in their information, telecommunications, and energy systems as part of a strong contingency plan for unplanned disasters. A review of four top journals (*Journal of Business Logistics*, *International Journal of Physical Distribution & Logistics Management*, *International Journal of Logistics Management*, and *Supply Chain Management Review*) in logistics and supply chain management since 2001 resulted in few academic articles on disaster planning within supply chains. Lee and Wolfe (2003) have proposed using the lessons from the total quality movement to improve supply chain security. In fact, the authors argue that supply chain security can be improved using total quality management principles while simultaneously improving the productivity of the supply chain. In 2002, Sheffi discussed the impact of recent terrorist attacks on managing supply chains. Sheffi suggested that improved relationships between public and private interests will be critical in improving the future security of supply chains. He also proposed that firms will have to create more redundancies in their systems and rethink their inventory management strategies to be better prepared for future attacks.

With the support of the Council of Logistics Management, Helferich and Cook (2002) completed perhaps the most comprehensive review of supply chain security in the aftermath of September 11th. One valuable part of their management report is an annotated bibliography of disaster planning and emergency response research and articles from the previous 25-30 years. The vast majority of articles in this comprehensive bibliography come from the business trade press, research in the disaster planning and management literature, and guidelines developed by government agencies such as FEMA. The resulting white paper and research report provides managers with a thorough review of current research, offers a detailed process for development of a disaster management plan for the supply chain, and includes detailed information on resources, web pages, and government reports that can be used by managers while implementing disaster management plans.

While there is value in this recent research, it is clear from the annotated bibliography (Helferich and Cook, 2002) and a review of the top logistics journals in the past few years that there is a need for more conceptual and empirical research on disaster planning for logistics managers in the supply chain literature. In support of this need for more research, this paper proposes a decision model that utilizes location science to help logistics managers more efficiently develop a system of safe and secure locations for the storage of critical equipment and supplies that are needed during emergencies, as outlined by the disaster management literature and experts.

### **Model development and discussion**

Proper location of emergency resources within the supply chain in anticipation of a disaster or extreme event can provide tremendous paybacks during times of crisis. In other words, part of being ready for a disaster is being in the right place to start with. The problem of secure site location for disaster response equipment within the context of a just-in-case supply chain addresses this very issue. It is advocated here that the proper placement of disaster response equipment can have tremendous utility in terms



of national security, natural hazards, readiness against domestic terrorism, situations of uncertainty and risk, and the firm's bottom line.

Emergency resources need to be located in a manner as to not be vulnerable to attack. Yet, they need to be close to the areas to which they are assigned to serve. Therein lies the dilemma of the proposed research: how best to locate  $n$  emergency resources within the supply chain to best serve  $m$  areas without being vulnerable itself. To this end, this proposal is aimed at applying an analytical perspective to the problem of emergency resource location and allocation within the context of supply chain disaster management planning.

As noted, in the aftermath of September 11th, the Council of Logistics Management sponsored research on securing supply chains during times of crisis (Helferich and Cook, 2002). A large part of their research examined and summarized existing disaster management research and made recommendations to logistics managers about processes for implementing disaster management programs. The traditional disaster management process guidelines proposed by the FEMA *Emergency Management Guide for Business and Industry* typically revolved around three stages: planning, response, and recovery. Helferich and Cook (2002) have used FEMA's guide as the foundation of their suggested disaster management process for supply chain managers but have added mitigation and detection stages to provide a better fit for today's increasingly complex environment and supply chain systems. Mitigation is critical to lessen the impact of disasters on supply chain continuity and the length of disruptions. Detection has been added because many disasters or impending events can be complex and hard to evaluate. Including a detection stage as an important part of the process may increase the likelihood that a disaster is identified in a more timely manner (Helferich and Cook, 2002). Thus, after adding two stages to the foundation provided by FEMA, a five-stage disaster management process has been proposed by Helferich and Cook (2002) for supply chain managers. The stages are outlined in Table I.

The decision model proposed in this study is a first stage planning activity (anticipatory location of emergency resources within the supply chain) that directly impacts upon the fourth and fifth stages, or the ability of firms to effectively respond to and recover from critical events that threaten the continuity of supply chain operations.

