AN ANALYSIS OF HUMAN BEHAVIOUR DURING THE WTC DISASTER OF 11 SEPTEMBER 2001 BASED ON PUBLISHED SURVIVOR ACCOUNTS

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ABSTRACT

This paper presents an analysis of survivor experiences from the World Trade Centre (WTC) evacuation of 11 September 2001. The experiences were collected from published accounts appearing in the print and electronic mass media and are stored in a relational data base specifically developed for this purpose.

INTRODUCTION

The evacuation of the WTC complex represents the largest full-scale evacuation of people in modern times. The survivors of this disaster hold a tremendous amount of information concerning their experiences of the conditions within the structures and the evolving evacuation scenario. Only they know what they were doing immediately prior to and during the incident. By tapping into their experiences it is possible to investigate the inter-related processes associated with decision making, action planning and implementation and the information gathering activities which sustains these processes under adverse and rapidly changing conditions. Ideally, this information should be gathered from face-to-face interviews conducted as part of a scientific study. An alternative and less desirable approach relies on first hand accounts that have appeared in the mass media. These are usually the result of press interviews conducted by journalists or personal accounts produced by survivors on web sites or books. The difficulties with this approach include; an inability to target specific groups, interviewees are self selecting, journalists tend to only report the more sensational parts of peoples stories, inconsistency in questions posed, questions posed by journalists are not necessarily known, inability to ask specific questions. In effect, the accounts that appear in the mass media provide an uncontrolled snap shot view of the incident, and what we don't know from these accounts is as important as what we do know. Nevertheless, the data contained in such accounts can prove extremely useful in providing insight into behaviour during such incidents. Furthermore, the accounts were recorded very close to the event, some accounts being made a matter of days after the incident. Studies involving live interviews with survivors usually view the incident after the passage of a considerable amount of time, (in the case of the WTC, years) and so may be tainted by information gleaned from other accounts that have appeared in the public domain, memory lapses or selective amnesia. Therefore, the data collected from published accounts while not ideal, potentially contains invaluable information.

Following the WTC disaster, the Building Disaster Assessment Group (BDAG) of the UK Office of the Deputy Prime Minister, funded the Fire Safety Engineering Group (FSEG) of the University of Greenwich to gather, collate, categorise, electronically store and finally analyse data concerning human behaviour during the WTC evacuation. Reports were gathered from the literature published in the public domain. Material sources ranged from survivor accounts printed in newspapers and newspaper web sites, interviews in the electronic media, survivor web sites and books. Over 250 separate accounts were gathered that described occupant behaviour. Information appearing in print newspapers represents 70% of the accounts while information from websites (news and personal) represents 16% of the accounts. The remainder of the accounts have appeared in books, journals and the electronic media. These accounts provided information concerning 120 people from

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WTC1 (north tower or WTC1) and 119 from WTC2 (south tower or WTC2) and 21 of unknown origin. This paper represents a selected summary of a detailed report published by the UK ODPM [1].

THE EVENT

While the events of 11 September 2001 are well known, it is worth recounting the main facts. WTC1 was hit by American Airline Flight 11 at 08:46 a.m. The impact was nearly centred on the north face of the building which was hit between the 94th and 98th floors. WTC2 was hit by United Airlines Flight 175 at 09:03 a.m. The impact was at a skewed angle toward the southeast corner of the south face of the building which was hit between the 78th and 84th floors. WTC2 collapsed at 09:59 and WTC1 collapsed at 10:37. There are various estimates for the number of people in the building and the number of fatalities. Denis Couchon of US newspaper ***USA Today*** estimates that there were between 5,000 and 7,000 people in the buildings at the time of the impact and estimates that 2,784 people perished [2]. He estimates that 1,432 building occupants perished in WTC1 and 599 in WTC2 [3].

THE DATABASE OF HUMAN EXPERIENCE

The collected accounts were entered into a specially developed database. The database itself was designed to be a flexible qualitative research tool enabling the categorisation of occupants' experiences during the data input process. As part of the data entry, the entire verbatim data account was stored. In addition, each individual experience described within the account were stored and assigned specific behavioural references. This is similar to traditional qualitative analysis tools that allow users to categorise portions of textual accounts during the input process.

The categorisation of each experience involved assigning a main behaviour classification to the experience, for example, *'Experienced Cue'* or *'Smoke effect'*. A further refinement to the category was then specified that described the exact nature of the experience, for example the exact nature of the cue or smoke effect (see Figure 1).

