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Responding to Disaster in Socio-technical Systems

Two Case Studies

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***Abstract*— This paper investigates the cognitive and behavioral processes underlying efforts to respond to disaster within complex socio-technical systems. The main focus of this work is on understanding the impact of disaster severity on these processes. Data for the study are taken from after-action reports compiled by police department personnel who took part in response operations to the 11 September 2001 World Trade Center attacks and the 19 April 1995 Alfred P. Murrah Federal Building bombing. The results of this analysis show strong evidence that hypothesizing and observing are more commonly performed in low severity events while experimenting is more commonly performed in high severity events. Additionally, behavioral improvisations are more commonly performed in high severity events. Implications of this work for theory and practice are discussed.**

Keywords—socio-technical systems, emergency response, cognition, behavior, improvisation, decision making

I. Introduction

Large-scale disaster response operations require different levels of interaction among response personnel, technical systems, response organizations and the environment. This environment can exhibit many properties that are characteristic to socio-technical systems (STSs), including interdependency among people, technical systems, and organizations. The demanding nature of response operations requires response personnel to think and act quickly, use available resources as efficiently as possible and form and disband teams in real time to achieve various goals [1-4]. Examples of creative thinking and improvised decision making in large-scale disaster response include the development of new procedures, new uses for resources, and new roles for response personnel [5, 6]. The literature on organized response to disaster illustrates the relevance of both planning and improvisation in these operations [7-12].

The objective of this study is to investigate the impact of disaster severity on cognitive and behavioral processes of emergency response personnel following two large-scale disasters. The particular focus of this study is on cognitive underpinnings of both conventional and improvised behaviors. The study therefore is intended to provide further empirical evidence to inform theories of behavior within STSs. It also provides a link between cognitive and behavioral-level understanding of how these systems recover from highly disruptive shocks, thus contributing to understanding of organizational resilience. Data for the study are taken from action reports from both 11 September 2001 World Trade Center attacks (WTC) and 19 April 1995 Alfred P. Murrah Federal Building bombing (OKC). Analyses of the data focus on identifying the effects of environmental context on cognitive and behavioral activities of police personnel during large-scale emergency response operations.

II. Background

The study presents the characteristics of STSs and discusses these characteristics in the context of large-scale disaster response operations, further discusses the commonalities of emergency response operations and STSs as well as emergent requirements of large-scale disaster response operations.

A. What is a Socio-Technical System

An STS is a system composed of social and technical subsystems, with outputs produced by joint interactions between the social and technical systems that comprise the STS [13]. STSs are in continuous interaction with the external environment, and environmental factors may impact the relationship between system inputs and outputs.

The social system consists of people, relationships among them, reward systems, and authority structures [14]. Individuals are represented within the systems in terms of their particular attributes (e.g., skills, knowledge) as well as the relations among them. Organizations may be represented by in terms of the reward systems and authority structures they offer.

The technical system consists of processes, tasks and technologies needed to transform inputs into outputs [14]. Processes and tasks might be highly interrelated with the organization. Capability and effective use of technical systems as well as the degree of fit between technology and organization might significantly improve outputs of the STS.

Environmental context of STS represents the space and time within which the STS operates. STSs are in continuous interaction with their environment. They affect the environment with their outputs and are affected by inputs from the environment.

B. Emergency Response as a Socio-Technical System

Emergency response organizations are a composition of technical systems, people, organization and environmental

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context. The section explains the elements of large-scale emergency response operations in the context of STSs.

The social system of large-scale emergency response STSs is expressed here in terms of professional responders. Tasks of response personnel are defined by the response organization they belong to. Responders' cognitive and behavioral processes might have significant effects on the outcomes of emergency response tasks. More than one organization may respond to a disaster and work collaboratively with other organizations during response operations. Scale of the disaster event may result presence of more than one response organization. Presence of more than one organization and necessity of collaborative work might increase the degree of complexity in large-scale emergency response operations.

The technical system consists of the equipment and systems used during emergency response operations. Based on the position of the personnel within an organization, available technologies and technical equipment differ. Technologies used in large-scale disaster response operations vary from carry on equipment (e.g., handheld communication devices, protective clothing, high-rise roof kits, fire extinguishers and mobile command posts) to vehicles (e.g., police cars, ladder and pumper trucks, ambulances and helicopters) and on site systems (e.g., elevators systems and ladders) to more stationary systems (e.g., command posts, radio repeaters).

During response operations processes such as evacuation plans are applied to inputs (e.g., response personnel and trapped people) to produce outputs (e.g., evacuated people). Environmental factors such as burn rate in the building may influence how these processes are applied.

