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# Innovation in Demolition:
# A Case Study from the Cleanup of Ground Zero

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## ABSTRACT

The deconstruction of Ground Zero following the 2001 World Trade Center attack required massive mobilizations of equipment and personnel, all directed towards the speedy removal of 1.6 million tons of material from the site. Remarkably, this was accomplished ahead of schedule, below budget, and without any serious injury. The scale and tight time schedule of the operation made it unique among debris removal operations. Complicating matters was the need to invent new procedures and new management structures in order to meet the project's goals. This study uses data directly associated with these operations to develop a set of preliminary design requirements for information systems intended to support large-scale debris removal operations following disasters. The results of the analysis suggest that such systems should be extensible, so that they can be used within and among unpredictable organizational structures; flexible, so that they support real-time generation of new procedures; and integratable, so that they are capable of communicating with a variety of other systems.

### Keywords

Emergency response, organizational decision making

## INTRODUCTION

Due to their size, complexity and rarity, extreme events such as natural or technological disasters challenge society's capabilities both for planning and response. While information technologies and advanced modeling techniques continue to expand how society can limit and manage extreme events (Rinaldi, et al., 2001), flexibility remains crucial to an organization's ability to respond to these events (Mileti, 1999; Stewart and Bostrom, 2002). The response to the 2001 World Trade Center attack offers numerous examples of how flexibility may contribute to resilience: subway maintenance workers joined the response effort to remove obstacles and lift and move heavy debris and wreckage (Kennedy, 2001); police responded without the use of cellular phones and pagers (Rashbaum, 2001); and electric utility crews improvised a solution to widespread power outages (Banerjee, 2001). Removal of debris from Ground Zero—the area immediately in and around the Twin Towers—became a national priority immediately after the attack. Massive mobilizations of equipment and personnel were made, first to attempt to rescue any survivors and then to begin removal of 1.6 million tons of material from the site. It was soon obvious that new procedures and new organizations would be needed to conduct the operations (Langewiesche, 2002; Myers, 2003). As stated by Langewiesche (2002), "[t]he inapplicability of ordinary rules and procedures to such a chaotic environment required workers there to think for themselves, which they proved very capable of doing."

What is the appropriate role—if any—of information technology in responding to such events? This paper examines a case of engineering innovation during debris removal operations at Ground Zero in an attempt to answer this question. Task-technology fit theory is applied to the case in order to illuminate a set of requirements for information systems to support large-scale debris removal operations following disaster. Analysis of the case also suggests some of the limitations of possible limitations on the use of technology, even some of the uses suggested by the theory. The case and the background to it illustrate an observation made by Kreps (1991) and since reiterated by others(Klein, et al., 1993; Turner, 1995): that emergencies routinely create non-routine situations. Responding organizations must plan for improvisation.

## BACKGROUND

Extreme events may be regarded as events which are rare, carry uncertain consequences and have potentially high and broad consequences (Stewart and Bostrom, 2002). Responding to an extreme event is likely to require multiple decision makers reasoning and making decisions about complex systems such as physical infrastructures (Stewart and Bostrom, 2002).

Moreover, risks to life, property and the environment may supersede the controlled collection of data. Time pressure arises from such factors as the threat of building collapse and the elapsed time from the initial incident to find survivors. Risk is present in the situation as possible threats to life, property or the environment. Time pressure arises from factors such as a threat of building collapse or policy constraints on minimum response time. The impact of time pressure on decision making has only recently begun to be addressed (Marsden, et al., 2002).

The onset of an extreme event may result in mobilization of an emergency response organization, defined as an assembly of individuals who work together to manage the response to an emergency (Belardo, et al., 1984). Managing an emergency in general usually includes monitoring operations during normal conditions, selecting an appropriate procedure when planned-for contingencies arise, and revisiting the appropriateness of these procedures as other potentially disruptive events occur (Beroggi and Wallace, 1994; Beroggi and Wallace, 2000). Unplanned-for contingencies—events for which no planned-for procedure exists—create the need for the responding organization to develop and deploy new procedures in real-time. An unplanned-for contingency may have its genesis in numerous circumstances: an emergency situation may evolve, so that implemented plans are no longer applicable (Turner, 1995); it may be multi-faceted, requiring responding organizations to combine many plans in unexpected ways; it may occur concurrently with other situations, thus creating resource shortages or outages (Turner, 1995); and, finally, it may require activities that are not immediately assignable to a particular organization (Scanlon, 1994). Improvisation is one approach to responding to unplanned-for contingencies, since as stated by Kreps (1991), "Without improvisation, emergency management loses flexibility in the face of changing conditions."