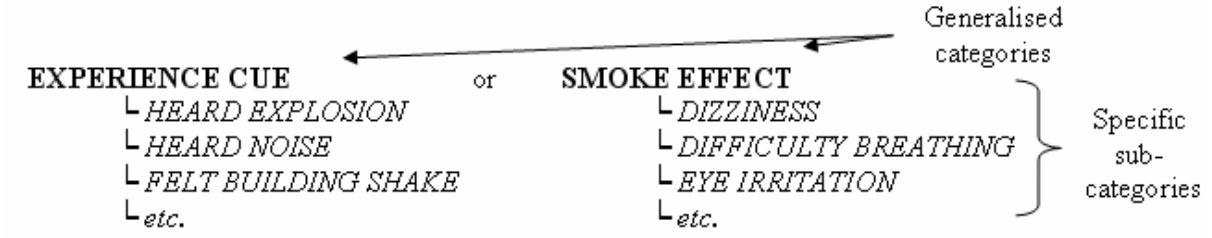


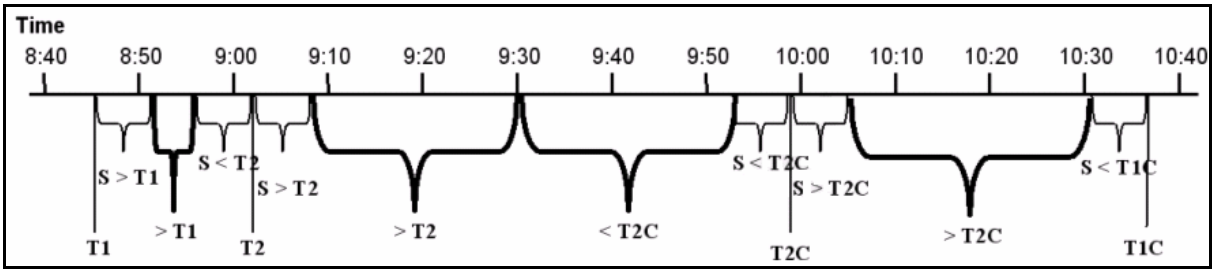
Figure 1: An example of the experience categorisation scheme

The rationale for the database was that all information was centred on an experience. Each experience was assigned a main category and a sub-category that described the nature of the experience. The experience was also tagged with details of the experience location, time reference, evacuation phase and references to the personal details of the occupant that described the experience. A distinguishing feature of the database is that it is not only able to store experiences but also the location of the experience and a time reference for the experience. The developed database proved well suited for investigating time critical evacuation issues.

The database contains reference to a total of 3291 experiences from 260 people (1869 accounts from WTC1, 1411 from WTC2 and 11 from unknown locations). Gender information was available for 240 people, 164 of which were male and 76 female. The quality of this data varied enormously. While some accounts were several pages long, others were only a couple of paragraphs in length. Of more importance, some accounts provide important detailed information such as a detailed description of events, locations at which events took place and reference to key time markers. The reports mainly came from occupants that begun their evacuation in the upper floors of either tower. Within the database, 73 (61 %) and 91 (76 %) of the occupants from WTC1 and WTC2 respectively were initially located on or above the 78th sky lobby. It is likely that this bias originates from the medias natural desire to focus on accounts that described the most extreme conditions during the disaster.

Time References

Four key event markers were identified, namely the impact into WTC1 at 8:46am, the impact into WTC2 at 9:03am, the collapse of WTC2 at 9:59am and the collapse of WTC1 at 10:37am. Using these time makers in some accounts it was also possible to determine those experiences that occurred shortly before the key event markers, arbitrarily defined as within 5 minutes.



T1 = WTC 1 impact, T2 = WTC 2 impact, T*n*C = WTC *n* collapse, S = shortly, < = within 5 minutes prior to, > = within 5 minutes post

Figure 2: Time references used within the database

This yielded an additional 6 markers. The remaining temporal gaps were assigned markers. The large period of time post T2 impact + 5 minutes to T2 collapse – 5 minutes was divided in two (see figure 2. Essentially the analyst entering data had to decide whether an action occurred nearer to T2 (WTC2 Impact) or T2C (WTC2 collapse). Where decisions could not be made due to insufficient information being available time references were not entered. Each time entry was checked by two data entries, differences in interpretation were explained and a final ruling made.

DATA ANALYSIS AND DISCUSSION

The database has been used to study a number of issues concerning the evacuation of the WTC. These can be broadly separated into two categories, pre-evacuation and evacuation. The pre-evacuation category is intended to cover behaviours prior to the physical act of attempting to evacuate, while the evacuation category is intended to cover those actions and behaviours during the physical act of evacuation. Due to space limitations, only a small proportion of the findings will be briefly discussed here, interested readers are directed to the BDAG report [1] for a full account. The following analysis considers pre-evacuation issues and evacuation issues.

Pre-Evacuation: Response Times

A key part of this study related to the generation of an estimate for occupant pre-evacuation time also referred to in this paper as occupant 'response time'. In this study, the pre-evacuation time encompasses all activities undertaken by occupants prior to the flight action i.e. decisive actions directed at exiting the floor and building. For example, pre-evacuation activities included behaviour in which a person begins to attempt to vacate their starting floor but, prior to entering the staircase, decides to return to their office to collect belongings. Likewise an occupant moving to a different room to seek shelter would also be classed as engaging in a pre-evacuation activity. The distinction is subjective but allows us to differentiate between actions and experiences that occurred during descent (and in some cases ascent) and activities that occurred more locally to occupants' work places. Using temporal information contained within the database, it was possible to estimate the response times for 58 occupants in WTC1 (48% of the accounts from WTC1) and 57 occupants from WTC2 (48% of the accounts from WTC2), representing 44% of people in the database. Response time data was catergorised into three time slices,

- **Rapid responder** (Rapid response ≤ 5 mins),
- **Moderate responder** (5 < Moderate response < 17 mins), or
- **Long responder** (Long = 17 mins).

Note: The size of each response category was influenced by the spread of temporal markers reported by occupants.

The response time for occupants in *both buildings* was measured from the impact on WTC1 i.e. T1. Over 90% of the people in WTC2, for which we have response time information i.e. 53 people (representing 45% of the accounts from WTC2), reported starting their evacuation prior to T2. The majority of people in the database, for which we have response time data were categorised as rapid responders, with 53% (31) of the occupants in WTC1 and 67% (38) of the occupants in WTC2 responding within 5 minutes of T1. This occurred in WTC2 despite several occupants reporting that they heard instructions over the PA system in WTC2 that there was no need to evacuate as WTC2 was secure. On the whole it was noted that occupants in WTC2 had shorter response times than those in WTC1 (see figure 3). Analysis of the data suggests that this may have resulted from occupants in WTC2 having better knowledge of the event than those in WTC1 [1]. More generally we find that most occupants began moving relatively quickly. However, some occupants spent considerable time involved in activities prior to beginning their evacuation. The longest response times identified within the database for occupants from WTC2 was 45 minutes (2% of occupants in database) while for WTC1, the longest reported response time was 74 minutes (5% of occupants in database). While it is difficult to generalise due to the lack of data, the rapid response times of occupants in WTC2 relative to WTC1 may have contributed to the smaller death toll experienced in WTC2.