The environmental context of response operations can have significant influence on required technological equipment. Use of helicopter units might be inevitable during a high rise building evacuation operation while the units might not be required during a bomb disposal operation. In this study, environmental context represents the habitat where large-scale emergency response organizations fulfill their operations. It is expected to observe significant changes in the STS in terms of operation methods and response outcomes with the change of environmental context.

One of the identifying differences of two events is the initial number of affected people at the time of attacks. In the case of WTC, National Institute of Standards and Technology estimated that 17400 ± 1180 people were inside in World Trade Center Tower 1 and 2 [15]. In the OKC case, an estimated number of 646 people were thought to have been in the building when the bomb exploded [16].

As shown in Table I, the number of casualties was approximately 2800 for WTC [15] and 168 for OKC event [17]. Based on the number of casualties, WTC may be said to have been more severe event than OKC. The increase in event severity forced responding organizations to allocate more personnel and material resources to the response operation.

TABLE I. COMPARISON OF TWO DISASTERS BY INITIAL NUMBER OF AFFECTED PEOPLE AND NUMBER OF CASUALTIES

Disaster	# of people in the building(s)	Total # of casualties
WTC	17400	2800[a]
OKC	646	168

a. Approximate number of total casualties

C. Study Framework

This section explains the cognitive and the behavioral frameworks used in the study in detail.

1) Cognitive framework: The study applies human problem solving approach to problem solving tasks during emergency response operations. As stated by Klahr and Simon [18], problems consist of an initial state, a goal state and a set of operators to transform initial state to goal state by a series of steps. The set of states, operators, goals and operator constraints is defined as problem space. The search for the path leading to the goal state is characterized as problem solving process [19].

One of the challenges responders face might be the ill definition of the problem: the initial problem state might not be very well known, the goal state might be defined vaguely and operators might not be applicable at all times due to constraints in the field. Facing such a situation, responders might be inclined to rearrange problem space in real time. They have to observe response operation conditions, identify response goals, make claims about the tasks and act to accomplish the tasks. The following definitions are used to describe these activities.

Observing refers to the act of noting and recording information. An observing event is said to occur when there is a statement about personnel and/or material resources or about the broader context of the events.

Goals refer to a desired state of the world. A *goal orienting* event is said to occur when an individual expresses a desire to attain a particular situation of state of the world [20].

Hypothesizing refers to the explanation of an observation or phenomenon. A hypothesizing event is said to occur either when there is a statement about the relationship among personnel, material or both types of resources or when there is a statement about predicted or postulated effect of allocations of personnel and/or material resources.

Experimenting refers to performing tests in order to demonstrate a known truth, examine validity of a hypothesis or determine the efficacy of something previously untried. An experimenting event is said to occur when an allocation of personnel and/or material resource is reported.

2) Behavioral framework: Webb [21] investigated underlying behavioral components of performance during emergency response in his previous work. He studied degree of improvisation of four behavioral components: procedural, status and location/facility changes and equipment improvisations during emergency response operations [21]. This study applies Webb's framework with some changes. Four dimensions of behavior used in this study are as follows:

Status component of a behavior refers to the activities of individuals that are related to the scope of their roles.

Equipment component of a behavior refers to use of tools or equipment to perform an activity.

Procedure component of a behavior refers to the way of performing an action in the current context.

*Location/*facility component involves identification of a location where an activity is performed.

Responders are said to improvise when they perform in a non-routine manner at least in one of the behavioral components. For example if a police personnel involves in perimeter patrol operation of the disaster area by using a police car, there is no improvised behavior in four dimensions of the framework. Procedure component is performed conventionally since the responder is involved in the routine task of patrolling the perimeter. On the equipment side, police car is used thus there is no novel performance in terms of equipment use. In status component, the responder is maintaining his/her conventional status as police personnel and lastly the location is a routine location for performing perimeter patrol operation.

D. Research Propositions

WTC attacks had a larger impact, destruction and severity than OKC attack. The increased severity of the event required responders to act quickly and engage in more activities (i.e., there were more people to evacuate, surroundings of WTC area was denser thus limiting emergency response operations) As a result of the scale of two events, responders in WTC area needed to 'act' more than 'think', leading to first research proposition:

P1: Hypothesizing events occur more frequently in low severity events than in high severity events.

The scale of the WTC attacks resulted with a higher number of casualties and more damage compared to OKC attack. Complexity of response operation was also higher in WTC owing to differences in the response environment (e.g., requirement of responding to tall buildings). As a result of increased response personnel activity, it is hypothesized that responders in WTC area required more observations in order to understand requirements and act, leading to the second research proposition:

P2: Observing events occur more frequently in higher than in lower severity events.

