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EVACUATION OF THE WORLD TRADE CENTER: WHAT WENT RIGHT?

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Abstract

The evacuation of the World Trade Center on September 11, 2001 was not the first evacuation of the 110-storey high towers. Partial and full evacuations had taken place on other occasions. One particular event was the full evacuation of the two towers on Friday February 26, 1993 when a bomb exploded in the underground garage. The comparison of the 1993 and 2001 evacuations allows contrasting the occupants' understanding of the situation, their response and behaviour. Study results of the 1993 evacuation are compared to the analysis of first-person accounts found in the media following the 2001 disaster. It is concluded that the two full evacuations differ substantially. In September 2001, if the conditions had been similar to the ones experienced in 1993, many more occupants would have had perished. The low number of fatalities below the floors of impact in 2001 suggests that several factors contributed to support the evacuation, which resulted in a successful evacuation for most occupants, located below the floors of impact.

Keywords: World Trade Center, Occupant, Evacuation, Tall building

1. Introduction

Following the World Trade Center (WTC) bombing in 1993, the National Fire Protection Association (NFPA) and the National Research Council Canada (NRC) undertook a study of the evacuation of the towers. This study used a questionnaire survey distributed to the floor fire wardens of all tenants of the two towers. The survey was sent to 1,598 employees. Over 400 usable surveys were returned. These surveys were the basis of several papers published on the actions of the occupants of the two towers during that evacuation (Fahy & Proulx, 1997, 1996; Proulx & Fahy, 1995; Fahy, 1995).

Immediately after the attack on September 11, 2001, first-person accounts describing the evacuation of the two towers were collected. First-person accounts were gathered from newspapers, radio and television programs, email exchanges and a variety of websites. This large quantity of material was coded and analyzed to obtain a better understanding of the personal evacuation experiences of survivors located on the different floors of the two towers. Although media accounts are not necessarily reliable accounts of events, and certainly do not provide the scientific rigour of a proper study, they do present important insights into the events of the day. Of particular interest were the responses of occupants who had experienced the 1993 evacuation and the role that improvements made after the bombing in 1993 may have had during the evacuation in 2001.

2. The 1993 Evacuation

On Friday February 26, 1993, at 12:18 a bomb in a vehicle parked on a basement level below the WTC plaza exploded, killing six people who were on the basement levels. The resulting fire was confined to 25-30 vehicles, but smoke and dust migrated throughout the two towers. The complex's emergency communication systems were damaged and the power was interrupted. All the occupants of both towers evacuated. Several occupants took hours to make their way out of the darkened buildings.

The NFPA and NRC, with additional funding from the National Institute of Standards and Technology (NIST), undertook a study of the evacuation of the towers. The goals of the study were to:

- use a scientific approach to gain an understanding of the dynamic interaction of human behavior, the physical environment and the products of combustion;
- identify and quantify escape modes and routes taken;
- document the hazardous conditions as perceived by the occupants; and
- develop findings for fire safety procedures and educational efforts.

The Port Authority of New York and New Jersey provided support for this study. A questionnaire survey was conducted 5-6 months after the event when the occupants moved back into their offices. A total of 1,598 surveys were distributed to members of the fire safety team of the two towers. A total of 406 usable surveys were returned, which is a return rate of 25%.

The study results have been summarized in several papers (Fahy & Proulx, 1997, 1996; Proulx & Fahy, 1995; Fahy, 1995). Below are some key findings:

- There were significant differences in perception of severity of the incident initially from occupants of the two towers: occupants of Tower 1 perceived the situation as much more serious compared to occupants of Tower 2;
- There were no significant differences in perception and response according to gender or age;
- People were found to be prepared to move through smoke even if they thought they might be heading toward the fire;
- Most occupants evacuated in total darkness;
- The mean time to start evacuation after initial awareness of the incident was 15 minutes for Tower 1 occupants and 35 minutes for Tower 2 occupants; and
- Less than 10% of the occupants had participated in drills (although the survey had been distributed to tenants' fire wardens).