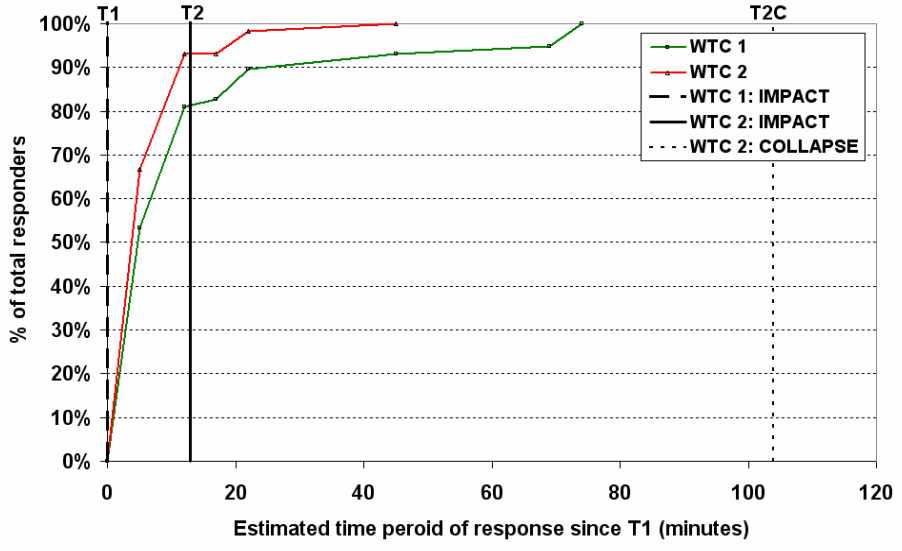


Figure 3: Percentage cumulative frequency distribution of occupant response

An attempt was made to determine whether or not the speed of response was related to occupant location. Of the 115 people providing response time information, 97 occupants also provided initial location information. In WTC1, 97% of the data came from people located below the impact zone, while in WTC2, 22% of the data came from below the impact zone. Unfortunately, the nature of the data did not allow any meaningful generalisations to be made concerning the relationship between location and response time. However, it was noted that in WTC2, 71% of the occupants (for which we have both response time and location data) in or above the impact zone were classed as rapid responders.

Pre-Evacuation: Occupant actions

The number and nature of the actions performed by building occupants during the pre-evacuation phase was investigated. These actions were assigned to one of seven different class types, namely:

1. Confront the hazard such as, *collect a fire extinguisher*,
2. Seek temporary refuge such as, *hide under desk*,
3. Gather/provide information such as, *look out the window* or *speak to a colleague*,
4. Receive/provide assistance such as, *rescue trapped colleague(s)*,
5. Prepare for the physical act of escape such as, *collect belongings, or*
6. Do nothing at all, such as, *continue with work*.
7. Extreme behaviour, such as, *panic.*

In total 124 occupants supplied pre-evacuation experiences. Of these, 94/124 (76%) occupants detailed at

least one action during their pre-evacuation phase. A further 19/124 (15%) occupants described leaving immediately and reported no pre-evacuation phase actions. The remaining 11 accounts supplied experiences but it could not be determined whether they performed any actions. Of those that reported actions, *gather/provide information* was reported most frequently and represents 55% of all of the actions reported during pre-evacuation. The next most frequently reported action was preparing for the evacuation itself. This accounted for approximately 35% of reported actions. Only one instance of an occupant completely ignoring the event was found and reports of occupants confronting the fire were absent. The extreme behaviour action (which included the classic panic action or people behaving in an irrational manner) was only noted in 1/124 (0.8%) cases. If we examine the frequencies of reported actions across the two towers we note that the percentage *gather/provide information* is higher in WTC2 than WTC1 and that the percentage *seeking shelter* and *offering assistance* are both lower in WTC2 than in WTC1. This is possibly due to WTC2 being struck after WTC1, as a consequence a number WTC2 occupants began to evacuate prior to WTC2 being struck and so avoided dangerous post impact conditions. The fact that *gather/provide information* is the dominant reported action is significant as the requirement for this action could be removed if occupants are provided with appropriate information. Reducing the need for seeking information may assist in reducing response times and overall evacuation times. Improved communication systems and procedures for disseminating information will allow occupants to more rapidly make appropriate evacuation decisions.

Within the database the order of occupant experiences was analysed to determine if there was any sequence to occupant actions during pre-evacuation. Given the limitations of the dataset, analysis was restricted to include occupants' *first*, *second*, *third* and *forth* actions. In addition, we examined occupants *last action* and where occupants undertook only one action their *first and last action*. The data suggests that *'gather/provide information'* constituted the most reported first (62%), second (48%) and third (61%) actions. However, preparing for evacuation was the most reported forth (54%) action. The last reported action were actions associated with *'preparing for evacuation'* in 68% of the reports within the database. Only 18% of reports represented seeking information type actions. The trend was not so clear for those occupants that only stated one action, i.e. occupants whose first action was also their last action. For these, actions were evenly distributed between gather/provide information (43%) and preparing for evacuation (51%). This analysis suggests a trend in which occupants were gathering/providing information early during their pre-evacuation and then preparing for evacuation towards the end of their pre-evacuation phase. These conclusions are considered important as they suggest a trend in the ordering of occupant actions during pre-evacuation. Reported initial actions tended to involve seeking information, whereas reported final actions tended to involve preparation to evacuate. Again this serves to highlight the need to provide occupants with immediate and good quality information so that they do not have to waste precious minutes determining the nature of the event before beginning their evacuation.