Responders are expected to fulfill more tasks when event severity is relatively higher. As expectations from responders are higher and there are relatively fewer personnel resources, more goal orienting events are expected. The third research proposition is formulated as:

P3: Goal orienting events occur more frequently in high severity events than in low severity events.

The actually or potentially higher casualties and damage associated with higher severity events are expected to lead to more 'acting' than 'thinking'. As there were more casualties and damage to the surrounding in WTC disaster, more experimenting events is expected in WTC response than in OKC response. Thus the fourth research proposition:

P4: Experimenting events occur more frequently in high severity events than in low severity events.

High severity events require organizations respond with additional personnel and material resources. On the other hand, response organizations have limited personnel and material resources. WTC response was more demanding than OKC response in terms of having relatively less personnel and material resources. Having less material resources to accomplish required actions and requirement to accomplish more tasks with available personnel requires responders to think creatively and in an improvised manner, leading to the fifth research proposition:

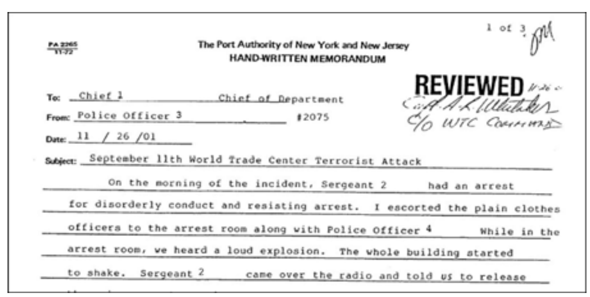
P5: There are more improvised behavioral components in high severity events than in low severity events.

P6: An exploratory research among cognitive events and behavioral components will be conducted to get further insight about interrelations of the constructs.

III. METHOD

Data for the study are taken from after-action reports submitted by police personnel who took part in the responses to these events. A random sample of thirty such reports is taken for each event. These reports were classified by their content. The total number of unique after action reports from which this sample was drawn was 168 for WTC and 41 for OKC. Each report was put into machine-readable format and a unique ID was assigned to each report and to each sentence within each report. An excerpt from one report and its machine-readable format is given in Figure 1 and Table II.

Trained coders worked independently to identify cognitive and behavioral events in the reports. Coders were first trained individually to be able to apply coding protocol on a subset of documents (i.e., training material). Coding results from training material were not included in this study. The training period further continued until the coders' results agreed with the results of the lead coder (i.e., one of the main authors). Following the training period, each coder coded a randomly selected subset of all documents.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The Port Authority of New York and New Jersey
HAND-WRITTEN MEMORANDUM

REVIEWED

To: Chief 1 Chief of Department
From: Police Officer 3 #2075
Date: 11 / 26 /01
Subject: September 11th World Trade Center Terrorist Attack

On the morning of the incident, Sergeant 2 had an arrest for disorderly conduct and resisting arrest. I escorted the plain clothes officers to the arrest room along with Police Officer 4 While in the arrest room, we heard a loud explosion. The whole building started to shake. Sergeant 2 came over the radio and told us to release

Figure 1. Excerpt from original police narrative report

TABLE II. MACHINE-READABLE VERSION OF FIGURE 1 EXCERPT

Doc#	Dsen#	Dis	Sentence
18	1	WTC	On the morning of the incident, Sergeant 2 had an arrest for disorderly conduct and resisting arrest.
18	2	WTC	I escorted the plain clothes officers to the arrest room along with Police Officer 4.
18	3	WTC	While in the arrest room, we heard a loud explosion.
18	4	WTC	The whole building started to shake.
18	5	WTC	Sergeant 2 came over the radio and told us to release the prisoner.

Content coding on cognitive side of the study aimed on identifying hypothesizing, experimenting, observing and goal orienting events in the reported sentences. The following examples illustrate the different types of cognitive events. The sentence "I looked down towards Tower 1…" presents example of an observing event as the respondent makes observations about the perimeter. An experimenting event is present when respondents report allocation of personnel or material resources (e.g., … I ran out to the concourse level…). Examples of goal orienting events are identified when responders report a desired state of the world. In the "…so they could help the injured people" example, desired state of the world is the one where the injured people receive help. Coders identify a hypothesizing event when responders make a statement about the relationship among personnel and/or material resources or predicted/postulated effects of allocations of resources. In "I knew I wasn't that far from exit…" statement, responder is reporting a relationship between him and his whereabouts. So, the sentence receives a hypothesizing event code in the data set.