In the months and years following the bombing incident, many improvements were made in the WTC towers. For example, the voice communication system on each floor was improved and evacuation drills were held every six months with staff training. In the three stairwells of each tower, photoluminescent paint was used to mark the steps and handrail and to illuminate the travel paths. Photoluminescent signs were also posted inside the stairwells on doors indicating the stairwell name, floor level and the closest re-entry floors. Battery packs were added to the emergency lights in the stairwells and a backup power supply was added for emergency systems. Evacuation chairs were provided for each disabled employee in the building.

3. First-Person Accounts from the Survivors of the 2001 Disaster

On September 11, 2001, it is estimated that 10-14 thousand occupants were in the two towers when they were struck by commercial airliners (Cauchon, 2001). In the moments following the attack journalists started interviewing survivors to obtain the story of their evacuation. These first-person accounts were presented on television or radio and published in newspapers, magazines, or websites and later reported in books and special media programs. During the 3 months following the events, over 280 first-person accounts were collected. The information provided, in some of these accounts, was so detailed that it provided sufficient material for a study. Additional accounts were gathered over the next year for a total of 480 first-person accounts.

It is recognized that the use of first-person accounts published in the media as main sources of information for a study has many limitations. The questions asked by reporters are unknown and can be different from each journalist or with each interview. It is suspected that the most dramatic experiences are reported and that some information may be left unreported or emphasized for the purpose of the article. These caveats do not imply that more rigorous research methods, such as surveys or interviews, are foolproof. There are, however, within these scientific approaches controls in place that are meant to provide consistency. The samples are selected so that reported data can be generalized over the larger population. The same questions are asked so that the same information can be obtained from every study subject. The questions are designed to be unbiased and are asked carefully so that the subject is not led to follow a certain line of thought. Despite the drawbacks of using first-person accounts as the source of information for a study, the high level of detail contained in some of these accounts, particularly the ones written by survivors themselves, provided the justification for the complete analysis of this information.

Further information on the events and evacuation of September 11 was obtained from a number of sources. There has been excellent reporting in the *New York Times*. For instance, on May 26, 2002 they issued a detailed piece on the experience of building occupants trapped above the points of impact in the towers. The best overall summaries of the evacuation can be found in *USA Today* articles by Dennis Cauchon. The reporter identified the fatality locations in the two towers in an article published on December 19, 2001. *USA Today* also released several first-person accounts. The CNN's website

(www.cnn.com) has had numerous accounts and video clips of interviews available for viewing. A documentary film was broadcast on CBS (Naudet & Naudet, 2002) and many interviews can be found on newscast websites. Six months after the events books started being published such as *September 11: An Oral History* (Murphy, 2002), *Report from Ground Zero* (Smith, 2002); or *Last Man Down* (Picciotto, 2002), which provided vivid recollection of the occupants' behaviour in the two towers on September 11, 2001.

4. Fatalities in the WTC Towers

The chronology of the events of September 11, 2001 at the WTC has been reported by several sources. To ensure consistency in discussing these events it is important to refer to the facts detailed in the Federal Emergency Management Agency, Building Performance Assessment Team Report. The FEMA report states that a commercial airplane hit Tower 1 between the 94th and 98th floors at 8:46 a.m. Sixteen and a half minutes later, at 9:03 a.m., a second airplane hit Tower 2 between the 78th and 84th floors. Despite the massive damage caused by the impact and following intense fires, each structure remained standing for a while. As these fires spread, the structures weakened, eventually leading to total collapse 56 minutes after impact for Tower 2 and 1:42 minutes for Tower 1 (FEMA, 2002).

The exact number of occupants in each tower that morning will probably never be known. According to an article published on December 19, 2001 in *USA Today* (Cauchon, 2002), there were 5,000 to 7,000 people in each tower at the time of the first attack on September 11, 2001. The article stresses that no one located above the point of impact in Tower 1 survived, while 99% of those located below the impact points were able to escape. A total of approximately 2,800 people lost their lives at the WTC that morning. The article suggests that, in Tower 1 above the crash 1,360 people died, while below the 91st floor, 72 died. In Tower 2, 599 occupants died, of which only 4 worked below the crash area. This data shows that, essentially, 76 occupants of the two towers who worked below the crash location died that morning. Because of the time at which the attack happened, it is assumed that several, if not most, of the fatalities from below the crash locations were occupants inside elevators heading to work. Many elevator cars could not be returned to a floor upon impact. Some elevator shafts had balls of fire coming down the full length of the tower giving no chance of survival to the elevator occupants.