Pre-Evacuation: Nature of the information gathering process

The seven classes of actions were modified and refined into eight action categories [1]. The *'gather/provide information'* action was divided into four specific actions; Seek Information (i.e. physically move to acquire information), Instruct or instructed by others, Local Verbal Communication and Remote Verbal Communication (i.e. telephone). Here we examine issues associated with Remote Verbal Communication. While engaging in telephone conversations is one means by which people can exchange information, it has the potential to slow occupant pre-evacuation and consequently increase their overall evacuation time. It is therefore important to gauge the frequency of telephone usage during emergency situations and understand the rationale behind telephone usage. Remote communication i.e. use of telephones, was frequently cited during pre-evacuation and with some frequency during the evacuation itself. In total some 30 telephone usage actions were reported (24 outgoing and 6 incoming) during pre-evacuation by occupants that successfully evacuated (see table 1). The distinction between survivors and fatalities is necessary as many calls were made by occupants who were trapped on the upper floors and were unable to evacuate. Here we are primarily interested in the calls made by occupants that successfully evacuated. These came from 19 people, i.e. 19/94 (20.2%) of the population that stated actions and could have survived. Furthermore, 75% of the outgoing phone calls were to relatives. Thus the majority of phone calls made by

survivors during *pre-evacuation* were not to emergency personnel or colleagues within the building but to relatives. It is interesting to examine the nature of these calls.

The database suggests that in these phone calls occupants would typically discuss the unfolding events with family commonly telling them what had happened and what their intentions were, for example, *"I called my nanny at home and told her to page my wife, tell her that a bomb went off, I was ok, and on my way out. My wife had taken our 9 month old for his check up."* [Experience 79]. In other instances occupants supplied information about the event and at the same time requested additional information, for example, *"I hung up with them and proceeded to call my wife and tell her I think some kind of bomb went off. She said she would check the TV and get back to me. By this time it was approximately 08:55."* [Experience 1093]. The main reason for making the phone calls cited by survivors was to provide information to family members (9/24 or 38% of calls). Calling to provide purely emotional support, to gain information and or to warn or instruct other people of danger were found with only minor frequency. However, it should be noted that most conversations would involve some element of emotional support and an exchange of information of various types. Conversations in which callers stated that they loved someone but mainly discussed the event itself and what they were going to do next would have been classed as *Giving Information*. The propensity of occupants to make telephone calls is considered important as it is an action that slows occupant evacuation, especially as the majority of calls involved providing rather than receiving information.

Table 1: Recipients of telephone calls made from tower occupants and main topic of conversation

		Relative	**Friend**	**Colleague**	**911**	**Lift intercom**	**Total**
Survivors	**Pre-evacuation**	18 [75%]	4 [17%]	1 [4%]	1 [4%]	0 [0%]	24
	Evacuation	10 [53%]	3 [16%]	1 [5%]	1 [5%]	4 [21%]	19
		Main topic of conversation					
		Emotional support	**To get information**	**To give Information**	**Unknown reasons**	**warn / instruct**	**Total**
Survivors	**Pre-evacuation**	1 [4%]	2 [8%]	9 [38%]	10 [42%]	2 [8%]	24
	Evacuation	1 [5%]	1 [5%]	8 [42%]	8 [42%]	1 [5%]	19

Some 25 calls were made by occupants during their descent mostly by mobile phones although there are reports of occupants attempting to make use of land lines. The database suggests that trapped occupants made/received numerous phone calls, 76 calls from 46 occupants (1.7 calls/occupant), primarily to exchange information and for emotional support [1]. In addition, three survivors sent / received emails using mobile technology (Blackberry 2 hand held email devices) during the descent. They also reported that they passed the devices around to others during the descent. These emails were sent to and received from relatives and described what was going on around them. Other forms of information gathering such as radios and televisions are discussed in the main report [1].

Evacuation: Usage of elevators

Within the database there are no accounts describing the usage of elevators within WTC1. This is thought to be due to most lifts being disabled by the impact. However, there are 95 occupant accounts reporting some form of evacuation experience in WTC2. Of these, 26 accounts (28.4%) of elevator evacuation usage are pre-T2 and represent some 38 lift embarkations. Most of these accounts - 16/38 (42%) - took place at the 78th floor sky lobby and most - 11/16 (69%) - involved taking the lift all the way to the ground level. Two occupant accounts describe using elevators to travel upwards (from the 44th floor) to collect personal belongings on the 80th floor. This involved changing elevators at the 78th floor sky lobby. On their descent they only took the elevator from the 80th to the 78th floor. In total 5 occupants reported using an elevator more than once. All of these involved travelling to the 78th floor then changing to another elevator (2 to the bottom and 2 to the 80th floor; to collect belongings).

Given that the majority of elevator use occurred at the 78th floor sky lobby it was pertinent to assess, in more detail, the occupant accounts at this location. The occupant accounts suggest that the sky lobby was

densely packed with people – most of whom were waiting for elevators for example, one occupant stated "*… he looked into the marble-lined lobby, more than half a city block long, and saw people were standing shoulder to shoulder, waiting for elevators.*" [Experience 2182]. Other accounts substantiate his description of congestion and substantial elevator queues. It was particularly unfortunate that the assault on WTC2 took place just above the 78th sky lobby, a staging point where numerous occupants were waiting for elevators and assessing their evacuation options.