On the behavioral part of the study, coders identified behaviors, behavioral components (i.e., procedure, location, equipment and status) and the degree of improvisation of behavioral components (i.e., 1 if improvised, 0 if conventional and 9 if unknown) for reported sentences. The following examples illustrate the different types of behavioral events. Following sentence presents four behavioral dimensions employed in the study. "I was then given a backboard by a fireman, myself and another citizen placed Victim1 on the backboard, we strapped him on it and carried him from NW 5th and Harvey to NW 6th and Robinson and released him to an EMSA Paramedic." In the sentence, responder performs the procedure of helping and carrying a victim out of the disaster area. As this is not a conventional police personnel procedure, an improvised procedure component of behavior is identified. Investigating the status of the responder, it can be seen that he/r is performing out of the limits of a police officer (i.e., employing position of a paramedic), which leads to identification of an improvised status component. During the reported event, the responder is using conventional backboard equipment and the activity is being performed in a conventional location.

IV. RESULTS

This section starts with presentation of descriptive statistics from content coding results for both cognitive and behavioral frameworks. Table III displays average number of cognitive event occurrences and corresponding standard deviations in both OKC and WTC events (recall that the sample size for each event is 30 individuals). In Table III, the "Hyp." column shows that responders in OKC event perform 3.3 hypothesizing events on average with 5.9 standard deviation.) Similarly, Table IV displays average number of behavioral component occurrences and standard deviations in both events (e.g., on average responders perform 3 procedural improvisations with 3.3 standard deviation in OKC event). Due to the high variability in the sample set transcript lengths, percentages of cognitive events and behavioral components were used instead of counts in the analyses.

TABLE III. MEAN NUMBER OF COGNITIVE EVENT OCCURRENCES

Disaster	Measure	Hyp.	Obs.	Goal O.	Exp.
OKC	Mean	3.3	25.7	2.0	16.8
	Std. Dev.	5.9	25.7	3.1	13.8
WTC	Mean	2.3	22.3	3.6	21.3
	Std. Dev.	4.1	19.9	7.0	17.5

TABLE IV. MEAN NUMBER OF IMPROVISED BEHAVIORAL COMPONENTS

Disaster	Measure	Proc.	Loc.	Stat.	Equip.
OKC	Mean	3.0	0.4	0.2	1.1
	Std.Dev.	3.3	0.6	0.5	1.8
WTC	Mean	3.4	1.1	0.5	0.7
	Std.Dev.	3.9	1.3	1.1	1.3

A. Data Desription and Analysis Results

Table V presents the averages and standard deviations of cognitive event percentages. For example, mean value under observing column of OKC event tells us that, on average, observing event constituted 52% of total cognitive events performed by a responder. Similarly, standard deviation of observing event percentages in OKC disaster is 9%. Standard *t*-tests were used in answering research questions P1 through P5.

P1: Consistent with P1, on average, hypothesizing events constituted a larger percentage of performed cognitive events in OKC disaster. Hypothesizing events in OKC disaster constituted 6% of responder activity while this value is 3% for WTC disaster. The difference in mean hypothesizing event percentages of 3% is statistically significant (p=0.02).

P2: Contrary to P2, observing events constituted a larger percentage of performed cognitive events in OKC disaster. Observing events on average constituted 52% of responder activity in OKC disaster while this value is 45% in WTC disaster. The difference of mean observing percentages is 7% and the test result is statistically significant (p=0.01).

P3: Consistent with P3, goal orienting events constituted a larger percentage of performed cognitive events in WTC disaster. Percentage of goal orienting events in OKC and WTC is on average 4 and 5 respectively. Although goal orienting events constitute a larger percentage in WTC event, 1% difference is not statistically significant (p=0.29).

P4: Consistent with P4, percentage of experimenting events in WTC disaster is larger than experimenting events in OKC disaster on average. Responders in WTC disaster participated in experimenting events 47% of their time. In OKC disaster this value is 39%. The difference between average experimenting percentages is 8% and this test result is statistically significant (*p*=0.01).

On the behavioral side of the study, Table VI presents averages of improvised behavioral component percentages. For example, procedure improvisation percentage of a given actor is calculated by dividing number of procedural improvisations with the total number of procedural behaviors of that respondent.