According to the *USA Today* article, other fatalities that morning were 479 rescue workers, 157 occupants of the hijacked jets, an estimated 147 day workers or delivery people and 10 bystanders outside the building.

Overall it is estimated that 8,000 to 12,000 occupants of the two towers at the WTC escaped the buildings that morning. With essentially 76 occupants who worked under the impact points who perished, the evacuation of the two WTC towers can be considered a very successful evacuation.

5. Evacuations of 1993 and 2001

There are a few issues for which useful levels of details are available from the first-person accounts of 2001, which could be contrasted with the findings of the 1993 evacuation study. The results of the 1993 study are based on the analysis of the 406 questionnaires. Data for the 2001 evacuation was obtained from the content analysis of 480 first-person accounts from 324 individuals, as some survivors provided multiple accounts to different media. For those survivors for whom numerous accounts were found, the information across the accounts was collapsed into one for analysis. For each study, some questions were not answered or the evacuees did not discuss specific issues, consequently results discussed in this paper are based only on valid answers disregarding the missing data. The variables compared for the 2 evacuations include: initial awareness of the event, perception of severity, delay times, announcements and evacuation times.

5.1 Initial Awareness of the Event and Perception of Severity

In 1993, the explosion was the first cue for the majority of occupants in both towers: 84% in Tower 1 and 74% in Tower 2. Only 28% of the occupants of Tower 1 and 18% in Tower 2 thought the situation was extremely serious. At the same time, 33% of the occupants of Tower 1 and 44% in Tower 2 thought the situation was no more than slightly serious.

Although there were significant differences in perception of severity of the incident initially from occupants of the two towers, there were no significant differences according to gender, age or location in the tower. However, respondents were more likely to consider the incident serious if they were first alerted by the explosion than if their first cue was the loss of electrical power.

On September 11th, the occupants of both towers were presented with very powerful cues. Occupants in Tower 1 were most likely to report the building motion from the impact, the building swaying, trembling – many thought the building was going to tip over. Occupants in Tower 2 were more likely to report visual cues such as the fireball or debris. The cues reported seemed to vary with the location of the occupants in the tower, with those closer to the impact point reporting far less ambiguity and more awareness of the seriousness of the situation. Out of 177 first-person accounts, 147 (83%) judged the situation as very serious, 17 (10%) as somewhat serious and 1 not serious at all; 12 or 7% initially judged the situation not serious but rapidly changed their assessment to very serious. Many occupants in Tower 1 reported that they did not know what had happened and did not realize the magnitude of the event until they reached the tower lobby or the outside. Many reported believing that a commuter plane or helicopter had struck the building. In Tower 2 several occupants had direct views of the events in the other building; they mentioned the balls of fire, jumpers, debris and heat. Interestingly, some occupants on fairly high floors in Tower 2 did not see or hear anything to indicate a problem. One worker on the 93rd floor of Tower 2 happened to look past the receptionist, out the window, and was surprised to see paper floating in the air that high up. Immediately after that, he heard other building occupants moving in the stairwells and realized that people were evacuating.

Some of the variation for the initial cues perceived and responses can be explained by the variety of floorplan layouts in use through the towers. Some of the floors had offices around the perimeter of the floor, leaving little view out windows for those located closer to the core. Other floors used an open floorplan with workers in cubicles, allowing easier visual access out the windows throughout the floors. Open floorplan layouts also allowed occupants to observe the response and actions of others and favored interactions among occupants which was important in the decision-making process.

5.2 Delay Times

In 1993, building occupants in Tower 1 reported delays of as long as four hours, and in Tower 2 of 3 hours, from the time they first became aware of the incident, until they began their evacuation. The median delay times were five minutes in Tower 1 and 10 minutes in Tower 2. The combination of ambiguous cues, absence of information and instruction, smoke and crowds in the stairwells and lack of lights contributed to the delay. Some building occupants were instructed by their company management to wait for assistance.