The significant elevator use, in itself, indicates that occupants did not follow the recognized protocol for evacuation. There seemed to be some confusion as to whether using the elevators was a permissible evacuation strategy, for example an occupant is reported to have said *"Shouldn't we be taking the stairs in an emergency like this?"* which was replied by her colleague with, *"No! Just get in the elevator! C'mon!"* [Experience 1172]. Another occupant stated that "*it was okay to take an elevator as they still had power.*" [Experience 1064]. Some occupants explicitly stated that they did not relish the thought of evacuating via the stairs, "We got to the 78th floor and Judy said, *"Let's see if the elevators are working. I'm thinking I shouldn't be taking an elevator, but I guess the thought of walking down 78th floors in my high heels was not exactly something I wanted to do."* [Experience 3314]. Regardless of their reasons, significant elevator use occurred in WTC2. Further accounts described 25-30 people being in elevators and that "*elevators were all over capacity*" [Experience 2389].

Based on the reported usage of elevators in the database, it is not possible to conclude that the elevators played a significant positive role in the evacuation success of WTC2. However, it is interesting to note that occupants in WTC2 reported low levels of congestion on stairs and high rates of descent (see [1] and sections below). It would appear reasonable to assume that the heavy reported usage of elevators in WTC2 prior to T2 could have made two positive contributions to the evacuation. Firstly, heavy usage of elevators would have assisted clearing large numbers of people from the upper floors of WTC2 prior to the assault on that building. Secondly, the usage of elevators by significant numbers of people would have eased the congestion on the stairs in WTC2, making movement on the stairs more efficient.

Evacuation: Obstructions on Stairs

In the accounts of survivors from WTC1 it was noted that occupants made frequent mention to adverse conditions on the stairs. This included the effective halving of stair case capacity as un-injured occupants tended to stand to the left of the stair, either to allow the injured to pass down the stairs or to allow firefighters to pass by up into the building. In addition, many occupants mentioned experiencing water on the stairs. Clearly, all these obstructions would contribute to slowing the descent of occupants in WTC1. Unlike the accounts from WTC1, there were no reports of water on the stairs from WTC2. Accounts describing delays resulting from the passage of injured occupants were scarcer in WTC2. This may have resulted from the initiation of the WTC2 evacuation some 17 minutes before the T2 impact and the heavy use of elevators in the evacuation of WTC2. It should also be recalled that over 90% of the WTC2 accounts for which we have response time data relate to people who started their evacuation prior to T2. Thus, a considerable amount of information within the database relates to the early stages of the incident. In the accounts from WTC2 there were only five reports describing the passage of the injured down the stairs. Some accounts described occupants helping other injured occupants down the stairs. These five reports describe the injured passing non-injured on the stairs, for example:

> *"The critically injured were passing us"* *[Experience 3286]*

> *"When we got below the thirtieth floor, they started to bring down injured people from flights above."* *[Experience 2614]*

Another account describes having to stop to let the injured past,

> *"We just keep going after that, not stopping until an injured man needs to pass us. When he passes us he turns around and says "how you doin'?" We realize that it's Keating Crown, a coworker injured when the plane hit the building. Blood covers him from head to toe."*

[Experience 322]

Another account describes an evacuation regime in which occupants only used one side of the stairs.

> *"Firefighters were coming up on the inside, people were going down on the outside, and the injured people went down the middle."* *[Experience 3129]*

Reports of firefighters in WTC2 were also scarcer than in WTC1 although firefighters were obviously present. This too may result from significant numbers of firefighters entering the building only after the WTC2 impact and some 17 minutes after the WTC2 evacuation started. It should again be recalled that 45% of the WTC2 accounts in the database relate to people who started their evacuation prior to T2. Only three reports describe the progress of firefighters on the stairs. As in WTC1 they were described as carrying equipment and moving slowly:

> *"It was somewhere in the 50s that they encountered the first firefighter, she said. They were moving in small packs, carrying a load of heavy equipment, which clearly slowed them down."* *[Experience 762]*

Evacuation: Estimating a Rate of Descent

In order to calculate a descent rate it was necessary for occupants to specify approximately where they were at a two different times, preferable some distance apart. Unfortunately in most instances occupants were unable to define the time that they begun evacuating and /or where they were at specific times. Indeed, only 24 reports provided enough detail to attempt a calculation of descent movement rate. Furthermore, most of these accounts failed to provide a suitable time reference at a specific location. For many accounts a *time range* could be determined. As such, these accounts had both an upper and lower bound to each time reference, i.e. *"I was at floor 24 sometime between 8:46 and 8:51"*. Two measures were devised for these occupants. One measure was termed 'conservative' and represents the difference between the earliest estimated departure time and the latest estimated arrival time. This measure represents the estimated maximum reported time to travel between the two locations. The second measure is termed 'optimistic' and represents the difference between the latest estimated departure time and the earliest estimated arrival times. This time represents the shortest reported time period to travel between to locations.

Another difficulty was the degree of variability in the level of detail provided in occupant reports. Whilst some accounts may have specified their action at a specific time marker they would only provide a vague description of their location (for example, between the 2nd and 44th floors). Similarly, reports that specified precise markers and locations for departure and arrival (for example "I left floor 102 at 9:02 and evacuated at 9:45") may include numerous non-movement actions during the descend (for example, leaving the stairs to make a phone call in a conference room, stopping to get a drink, etc.). Where the data was grossly unreliable (e.g. '*I was somewhere between the 2nd and 44th floor*'), it was excluded from further analysis. The remaining data was assigned a level of reliability according to the accuracy of, the markers and locations specified for departure and arrival and the number of obstructions and non-movement actions undertaken during evacuation.