### **Secure site location decision process**

The secure site location decision process proposed in this research combines the recommendations from disaster management agencies, service expectations within the supply chain, and location science into one process. The resulting model will lead to the selection of a minimum number of emergency resource locations that provide logistics managers with quick access to critical resources while minimizing the total costs spent by the supply chain preparing for future crises.

#### *Step 1. Identify the emergency resources needed at each secure location*

Helferich and Cook (2002) noted that critical documents, such as contact lists of key managers, government agencies, and non-profit organizations, area maps, and other essential checklists for managers, be stored in a safe and secure location. In addition, FEMA's *Disaster Management Guide for Businesses* outlines other critical items, such as medical supplies, generators, water, and back-up communications, that should be available during emergencies. These and other similar sources provide a starting point

Stages	Planning	Mitigation	Detection	Response	Recovery
Major steps	<ol style="list-style-type: none"> <li>1. Establish a planning team</li> <li>2. Analyze capabilities and hazards</li> <li>3. Develop the plan</li> <li>4. Implement the plan</li> </ol>	<ol style="list-style-type: none"> <li>1. Define mitigation opportunities</li> <li>2. Develop mitigation plan</li> <li>3. Initiate development</li> <li>4. Continuous improvement program</li> </ol>	<ol style="list-style-type: none"> <li>1. Develop detection plan</li> <li>2. Acknowledge warnings</li> <li>3. Evaluate and act on observations</li> <li>4. Decide on need for further action</li> <li>5. Continuous improvement</li> </ol>	<ol style="list-style-type: none"> <li>1. Implement response plan</li> <li>2. Evaluate direction and control</li> <li>3. Evaluate communications</li> <li>4. Evaluate life safety</li> <li>5. Evaluate property protection</li> <li>6. Evaluate public services</li> <li>7. Evaluate community outreach</li> </ol>	<ol style="list-style-type: none"> <li>1. Review and implement recovery plans</li> <li>2. Ensure continuity of management</li> <li>3. Maintain employee support</li> <li>4. Resume operations</li> </ol>

**Source:** Adapted from Helferich and Cook (2002, p. 53)

**Table I.**  
Disaster management  
process overview

for firms in developing lists of emergency resources to compile at each secure location. Of course, each firm should add items to their list depending on the unique needs of their firm, supply chain, or industry.

*Step 2. Identify all critical facilities within the supply chain*

The second step in the process is to identify the locations within the supply chain that will need access to emergency resources. Again, these decisions will vary by supply chain because of differences in channel design, communications systems, sourcing decisions, and inventory management strategies. It is important to recognize that this is a supply chain analysis and not firm-specific (e.g. Helferich and Cook, 2002; Sheffi, 2002). The key to minimizing supply chain disruption is to consider all firms within the supply chain. The development of a continuity team comprised of managers from all the players within the supply chain could be an effective approach to improving communication among trading partners and supporting identification of critical facilities that need access to emergency resources (Moberg *et al.*, 2003).

*Step 3. Set maximum response time goals for access to emergency resources and minimum distances secure site storage areas must be placed from supply chain facilities*

Because the storage of emergency resources will be off-site and because each secure location may service multiple facilities, a decision must be made about the maximum time it should take any facility in the supply chain to gain access to emergency resources. This constraint is important because it will be a primary factor in determining how many emergency resource storage areas will be needed to cover the whole supply chain. Managers must also decide the minimum distance each facility will be from secure site locations. Managers must balance the desire to minimize costs with the need to provide reasonably quick access to the critical materials stored at each location. Again, gauging the service level expectations of all firms in the supply chain via continuity teams can help determine an appropriate response time.

*Step 4. Use the proposed decision model to identify the number and approximate location of emergency resource storage facilities*

After the decisions in the first three steps have been made, the decision model proposed below can be used to locate appropriate sites for the storage of the emergency resources. The decision model proposed to address this planning step is based upon the well-known set cover location problem.