Supporting improvisation in response to extreme events can mean providing training before the event occurs or decision support during the response to it. Providing guidance before the event occurs is akin to planning for improvisation, an approach that has been advocated by a number of researchers (Kreps, 1991; Mirvis, 1998; Weick, 1993; Weick, 1998). Providing support during the response entails the development of tools that are made available during the response (Mendonça and Wallace, 2002).

Studies based on field data offer opportunities for examining extreme event decision making in a rich environment characterized by complexity, uncertainty, risk and urgency (Vidaillet, 2001). These studies also enable researchers to consider how decision aids might be integrated into extreme event decision making. To this end, the following section examines one case from the response to the 2001 World Trade Center attack, focusing on how an *ad hoc* organization improvised in order to “unbuild” Ground Zero. The case is then analyzed in order to develop recommendations on information systems might (and might not) be integrated into similar response operations.

## STUDY DESIGN

This research is concerned with identifying and describing decisions about the placement and use of debris removal equipment during the first one hundred days following the attack, with particular emphasis on the role of improvisation. Two complementary perspectives are being taken. From the local perspective, some of the engineering challenges involved in equipment placement and use are being examined. The local perspective enables a detailed review of the flows and uses of data, and an exploration of how information systems might be used to support related activities. From the global perspective, we are examining how pieces of debris removal equipment (such as cranes) functioned in relation to each other and as part of a system. The present paper emphasizes the local perspective, examining one case in some detail. The analytic approach of this paper, which is adapted from prior research on task-technology fit (Zigurs and Buckland, 1998), is to describe the nature of the task then to speculate on the appropriate means of supporting it.

### Background

An *ad hoc* organization, comprised of individuals from both public- and private-sector organizations, formed to manage debris removal activities (Langewiesche, 2002). New York City’s Department of Design and Construction (DDC) coordinated the cleanup effort, with four construction companies—Turner, AMEC, Bovis and Tully—performing the actual demolition of the site. Turner worked on the World Trade Center 7 site on the north side of the complex. AMEC was responsible for the northwest corner of the foundation. Bovis handled the southwest corner with responsibility for the Marriot Hotel and the slurry wall. Tully cleaned the entire east side of the site. The Thornton-Tomasetti Group was brought in for their structural engineering expertise.

In the first few days following the attack, volunteers used whatever means were necessary to look for survivors (Langewiesche, 2002). The size and scope of the debris pile made this effort ineffective: heavy equipment was needed. Larger pieces of equipment, as shown in Figure 1, were therefore brought in from various parts of the country in order to remove the heavy debris and expose the cavities where survivors might be hidden (Langewiesche, 2002).

**Figure 1. Heavy Equipment at Ground Zero**

The cranes "came in various sizes, from the 'small' 320s (which could pull apart an ordinary house in minutes) to the oversized 1200s, monstrous mining machines rarely seen in New York, which proved to be too awkward for many uses on the pile. Most of the work was done by the 750s... Each 750 weighed in at 180,000 pounds (as compared with 140,000 pounds for the heaviest trucks, fully loaded)" (Langewiesche, 2002) p.181. Once the location for the crane was specified, a mat would be constructed on which the crane would either be assembled or onto which it would be towed (the latter case required the construction of a crane ramp).

### Data Sources

The company responsible for a sector filed daily (sometimes twice-daily) *Field Reports*. Initially, there was usually one report per sector, although as time progressed two or more teams would file reports jointly. Each report used a standard header containing the date of the meeting, sector and the names of the reporting engineers. The body of the report was usually filled in with bulleted items. A sample observation from a report was "Received and Reviewed proposed demolition plan for west façade of Tower 2 (South Tower)." The reports were hand-written. *Control Reports* were used to track the status of work across the site. The work reported in these reports included items such as security, fire suppression, building owner meetings and the like, as well as items directly related to decisions about debris removal equipment. These reports were usually typewritten.