Based on these factors each data point was classified as either:

- **Reliable**: Markers and locations well known and there was little extraneous actions *en route*.
- **Less reliable**: Markers and / or location were not well known but time references had relatively small ranges and / or there were some extraneous actions *en route*,
- **Unreliable**: Markers and / or locations were not well known and time references had large ranges and / or there were numerous extraneous actions *en route*.

Finally, some occupants specified a single departure time but had a range for arrival times or *vice versa*. The optimistic measure was taken as the shortest travel time and the conservative as the longest travel time. Occupants that specified exact timings for both departure and arrival were included in both the conservative and optimistic datasets.

Table 2: Summary of stair descent rates (floors/minute) and travel speeds (m/s) data for both towers

		Reliable	Less reliable	Unreliable	All	All - excluding unreliable
		floors/minute				
WTC 1	**Min**	[1.58] (1.76)	[0.5] (0.8)	[1.13] (1.36)	[0.5] (0.8)	[0.5] (0.8)
	Max	[2.5] (2.5)	[1.82] (5.45)	[2] (2.4)	[2.5] (5.45)	[2.5] (5.45)
	Mean	[1.82] (2.12)	[1.21] (2.16)	[1.68] (1.98)	[1.48] (2.1)	[1.41] (2.15)
	#	[5] (5)	[10] (10)	[5] (5)	[20] (19)	[15] (15)
WTC 2	**Min**	[1.3] (2.4)	[0.97] (1.09)	[0.92] (1.58)	[0.92] (1.09)	[0.97] (1.09)
	Max	[3.53] (4.29)	[1.67] (3.53)	[1.54] (3)	[4.29] (3.53)	[4.29] (3.53)
	Mean	[2.11] (3.08)	[1.34] (2.04)	[1.29] (2.36)	[1.79] (2.48)	[2.02] (2.54)
	#	[6] (7)	[4] (4)	[5] (5)	[16] (15)	[11] (10)
		m/s				
WTC 1	**Min**	[0.25] (0.28)	[0.08] (0.13)	[0.18] (0.22)	[0.08] (0.13)	[0.08] (0.13)
	Max	[0.27] (0.41)	[0.31] (0.83)	[0.32] (0.39)	[0.32] (0.83)	[0.31] (0.83)
	Mean	[0.26] (0.33)	[0.19] (0.34)	[0.27] (0.31)	[0.23] (0.33)	[0.21] (0.34)
	#	[3] (5)	[9] (10)	[5] (5)	[17] (20)	[12] (15)
WTC 2	**Min**	[0.2] (0.37)	[0.15] (0.17)	[0.15] (0.25)	[0.15] (0.17)	[0.15] (0.17)
	Max	[0.23] (0.71)	[0.26] (0.57)	[0.25] (0.47)	[0.26] (0.71)	[0.26] (0.71)
	Mean	[0.21] (0.49)	[0.21] (0.33)	[0.21] (0.37)	[0.21] (0.41)	[0.21] (0.43)
	#	[3] (7)	[2] (4)	[5] (5)	[10] (16)	[5] (11)

[] = conservative estimate, () = optimistic estimate

Evacuation: An Estimated Rate of Descent

Using the above scheme it was possible to calculate an approximate measure of the rate of descent for 17 occupants in WTC1 and 12 occupants in WTC2. Furthermore, in some accounts sufficient time / location references existed to sub-divide their movement into two portions, i.e. time from X to Y and then from Y to Z. These are referred to as movement phases in this paper. In total 4 reliable accounts were available for WTC1 and 4 for WTC2. These accounts yielded 5 distinct movement phases for WTC1 and 7 distinct movement phases for WTC2. Of the less reliable data, 8 accounts yielded 10 distinct movement phases for WTC1 and 3 accounts yielded 4 distinct movement phases for WTC2. For each tower we found 5 unreliable accounts that yielded 5 distinct movement phases. A summary of the calculated stair descent rates (floors/minute) and travel speeds (m/s) are presented in table 2.

It can be seen from figure 4 that the reliable data for WTC1 is tightly clustered at 1.8 floors/minute (conservatively) and 2.1 floors/minute (optimistically). The fastest descent rate was 2.5 floors/minute and was achieved by an occupant who began her evacuation at 10:08 and moved under essentially free-flow conditions. Jake Pauls [4] suggests that a stair descent rate of 3.0 floors/minute would represent a slow-moderate speed in high-rise buildings. Clearly, the stair descent rates determined for WTC1 are significantly below this value. In contrast the data from WTC2 appears to be less well clustered with reliable data suggesting a mean conservative rate of 2.1 floors/minute and an optimistic mean rate of 3.1 floors/minute. The increased descent rate in WTC2 may have resulted from reduced levels of congestion on the stairs [1] and the absence of significant amounts of water at the time that the accounts were made. Once again recall that 45% of the WTC2 accounts relate to occupants who commenced their evacuation prior to T2.