TABLE V. MEAN PERCENTAGE OF COGNITIVE EVENT OCCURRENCES

Disaster	Measure	Hyp.	Obs.	Goal O.	Exp.
OKC	Mean	6%	52%	4%	39%
	Std. Dev.	6%	9%	4%	10%
WTC	Mean	3%	45%	5%	47%
	Std. Dev.	3%	12%	6%	14%

TABLE VI. MEAN PERCENTAGES OF IMPROVISED BEHAVIORAL COMPONENTS

Disaster	Measure	Proc.	Loc.	Stat.	Equip.
OKC	Mean	20%	2%	1%	6%
	Std.Dev.	16%	4%	3%	8%
WTC	Mean	25%	9%	3%	4%
	Std.Dev.	24%	11%	6%	8%

As presented in Table VI, on average, procedural improvisation constituted 20% of total procedural behavior of a respondent in OKC disaster with 16% standard deviation. On the other hand in WTC disaster, procedural improvisation on average constituted 25% of total procedural with 24% standard deviation.

Leading to the answer of fifth research proposition, improvisation percentages can be seen in Table VII. Percentage of behavioral improvisation of a given respondent is calculated by dividing total number of improvisations (i.e., number of improvisations across all four behavioral components) with the total number of behaviors (i.e., improvised and conventional behaviors). The numbers presented in Table VII are basically means and percentages of improvisation across all respondents for each disaster.

As presented in Table VII responders, on average, improvised 7% of their behaviors in OKC disaster with 6% standard deviation. Similarly in WTC disaster, responders improvised 10% of their behaviors with 8% standard deviation.

TABLE VII. MEAN PERCENTAGE OF IMPROVISATION

Disaster	Measure	Improvisation
OKC	Mean	7%
	Std. Dev.	6%
WTC	Mean	10%
	Std. Dev.	8%

P5: Consistent with P5, there are on average more improvised behaviors in WTC. As listed in Table VII, mean percentage of improvised behaviors is 7% and 10% in OKC and WTC disasters respectively. Mean percentage improvised behavior difference between OKC and WTC is -3%. Although, as hypothesized, there are on average more improvised behaviors in WTC than in OKC, there is no statistical evidence that this difference is significant (*p*=0.1033).

P6: Correlation Analysis Results

Results of the correlation analyses between the behavioral components and the cognitive events in WTC identified three significant relations. Hypothesizing vs. equipment and hypothesizing vs. status correlations are significant at 0.05 level. Pearson correlation coefficients for these two tests are 0.42 (*p*=0.02) and 0.41 (*p*=0.03) respectively. Observing vs. status correlation is significant at 0.1 level with Pearson correlation coefficient of -0.35 (*p*=0.055).

In the OKC event side of the analyses, only goal orienting vs. location correlation was significant at 0.1 level with Pearson correlation coefficient of -0.32 (*p*=0.09).

V. DISCUSSION/CONCLUSION

The study has revealed and compared cognitive and behavioral processes embedded within two different socio-technical systems. On cognitive side of the study, responders dedicated themselves more to hypothesizing and observing events in OKC disaster. On the other hand in WTC disaster goal orienting and experimenting events were more commonly performed. The decrease in hypothesizing events in WTC event was addressed by the increased need of acting rather than thinking. As WTC event was more severe in nature, responders were inclined to identify the first best alternative than the optimum one [19]. The increase in goal orienting events in WTC event was explained by the increase in the requirement for responders to participate in more activities. As expectations from WTC responders were relatively higher than OKC responders, WTC responders worked more goal oriented.

Behavioral part of the study showed that the responders to WTC event improvised more than the responders in OKC event on average. The increase in mean improvising in WTC event was not statistically significant. By investigating individual components of behavior, a significant difference in location improvisation is observed. The responders in WTC event improvised location behavior more than responders in OKC event where the difference is statistically significant. Responders performed procedure and status improvisations more commonly in WTC event but the difference between two events is not statistically significant. Differently from other behavioral components, there was an increase in equipment improvisations towards OKC event. Although there was an increase in equipment improvisations, the difference was not statistically significant.

Exploratory research on the relations of the cognitive events and the behavioral components showed different correlation patterns in two events. There was only one significant correlation term in the OKC event while three significant correlations were identified in the WTC event. The causes of the changes in the correlation terms require continuation of the research to understand how responders think, make conventional and improvised decisions and act.

Differences of the environmental contexts emanated by the severity of two events showed significant differences in the ways emergency responders make decisions in the context of emergency management.

The results of the study show empirical evidence that the ways response personnel think and act are affected by the environmental context changes. The changes in the activities of response personnel might affect the overall operation style of the large-scale emergency response STSs. In this matter, the study supplies a deeper understanding about STSs in terms of effects of the environmental context changes. The results of the study might be used to improve responder activities during organizational response to large-scale emergency response operations thus increasing the accuracy and efficiency of incident management by further studying the links between cognition and behavior.

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