The day-to-day location of large debris removal equipment was hand-recorded by field engineers who walked the site and annotating site plans. The annotations were then entered into AutoCAD drawings and archived as *Crane Maps*. These maps allowed engineers to view the approximate maximum reach of each crane, and therefore the areas of the site where debris could conceivably be removed by the cranes. As new equipment made its way to the site or as cranes were moved around the site, the maps were updated.

Finally, *Engineering Drawings* were used for various purposes. Some presented specifications and instructions for work (such as the placement of cranes in difficult locations). Others were used to communicate site assessments (e.g., extent and nature of damage to structures). Standard engineering design methods were used to produce the diagrams. Many drawings were made by hand; others were made using purpose-built software.

### Case Study

The force of the falling debris from the collapse of Twin Towers impacted various critical infrastructures in lower Manhattan, resulting in disruptions to many vital services (Langewiesche, 2002): electrical power was cut; landline and cellular telephone services were disconnected; ferries between New York and New Jersey changed their emphasis from commuter transport to emergency evacuation; the commuter rail line, known as PATH, was plugged at the Jersey City, New Jersey side to prevent river water from sending streams not only between this New York-New Jersey tunnel system, but the New York City subway system itself. Additionally, a number of subway tunnels which had transported commuters to the World Trade

Center area had been crushed and were unusable. The Cortlandt Street Station, which provided access to the 1/9 subway and was located directly under the World Trade Center complex, was one such station. The reopening of the line was considered a prime objective in the recovery of the transportation system.

In October, one of the site contractors proposed placing a crane over the tunnel of the 1/9 subway line in order to remove nearby debris. An engineering study was conducted to decide if damaged support beams in the 1/9 subway station tunnel could support the load of the crane. DDC, TTG, Tully and New York City Transit (NYCT) met on 29 October to discuss the issue. The crane the contractor intended to use would produce a distributed load of approximately 2000 pounds per square foot (psf). The way that the crane would be placed over the station and the mat used to distribute the weight of the crane were two variables used to determine if extra support, known as shoring, would be required in the roof of the station.

Structural concerns constrained where the crane could be placed, as well as what would have to be done to place it. Most of the station structure under consideration to support the crane was found intact. The surrounding area was filled with debris; some columns in the tunnel were buckled; and steel beams from the towers had penetrated the roof of the tunnel, thus further weakening it. The placement of the crane needed to be close to the bathtub wall in order to maximize the debris removal not only in the area of the towers, but also World Trade Center 6, north of Tower 1. Maintenance of the integrity of the bathtub was a key concern, and its compromise could have had dire results:

“[T]he waters would gush uncontrollably through the entrances to the twin PATH commuter-rail tubes—cast-iron tunnels that penetrated the slurry wall near the lowest (B-6) level, and sloped under the Hudson to a slightly lower station in New Jersey, at Exchange Place. Such a flood would perhaps not be as destructive as the cataclysmic surge that had been feared on September 11, from a rupture below the Hudson of the tubes themselves, but it would likely have the same sequential effect, spreading through the New Jersey rail connections and back into New York around Greenwich Village, pouring into the West Side subways and causing unimaginable havoc with the functioning of the city.” (Langewiesche, 2002), p.120.

The position of the crane could not be near the escalator bank that went from the mezzanine level to the station area. TTG was to design a mat to be placed under the crane to distribute its load to a value of 1000 psf. If reduction of the load by half of the initial estimate was not feasible, addition shoring to support the structure would be designed. NYCT indicated that leaving the crane in one position, providing shoring for support of 2500 psf for safety would be acceptable.

Concern about slurry wall movement is reflected in meeting notes from 29 October regarding the placement of the crane mat. Engineers noticed a slight movement (less that 2 inches) and took corrective action to prevent a collapse. The note related the change in the slurry wall to a possible imbalance against the subway wall. Additional bracing would be needed. A check list was developed to evaluate the shoring requirements for the 1/9 tunnel. Subsequent investigation of the subway on 1 November showed that the structure below the 1/9 at the PATH escalator was intact. Each beam was measured with a tape measure to provide a basis for the load calculations. An extra 1/8 inch was included to take paint layers into account. Initial load capacities were derived from standard sources. The complete engineering study was completed on 3 November.