On September 11th, after perceiving the initial cues 126 survivors or 54% of the 234 first-person accounts for which a delay time to start can be estimated, started 'immediately' their evacuation, as presented in Table 1. Starting 'immediately' includes people who took the time to rapidly grab their laptop, purse or jacket. A higher percentage of survivors of Tower 2 started 'immediately', 60.4% compared to Tower 1, 49.3%. Survivors who left 'shortly' after the initial cues are the ones that took up to 5 minutes retrieving belongings or gathering coworkers. Survivors who 'delayed' their time to start searched their floor, planned what to do with coworkers, made several calls, watched TV, shut off equipment or continued working. Some survivors initially decided to stay, usually to help others, direct or assist coworkers. A few survivors were initially stuck in Tower 1 by pieces of wall or ceiling which had collapsed or were stuck between floors inside elevators.

Table 1. Delay to Start Evacuation from First-Person Accounts 2001

Delay Time	Tower 1		Tower 2		Total	
Immediately	68	49.3 % ¹	58	60.4 %	126	54 %
Shortly	16	11.6	15	15.6	31	13.2
Delayed	34	24.6	15	15.6	49	20.9
Stayed	11	8.0	8	8.4	19	8.1
Stuck	9	6.5	0	0.0	9	3.8
Total	138	100.0 %	96	100.0 %	234	100.0 %

1- Percentages exclude "Other" and "No answer" responses.

5.3 Announcements

In 1993, no announcements were made to the building occupants, because the communications system located in the basement had been destroyed by the bomb blast. The occupants had been trained to go to the voice annunciator in an emergency and await further instructions. That day, those instructions never came.

On September 11th, announcements were made over bullhorns and voice communication systems. In Tower 2, sometime during the 16.5 minutes that separated the two attacks, a message came over the public address system telling people that an airplane had hit Tower 1, Tower 2 was secure and that it was safe for occupants to return or stay in their offices. The exact wording of the live voice message is not available and the officer who issued the message did not survive. It should be stressed that the message content was perfectly correct at the time it was made. It is estimated that the Tower 2 announcement was issued at approximately 9:00 a.m., as the majority of survivors claimed they heard it just a couple of minutes before Tower 2 was struck, which occurred at 9:03 a.m. One survivor from the 103rd floor of Tower 2 describes that he had reached the 70th floor when he heard the announcement and he decided with his colleagues to continue down. He had descended another 3 floors to the 67th, when the second airplane hit the tower. Of the 60 survivors in Tower 2 who mentioned hearing the announcement in their accounts, 53 decided to disregard the instruction and continue their evacuation while 7 people decided to turn back but didn't have time to go very far before their tower was hit; they then turned back down.

The concept of "Commitment" is an occupant factor frequently reported as affecting an individual's response to fire cues (Sime, 1995). For example, a person who has just been served dinner in a restaurant will be reluctant to abandon his meal to evacuate the building when an alarm sounds: the person is committed to complete this activity before turning his attention toward an ambiguous unexpected event. On September 11th, the people who had decided to evacuate Tower 2, already knowing that an event affected Tower 1, may have been committed to their decision and, if so, were not deterred by the announcement so they carried on. Others who either stayed at their desks, or began to evacuate with some reluctance or reservation, may have felt that the announcement reinforced their decision to stay or gave them the "permission" they needed to return to work.

5.4 Evacuation Times

In 1993, the evacuation movement time varied from a few minutes to more than 3 hours. Table 2 shows the reported evacuation movement times from the survey respondents. These times reflect the time it took them to leave the building once they began their evacuation; these times do not include the elapsed time from the onset of the incident. The movement times for the occupants in Tower 2 were generally shorter because so many waited until the situation was stabilized and the evacuation was better assisted and the stairwells less crowded.

Table 2. Evacuation Movement Time for the Two Towers in 1993

Time	Tower 1		Tower 2		Total	
Less than 5 minutes	2	0.9 % ¹	1	0.7 %	3	0.8 %
5 to 30 minutes	28	12.9	35	23.5	63	17.2
30 minutes to 1 hour	56	25.8	71	47.7	127	34.7
1 to 3 hours	114	52.6	42	28.2	156	42.7
Over 3 hours	17	7.8	0	0.0	17	4.6
Total	217	100.0 %	149	100.0 %	366	100.0 %

1- Percentages exclude "Other" and "No answer" responses.