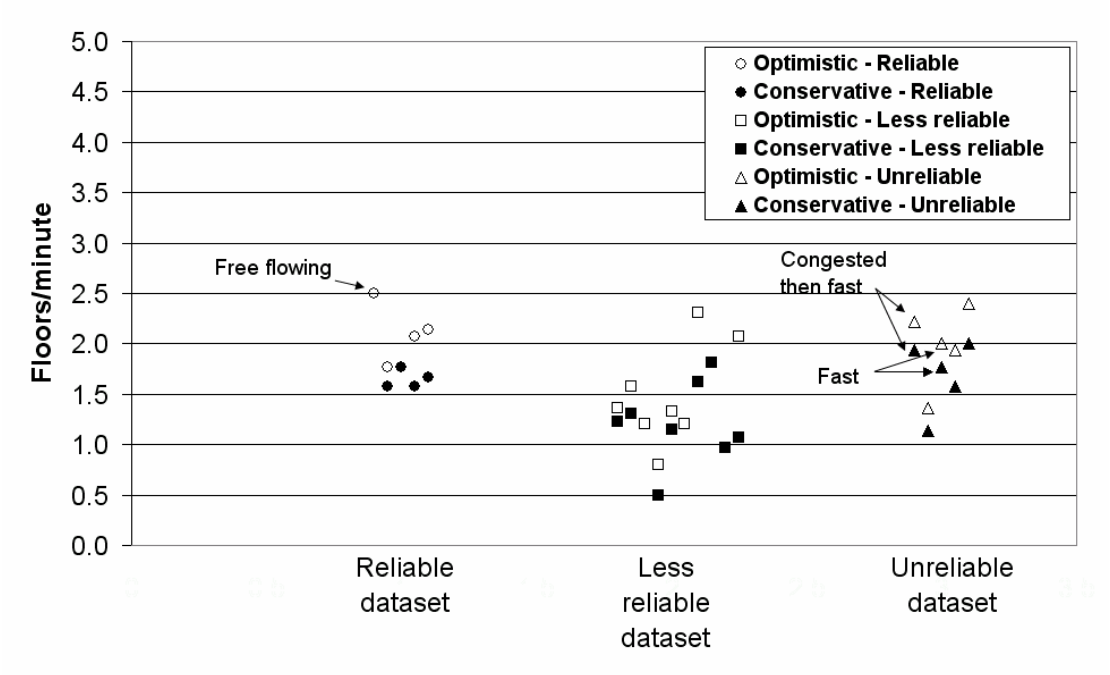


Figure 4: Estimated floors/minute for WTC1 (occupants' description of flow conditions denoted by arrows)

Most of the reliable and less reliable data used in estimating the descent rates in WTC1 originated from evacuations that started early in the evacuation process, just after T1. It is likely that these people would have encountered heavy congestion on the stairs. In WTC1, 53% of the people started their evacuation just after T1 and 81% started their evacuation just before T2. Indeed, most of the people in this sample reported delays and some undertook non-descent actions. The main reported delays were meeting firefighters (9 accounts) and congestion (6 accounts, 4 from the reliable data set). Other less frequently reported delays involved encountering locked doors along the evacuation route and having to move aside to let the injured pass. Only one person in this group described experiencing no delays. In estimating the descent rates in WTC2, all of the reliable data originated from evacuations that started shortly after T1 and before T2. However the data from the less reliable data set originates from much more varied evacuations, some starting prior to T2 and some after T2. There were only 2 accounts in the WTC2 dataset that reported meeting firefighters coming up the stairs and 6 accounts of congestion on the stairs (5 of these were from the reliable data set), a further 4 data points involved little congestion.

Evacuation: Estimating a descent travel speed

A more general measure of movement rate is the average movement velocity or travel speed. To estimate the movement speed it is necessary to estimate the travel distance that each occupant traversed between two locations. Unfortunately, the data available from the occupant accounts made this rather difficult. Indeed, in most accounts it was not possible to determine which staircase was used, yet alone whether occupants travelled down the inner or outer path on the stairs. Compounding this difficulty, some occupants undertook non-evacuation movement actions during their descent.

Given these limitations an estimate was calculated based on the assumption that occupants moved down the centre line of the staircase and includes non-evacuation movement time but not additional distances that may have been incurred. As such the estimate of travel speed in this study represents an *average* travel speed in a continuous line down the centre of the stairs from location X to location Y. As detailed floor plans of the buildings were not available for this study, estimates of stair geometries were made from various published sources containing the dimensions of stair geometries. Similarly, the length of the stair transfer corridors (protected horizontal corridors used to reposition stairs within the building) were not known. Based on material published in *USA Today*, it is estimated that these transfer corridors were between 10-35 metres in

length. However, as it was not possible to determine which staircase each occupant used it was decided to ignore these distances in the travel speed estimates. Whilst not ideal, the impact of this omission is only likely to be small given the large distances that occupants travelled. Finally, for those occupants for which it was not possible to determine which staircase was used (i.e. most occupants), an average of the travel distance for the larger staircase (B) and the smaller staircase (A or C) was taken. The total estimated descent distance from the 110th floor to the stairwell exit on floor 2 was calculated as 1061 m when using staircase B and 1026 m if using staircases A or C.

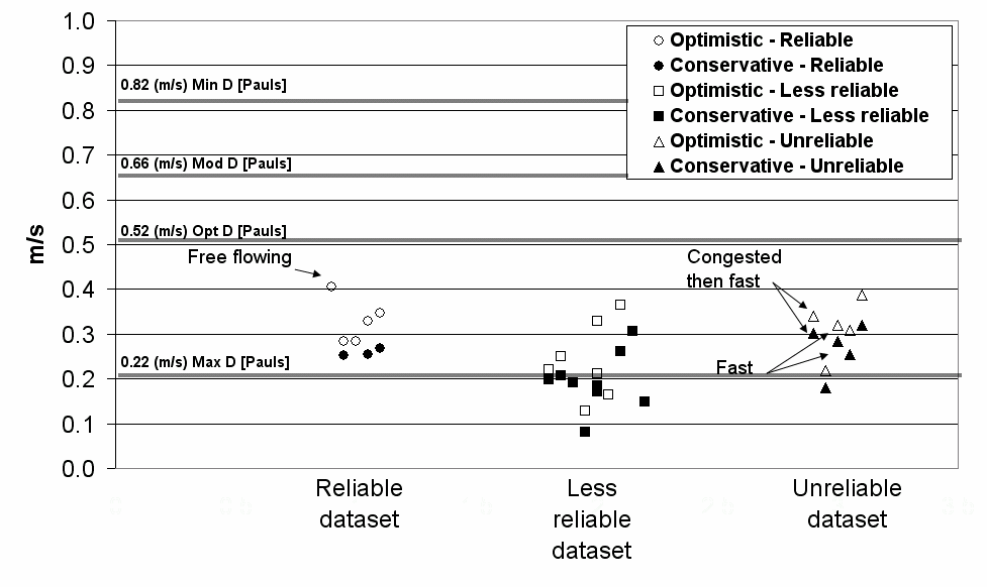


Figure 5: Estimated movement speed (m/s) for WTC 1 (D=population density)