The task then became to find a point along the tracks that suffered the least amount of damage and would provide a position that would enable the maximum amount of debris to be removed from the surrounding area. The depressed area east of the tunnel would cause poor visibility for the crane operator. Placing a spotter at a higher location to guide the operator put the spotter and other workers at a higher safety risk.

On 7 November, the engineering design for the shoring was completed. The positioning of 12-inch by 12-inch timber supports was offset by 1.5 feet to 2.5 feet from a damaged column. Steel blocks were added to the top of these timber supports. A timber mat to support the actual crane was placed on top of the support beams perpendicular to the subway tunnel. The crawler tracks for the crane to move into position were placed parallel to the subway tracks.

Once the point of greatest support was located, the next decision was gaining access to that point to place the crane. The damaged structure was collapsed and the area filled with dirt and other support material known as dunnage to create a roadway into the location. The collapsing of the damaged pieces of the tunnel was done before the crane began to move into the site. If the tunnel was not compressed, the weight of the crane could collapse the tunnel more with the added complexity of having the crane stuck in the debris. This minimized the time for removing debris before the placement of the crane and minimized the amount and cost of shoring the tunnel that was more or less left intact.

Examination of the subway tunnel showed column damage severe enough to collapse under either of the two candidate cranes, a Manitowoc 4100 or a Liebherr 1400. A plan was devised to maximize the coverage of the crane arm—thereby reducing the crane’s dynamic force—while providing for operator safety. The dunnage for the crane was made from the tower debris itself instead bringing new material to the site. To minimize the amount of shoring performed beneath the site which were the most dangerous to work in, the crane itself collapsed the unneeded parts of the tunnel to provide the access road for trucks. Debris was then loaded onto trucks for transport to a landfill.

The initial estimate to restore subway service along the 1/9 line was approximately three years. To speed restoration of service, the Cortlandt Street station was not reopened. The new stop for the World Trade Center area was the Rector Street station, several blocks south of the site. Service was eventually restored on 15 September 2002, two years ahead of schedule.

## DISCUSSION

Debris removal operations were managed by an *ad hoc* organization comprised of individuals from the public and private sectors. There is ample evidence to suggest that new procedures had to be improvised by this organization in order to meet the goals of the response (Langewiesche, 2002). In order to identify opportunities for supporting *ad hoc* and improvising organizations, a task-technology fit perspective (Zigurs and Buckland, 1998) is taken on the previous case. This perspective provides the means to classify and describe tasks according to their complexity (Campbell, 1988), and then to speculate on the technologies that are most appropriate for supporting the execution of these tasks (Zigurs and Buckland, 1998).

Campbell (1988) proposes four categories of tasks: *problem solving* tasks, which involve finding the best way to satisfy a single criterion; *decision* tasks, in which "choosing or discovering an outcome that optimally achieves multiple desired end states" is emphasized; *judgement* tasks, in which task-associated information is "conflicting and probabilistic in nature;" *problem* tasks, in which there is "a multiplicity of paths to a well-specified, desired outcome;" and *fuzzy* tasks, which include "both multiple desired end-states and multiple ways of attaining each of the desired outcomes."

Four main tasks concerning the placement of the 1/9 tunnel crane may be identified. The first task was to determine the location of the intended crane over the tunnel. The purpose of this task was to arrive at a decision on whether or not the intended crane could be placed in the desired area, whether some other crane would have to be used, or whether it might be impossible to place a crane there at all. This task combined elements of *judgement* and *decision*. An outcome had to be discovered that would enable debris removal by the crane, would preserve the structural integrity of the station and could be executed in a timely and safe manner. Inspection of the engineering drawings associated with this task suggests that information such as tunnel inspection reports was treated in a somewhat probabilistic way: engineers used heuristics to develop conservative estimates of the load-bearing capacity of tunnel columns, for example. (Note that, while the task may have been classified as fuzzy, the written record does not appear to indicate that there were multiple ways of achieving the desired outcome. Indeed, it seems that—given the time constraints—engineers were searching for the first-best alternative. Moreover, there was substantial focus on the objectives and a clear need to decide whether or not to place a crane at or near the proposed location.)