On September 11th, the occupants of Tower 1 had 1:42 minutes to leave the building before the collapse. Some people on the 90th and 91st floors of Tower 1 reported leaving the building in as little as 45 minutes. In 1993, the median evacuation time from the 90th floor in Tower 1 was 2.5 hours. No one evacuated in less than two hours. In 2001, if conditions in the stairs had been the same as in 1993, far more people would have been killed.

In Tower 2, building occupants had 56 minutes to evacuate after their building was struck. In 1993, many Tower 2 occupants evacuated in an hour or less because they waited a few hours until conditions improved and evacuated under less difficult conditions than the occupants of Tower 1.

On September 11th, there were several reports of fairly rapid evacuations of even severely burned victims. One account from Tower 1 reported that hundreds of people in the stairs stepped aside so that she and the severely burned woman she was assisting could pass. She reported moving from the 78th floor to the outside in less than 20 minutes. However, most first-person accounts did not report any specific times at which people took different actions or the time duration of activities. Nevertheless some mentioned their location at key moments such as where they were when Tower 2 was hit or when Tower 1 or 2 collapsed. Table 3 shows the number of survivors who reported being out by a certain time.

Table 3. Time Out of the Two Towers in 2001 from First-Person Accounts

Time out	Tower 1		Tower 2	
Before Tower 2 impact 8:46 – 9:02 a.m.	6	7.3 % ¹	8	27.6 %
Half hour after Tower 2 impact 9:03 – 9:30	13	15.9	6	20.7
Before Tower 2 collapse 9:31 – 9:58	21	25.6	15	51.7
After Tower 2 collapse 9:59 – 10:27	42	51.2	0	0
Total	82	100.0 %	29	100.0 %

¹- Percentages exclude accounts for which no time could be figured out.

Within the 16.5 minutes between the attacks, 6 survivors in Tower 1 and 8 in Tower 2 were already out of their tower since they reported observing Tower 2 being hit from the street. Among the 8 survivors of Tower 2 who were out of their tower before it was hit, 5 were from floors above the 78th floor who took an elevator to evacuate. No survivors from Tower 1 took the elevator to evacuate. In Tower 1, it appears that several survivors (51% of the accounts for which a time out could be worked out) escaped during the half-hour after the collapse of Tower 2 and before the collapse of Tower 1.

5.5 Impact of the 1993 Evacuation

Among the 324 survivors for whom first-person accounts were analyzed, only 30 reported being present during the 1993 bombing and evacuation of the WTC towers. Of them, 11 survivors claimed that their experience in 1993 helped them decide to evacuate readily on September 11, 2001. Only two people who were present in 1993 delayed evacuating and one person initially stayed. Three of these survivors reported being prepared for another evacuation because of the 1993 bombing with 'evacuation kits' containing flashlights, masks, glow sticks, whistles and water.

Four survivors reported seeing the photoluminescent stripes on the stairs, railings and stairwell doors – an improvement the Port Authority made following the 1993 bombing. As one survivor stated, "All you had to do was follow those yellow-green stripes. They were wonderful. The stripes were especially valuable when the emergency stairs stopped and people had to travel horizontally through mechanical equipment spaces that had many doors" (Masetti, 2001).

A paraplegic survivor from Tower 1 who was also present during the 1993 evacuation commented on the successful use of an evacuation chair on September 11th. The evacuation chairs were part of the improvements made to the evacuation process after the 1993 bombing. In 1993, this disabled person was bounced down the stairs in his electric wheelchair from the 69th floor to the 43rd floor, where he was then transferred to a stretcher and carried down the rest of the way. It took him 6 hours to evacuate from the 69th floor in 1993. On September 11, 2001 using the evacuation chair enabled him to escape the 69th floor of Tower 1 and get to street level in 30 minutes. He went on to say, "If it weren't for the evacuation chair, I would not have made it" (Fink & Mathias, 2002).