The set cover location problem is a prominent area of research within the location science community and a mature body of research exists on set cover location models (e.g. Toregas *et al.*, 1971; Minieka, 1970; Moore and ReVelle, 1982; Lorena and Lopes, 1994; Capara *et al.*, 2000). However, none of the available literature within the facility location domain has broached the topic of secure site location for disaster management planning.

In general, the use of a set cover location model would necessitate the use of some existing but very complex solution methods for the associated set cover location problem (e.g. Sule, 2001; Daskin, 1995; or Handler and Mirchandani, 1979). However, in addition to the usual maximum distance constraints found in the generalized set cover location problem (which are derived from the analysis in step three above), managers must also decide upon a minimum distance each secure location must be from each



supply chain facility. These constraints force solutions away (i.e. a minimum distance away) from the existing facilities within the solution space. This in turn makes the solution space much smaller and far more manageable. Furthermore, it is believed that these minimum distance constraints will yield a singular structure to the underlying network that will allow feasible and robust solutions to be found quite readily to this very hard problem (the generalized network set cover location problem is known to be NP-complete – (e.g. Megiddo and Supowit, 1984).

The proposed set cover location model is:

$$\text{Min } \sum_j X_j$$

Subject to

$$\sum_j \sum_i d(X_j, m_i) \geq \text{min distance}$$

$$\sum_j \sum_i d(X_j, m_i) \leq \text{max distance}$$

$$\sum_j a_{ij} X_j \geq 1$$

$$X_j = 0, 1 \forall j$$

where,  $X_j$  is 1 if we locate emergency resources at candidate site  $j$  and 0 otherwise,  $m_i$  specifies the supply chain facilities to be covered,  $a_{ij}$  is 1 if candidate site  $j$  can cover the demand at supply chain facility  $i$ , and  $d(X_j, m_i)$  represents the distance between secure site supply chain storage facility  $j$  and supply chain facility  $i$ . The third set of constraints in this formulation ensures that supply chain is completely covered. As noted, the oddities in this formulation of the problem are the minimum distance constraints. These constraints essentially manifest circular-shaped regions in which emergency resources should not be stored.

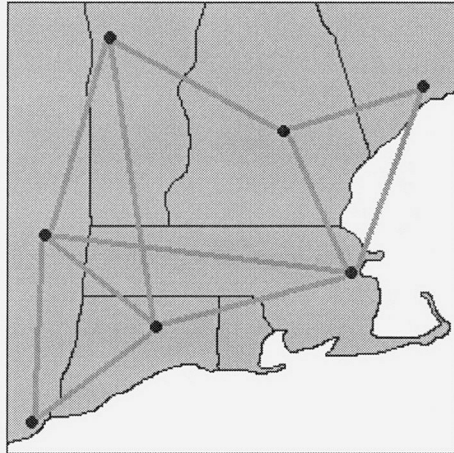
The four-step secure site decision process detailed above has been put forth to help logistics managers make informed decisions on a crucial disaster planning topic. The set cover location model presented in step four, which incorporates the response time maximums and distance minimums for safety determined in step three, will provide logistics managers with the minimum number of secure site locations needed to meet the constraints specified by management. The model will also provide managers with areas or regions where they can locate the secure site facilities and satisfy the constraints. The result is a truly interdisciplinary solution procedure to a complex problem. An example scenario is now detailed that shows the four step process and how it can help supply chain managers make informed decisions as to the location of secure off site facilities.

#### Example: four-step secure site decision process

Consider the following seven-city example in the northeast corridor: Albany, Boston, Burlington, Concord, Hartford, New York, and Portland (Figure 1). For this example, it is assumed that a critical supply chain facility is located in each of these seven cities (step two). It is also assumed that the logistics managers for this supply chain have

**Figure 1.**  
Supply chain network for  
seven critical facility  
example

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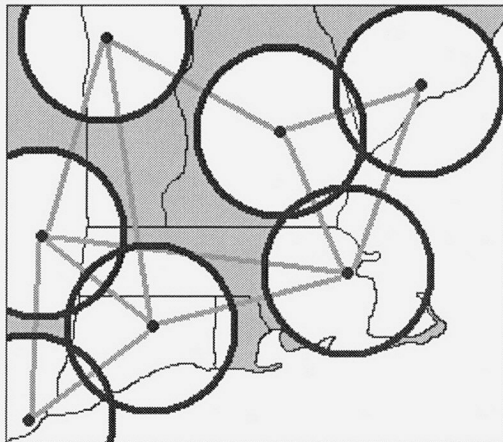
already completed step one of the process and have identified all of the critical materials, supplies, and equipment needed for each emergency storage location.