The second task, which was not completely independent of the first one, was to design the mat on which the crane would rest. Designing the mat required engineers to consider the location and estimated load-bearing capacities of the columns in the station, along with the types of material (wood, steel) that would be best-suited to the intended location. This task may be classified as a *problem solving* task, since the intended outcome was clear and there appear to have been various ways of achieving it. The third task was to decide how the crane components would be transported to the mat. A small number of alternatives were considered before the decision was made to collapse part of the tunnel and to construct a roadway. This task, like the second one, may be characterized as a *problem-solving* task, since the outcome was well-specified and various alternatives were considered. The fourth and final task was to place the crane on the mat. The archival data are insufficient to enable this task to be classified.

According to Zigurs (1998), the appropriate level of technological support for a task varies according to the type of task. Table 1, which is adapted from (Zigurs and Buckland, 1998), shows prescribed levels of support for three activities that are involved in accomplishing tasks: process structuring, support for communications, and information processing.

| | Task Categories | | | |
|---|---|---|---|---|
| *Technology* | Problem | Decision | Judgement | Fuzzy |
| Process Structuring | L | H | L | M |
| Communication Support | L | L | H | H |
| Information Processing | H | H | H | H |

**Table 1. Fit Profiles of Task Categories and Technology Dimensions**

Because task one combined elements of judgement and decision tasks, all three types of technological support might be provided in similar situations. However, a number of factors would severely reduce opportunities for introducing technology. Many of the considerations taken into account by engineers were highly technical and situation-specific. The tools for making the decision were not technologically-intensive: they included paper and writing instruments, hand calculators and simple measuring tools such as tape measures. Support was provided through technical manuals, presumably ones which were highly familiar to designers. Free-form sketching was integral to the early stages of the design. Indeed, the first sketch for this case was made on a piece of scrap paper. It may be that computer technology, while often used in standard design situations, may simply have been too inflexible and insufficiently portable to enable engineers to do their work efficiently. One possible opportunity for technological intervention may be in communication support. Engineering drawings were the *lingua franca* of the design teams, enabling the exchange of information from shift to shift using a common language. An advanced communication system might allow for drawings to be exchanged, commented upon, archived and retrieved by individuals in the office and field.

Tasks two and three, while less complex than task one, required numerous iterations of designs for the mat and for the transport procedure. The standard procedures for obtaining approval for work were exceedingly difficult to follow, in part because much of the work was highly non-routine in nature, in part because the time required to obtain the approval was not available. As such, process structuring tools would have to support the execution of processes that had recently been re-structured, often in response to conditions that could not have been planned-for. Information processing support might be directed towards enabling more rapid development of engineering drawings, and more support for conducting what-if analysis of the few scenarios considered. However, it should be emphasized that, during the response to extreme events, the amount of available skilled labor is likely to increase with event severity, perhaps reducing the need for information processing support.

## CONCLUSIONS

An examination of a case from the cleanup of the Ground Zero following the 2001 World Trade Center attack has been used to illustrate opportunities and limitation for information systems-based support for extreme event decision making. The particular focus of this work has been on debris removal operations, and what information system requirements may be generated by considering the fit between debris removal tasks and various technologies. An important conclusion of this work is that extreme events—by their very nature—create situations that could not have been planned-for. In these situations, improvised responses may be appropriate. For example, the case shows that both management structures and organizational procedures were generated in nearly real-time, sometimes simultaneously. When developing requirements for information systems to support extreme event decision making, it is therefore appropriate to consider designing computer-based tools that are intended to support the generation and execution of *new* procedures.

In conclusion, extreme events present responding organizations with complex situations having potentially widespread, catastrophic losses. They are likely to create the need for decision making by multiple organizations, so that a system to support extreme event decision making should be *extensible*, allowing for the participation of different individuals and organizations. Real-time development and deployment of new procedures is likely to be required during extreme event decision making. A *flexible* system will support organizations in deciding when and how to depart from planned-for procedures. Finally, despite the need for improvisation, decision makers in large-scale, highly technical operations will continue to draw upon and require access to models of the physical systems with which they interact. Technologies to support them must therefore be *integratable*, in that they are capable of communicating with and responding to these models.

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