Conclusions

The content analysis of first-person accounts provided some positive information on the evacuation of September 11, 2001. It seems that the improvements made to the egress system of the towers helped the evacuation. Movement out of the building continued under difficult conditions. Most people reported that others remained calm and demonstrated many altruistic behaviors. Many survivors mentioned seeing firefighters and felt reassured and safe due to their presence.

The comparison of the 1993 survey results and the content analysis of first-person accounts on the evacuation of September 11 indicated that:

- people judged the situation serious in both incidents although they did not know what exactly had happened;
- on September 11th occupants of Tower 2 had very strong visual cues from Tower 1, which increased their perception of severity of the incident and motivated rapid evacuation movement. Occupants of Tower 1 had less precise cues or had damage and injuries on their floor. They took more time to start their evacuation;
- overall there was less delay in starting evacuation on September 11th, which proved to be a good decision. In 1993, occupants were better off to either start right away or wait a few hours for the crowds and smoke to clear;
- if the conditions of the 1993 evacuation regarding the number of occupants, smoke condition and absence of lighting, guidance and signs in the stairs had existed on September 11th, far more people would have perished; and
- the improvements made to the buildings, the training received, the behaviour of the occupants, all contributed to allow nearly all of the occupants present below the impact points to escape on September 11th.

The evacuation of the World Trade Center on September 11, 2001 was a success. Nearly everyone who could physically get out did get out. According to *USA TODAY*, which is to date the best source of information on the potential location of the fatalities, 99% of the occupants below the crash sites survived. The reporter's analysis shows that two-thirds of Tower 2 occupants evacuated the upper floors during the 16.5 minutes between the attacks. Among the employees of the WTC, under the impacted floors in Tower 1, 72 people died, whereas under the impacted floors in Tower 2, 4 people died. It is assumed that half, if not more, of the deaths below the impacted floors in Tower 1 occurred in the elevators, which were carrying people at the time of impact. It seems that occupants with disabilities who could be moved by colleagues and rescuers escaped, except for obese people. The firefighters and other rescuers helped with the evacuation of several occupants. Although their movement disrupted evacuation in the stairwells by going against traffic, this counter flow did not prevent occupants from evacuating before the collapse.

The events of September 11, 2001 have changed forever the interest in high-rise building evacuation. Fire protection engineers, architects, building owners, code officials and the general public are now discussing at length how to ensure that high-rise evacuation will happen efficiently and in a timely manner. Shall we change the way we design high-rise buildings? Shall we limit a building's height to, let's say, 60 storeys? Should stairwells be scattered around the perimeter of the building instead of having them in the central core? Maybe more and wider stairwells are needed? Some wild inventors are suggesting new evacuation devices such as outside platforms, chutes or parachutes! All this discussion is very good – although it is important not to lose sight of the fact that the events of September 11, 2001 were unique and very unlikely to be repeated.

In reviewing the discussions held in the media it is the changes in the public perception of risk in high-rise buildings that should most worry researchers in fire safety. It is crucial to measure the degree to which the perception of risk of major fires or collapse has changed since September 11th. If there is a change in attitude toward safety in high-rise structures, how will this change evolve over time? It is essential to ensure that occupants are prepared to follow the emergency plan in high-rise structures which usually calls for phased evacuation or defend-in-place strategy. If occupants are not prepared to follow the emergency plans, it leads to serious implications for the design and organization of high-rise buildings. Maximum heights and occupancy loads will have to be reduced. A larger number of stairways will have to be provided, or capacity will have to be increased by changes in design. Elevators that are safe to use in fire situations will have to become commonplace. There will be a need

for refuge areas and refuge floors in high-rise buildings so that people who cannot get all the way out of the building will be able to retreat to a secure area.

The full lessons to be learned from the evacuation of the WTC towers cannot be discussed until a complete human behaviour study of the evacuation is conducted. Meanwhile, all that can be said is that considering the specific circumstances on the morning of September 11, 2001, the evacuation of the occupants below the points of impact was a success due in large part to the low occupancy that morning, the generally good conditions of the evacuation system supplemented with the improvements introduced after the 1993 events, and the excellent judgment and response of the occupants.

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