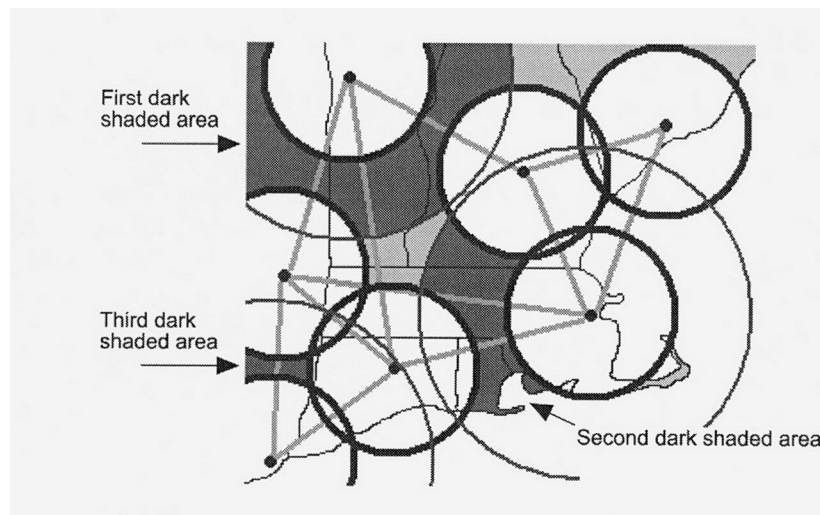
In step 3 of the process, logistics managers must set minimum and maximum distance constraints to ensure the safety of materials but also provide reasonable response times during disasters. In this example, the managers have determined that the secure site locations must be at least 50 miles away from every critical supply chain facility, but that there must be at least one storage site no more than 100 miles away from each supply chain facility. The circle around each city in Figure 2 depicts the 50-mile minimum distance constraint. No storage site can be placed within the area covered by these circles.

The fourth step of the proposed secure site location process is to use the minimum and maximum constraints and the proposed set cover model to determine the minimum number of facilities that can be employed to meet the standards set by management and to identify areas where the facilities can be located. In this seven city

**Figure 2.**  
Minimum distance  
constraints imposed upon  
seven critical facility  
example

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**Figure 3.**  
Three-facility solution to  
secure site problem

example, the minimum number of facilities needed is three. The three shaded areas highlighted in Figure 3 represent the three locations for secure facilities that meet the requirements of this example. Of course, the model only considers actual distances from facilities and does not consider the locations of roads and highways or the availability of appropriate storage facilities or locations to place emergency supplies within the shaded areas. Instead, the three shaded areas provide managers with a starting point for locations. Adjustments can be made to accommodate problems with access to roads or industrial areas to store equipment. The three-site solution demonstrated in this example saves the supply chain money by providing a solution that requires only three secure site locations instead of seven while still providing reasonably quick access to the equipment and materials needed in an emergency.

### Conclusion

Events from the past two years have forced firms to rethink and restructure their supply chain strategies in order to improve security and minimize the impact of future external incidents. While revisiting single-sourcing decisions and changing inventory management policies will likely help maintain continuity during future crises, experts have clearly demonstrated, and logistics managers have candidly admitted, that firms need to vastly improve their disaster management planning. The main contribution of this paper has been to utilize location science, which has been primarily used by logistics managers for the optimum location of warehouses or other facilities within networks, to develop a basic process for location of secure storage areas for critical emergency resources. While this process represents only one of many important decisions in disaster management planning, it is hoped this model will do its share in helping supply chains become better prepared for the next emergency.

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