Examining the reliable dataset for WTC1 suggests relatively slow movement speeds. The mean estimated average movement velocity is optimistically calculated as 0.33 m/s and conservatively calculated as 0.26 m/s. An occupant that began descent at 10:08 and described her descent as "*free flowing*", only attained an average estimated movement speed of 0.41 m/s. This average movement speed is below Pauls estimated movement velocity in his optimum density zone, i.e. 0.52 m/s [5]. All of the movement speeds are above Pauls crush density velocity (see figure 5) [5]. The spread of calculated movement speeds is 0.25-0.41m/s. The average estimated velocities in WTC2 are faster than those in WTC1. The mean average movement speed using only the reliable data for WTC2 was optimistically estimated as 0.49 m/s and conservatively at 0.21 m/s. The mean for WTC2 is broadly equivalent to Pauls movement rate in optimum conditions [5]. In WTC2 the range of velocities is broader then in WTC1 (0.2-0.7 m/s) with some occupants having relatively fast estimated velocities. These travel speeds are consistent with the implied conclusions that the available data for WTC2 is strongly focused on occupants who commenced their evacuation prior to T2, and hence prior to adverse physical conditions developing. Crowding of people on stairs would also have been reduced by the considerable number of people using elevators.

CONCLUSIONS

In reviewing the results presented in this paper, it must be remembered that the data on which the analysis is based was not collected in a scientific manner but from accounts in the public domain, primarily press accounts. As such it is difficult to generalise many of the findings. However, as much of the data was reported days after the incident, it provides a unique and insightful glimpse into the human response to such emergencies.

One of the key outputs from this research is information relating to occupant response time. Of the 115 people who provided information on which a response time could be estimated, 60% responded within 5

minutes of the assault on WTC1. In WTC2, over 90% of people who provided response time information, responded within 5 minutes of WTC1 being hit. From the data, it also appears that elevators played an important role in the evacuation of WTC2. There are a significant number of reports of people using elevators in WTC2 prior to the building being hit. This would have speeded up the evacuation process in WTC2 however, a significant number of people also delayed their evacuation – some with fatal consequences - waiting for elevators. Clearly, more work is required in exploring how elevators can be effectively used in large scale building evacuations. Occupant travel speeds on the stairs were also noted to be faster in WTC2 compared to WTC1. The data suggests that in WTC1, optimistically, mean movement speeds could have been as low as 0.33 m/s with a spread in travel speeds of 0.25-0.41m/s. In WTC2, the mean average movement speed using only the reliable data for WTC2 was optimistically estimated as 0.49 m/s with a spread in travel speeds of 0.2-0.7 m/s. These travel speeds are consistent with the implied conclusions that the available data for WTC2 is strongly focused on occupants who commenced their evacuation prior to T2, and hence prior to adverse physical conditions developing. Crowding of people on stairs would also have been reduced by the considerable number of people using elevators.

Of the people who provided information relating to their actions, 20.2% stated that they made phone calls. A significant number of these calls, 75%, where not to emergency services or colleagues but to family members and the majority of phone calls made by survivors were in the *pre-evacuation* phase. Surprisingly, most of these were to assure family members that they were OK – not to secure further information or advice. While it is difficult to generalise due to the lack of data, the rapid response times of occupants in WTC2 relative to WTC1 may have contributed to the smaller death toll experienced in WTC2. A more complete analysis is contained in the full BDAG report [1]. This analysis includes issues such as response of fire wardens, group behaviour, collection of items by evacuees prior to evacuation, occupant assessment of the situation, information gathering using electronic devices, occupant interaction with firefighters.

The data collected and analysed in this study will be used as the starting point for a much larger project into the evacuation of the WTC. The project, called HEED – High-rise Evacuation Evaluation Database – funded by the UK EPSRC (project GR/S74201/01) and involving the Universities of Greenwich, Ulster and Liverpool, aims to interview 2000 survivors of the WTC twin towers evacuation. The information from the this study and the present study will be instrumental in shaping our building codes and standards, building design practice and building management procedures for years to come. Furthermore, the information collected would be invaluable in assisting the development of behaviour models that are key components of evacuation models used in performance based building design.

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REFERENCES

1. Galea E.R. and Blake S.J, Collection and Analysis of Data relating to the evacuation of the Word Trade Centre Buildings on 11 September 2001, Report produced for the UK ODPM, to appear 2004.
2. Cauchon D., Not found or not existing, 40 names to leave WTC death toll, USA Today 29/10/03
3. Cauchon D., For Many on Sept 11, Survival was no accident, USA Today 19/12/01
4. Pauls J., Vertical evacuation in large buildings: Missed opportunities for research, *Disaster Management*, Vol. 6, No. 3, pp. 128-132, 1994.
5. Pauls J., Movement of People, in DiNenno (ed.) SFPE Handbook of Fire Protection Engineering, 2nd edition, pp3-263 to pp3-285, ISBN 0877653542, 1995.