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Vertical Evacuation in Large Buildings: Missed Opportunities for Research

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Summary

Although evacuation has long been a prime response to serious emergencies in buildings it has been studied relatively incompletely and superficially. As a result there is considerable confusion and even some misinformation about strategies, tactics and efficacy of evacuation in large buildings where, as in the case of high-rise (multi-story) buildings, evacuation typically occurs via stairs and more rarely by elevators (lifts). The case of the total evacuation of the two 110-story towers in the World Trade Center, New York City, is discussed to illustrate some possible flaws in our approaches to, understanding of, and dependence on vertical evacuation. Although that evacuation, on February 26, 1993, entailed on the

> order of 100,000 person-hours of occupant evacuation activity, relatively little systematic study has been conducted of what actually occurred. Thus, among lessons learned in that event, we cannot include a significantly improved understanding of large-scale evacuation of unusually large, high-rise buildings.

A pre-Mao Chinese proverb recommends that "Of the thirty-six ways to escape danger, running away is best" (Quarantelli 1973). Evacuation has a long history as a prime response to danger but, perhaps partly because it is typically performed in haste -- with attention focused on preservation of life, it has been subjected to relatively little systematic study. Experience suggests, however, that the relative paucity of research is partly a result of a general reluctance, in the building safety establishment, to study those aspects of building safety involving human factors. Indeed at least one of the few students of evacuation has contrasted psychological approaches with engineering approaches, using (amongst others) the title, "Crowd Psychology and Engineering: Designing for People or Ballbearings?" (Sime 1993).

As a long-term (27-year) student of evacuation and one working with both engineers and psychologists, I have often shared this opinion. Building upon personal experience, this brief paper is a somewhat informal reflection or commentary reviewing what we know about evacuation and, more importantly, what we are failing to find out -- *and apply* -- regarding the crucial human factors.

Background. In 1967, while a student in architecture and a part-time researcher at the National Research Council of Canada (NRCC), I began to examine the technical base for typical building code requirements for means of egress (means of escape). In 1969, when beginning an 18-year term as a full-time research officer with NRCC, I was fortunate to be asked by local and national fire authorities to observe and document evacuation drills in high-rise office buildings. Unprecedented observations were done over a period of a few years followed by two decades of publications, mostly dealing with application of knowledge about evacuation facilities and procedures, including those appropriate for people with disabilities. Also during this period, extensive field studies were performed of crowd movement and other behavior at facilities used for public assembly including those at Olympic Games in 1976 and 1988. A bibliography (at the end of this paper) lists representative literature resulting from this work. Only a portion of the insights and recommendations (for design and management) have been published from this work. Currently an effort is being made to prepare a book dealing generally with people movement in buildings and public places; however, progress on this is delayed by the demands of a consultancy and higher-priority work on a book dealing with the political realities of building safety control. One of the facilities recently dealt with in consulting activities was the World Trade Center in New York City. However, the discussion presented in this paper is based on information (about the February 1993 evacuation of the World

Trade Center's 110-story towers) obtained outside that consulting activity. The most notable resource was the special issue of *Fire Engineering,* December 1993, devoted to the World Trade Center bomb incident.

Crowd Movement Characteristics during an Evacuation

It should be clear that an evacuation of a multi-story building entails more than simply crowd movement. However, crowd movement, and the few quantitative characteristics that describe it, is the most easily documented aspect of an evacuation. Unfortunately, up until the Canadian observations of evacuation drills in high-rise office buildings in the 1970s, little detailed documentation had been done and thus, even of this relatively straightforward aspect of evacuation, there were some serious misconceptions in the technical literature.

Notably the Canadian observations were done at a time when field video recording techniques were in their infancy; equipment was expensive, heavy plus unreliable, and it offered relatively little performance in terms of recording time, sensitivity, etc. Therefore, many data were collected using audio recording information only (e.g., small cassette recorders which allowed various kinds of observations to be recorded and time-scales to be accurately preserved).

Key qualitative and quantitative data included: *what* were people doing; *who* and how many of them were doing it; *when* did this occur and what were the (time-based) rates of the occurrence;

where did this happen; and *why* (i.e., what factors influenced people's behavior).

From these data were typically derived the three main quantitative characteristics of crowd movement:

> *Density* the number of persons in a unit of area,
> *speed* the distance travelled in a unit of time, and
> *flow* the number of persons passing a point in a unit of time.

Generally, flow is the product of speed, density and the width of the travel route. For example, a flow of 1 person per second occurs at a point on the travel route when the density of the crowd is 1 person per square meter, the movement speed is 1 meter per second and the route is 1 meter wide.

Observations, combined with a critical review of literature, indicated that there were significant errors in predicting these relatively straightforward quantitative characteristics of crowd movement as well as the resultant evacuation times to clear all or part of a building. Prior to the mid 1970s, influential literature presented overly optimistic estimates and predictions. A full discussion of the errors is beyond the scope of this paper; therefore the interested reader is directed to items listed in the selective bibliography (especially Pauls 1988). Many earlier predictions tended to seriously underestimate -- by a factor of two -- the *flow time* (the time

during which there is crowd flow past a point such as at an exit stair discharge door). Another error was to ignore the *start up time* (the time between the initiation of an emergency condition and the beginning of crowd flow).

Total Evacuation Time. Stated most simply, *minimum total evacuation time* is the sum of start up time and flow time. The literature (e.g., Pauls 1988) contains formulas for calculating total evacuation time for a multistory building of a given population. Generally, an early error in using predicted times was to assume that they represented *maximum* times because of purportedly conservative estimates used for crowd movement characteristics. In reality, many literature sources reported flows that were unrealistically high; often briefly-sustained *peak flows* (observed under some nonemergency conditions) were assumed to be representative of sustained *average flows* that would occur in an emergency. It was incorrectly rationalized that the urgency of an emergency condition would impel people to perform -- in a sustained fashion -- at the best levels observed in other, nonemergency conditions. From studies of people's behavior in fire emergencies (e.g., Bryan 1988; Canter 1980, 1990; and Sime 1993) we know that this is not a good assumption because of the true nature and range of human social behavior -- in addition to evacuation -- in an emergency. The bottom line

is that evacuation times, predicted from mathematical formulas, should be regarded as *minimums* not *maximums.*

World Trade Center Evacuation in February 1993

A Prediction of Minimum Total Evacuation Time. Without going into detail on the formula involved (Pauls 1988), here is a prediction of the *minimum* time required under optimum conditions to evacuate the two 110-story towers of the World Trade Center in New York City. The prediction assumes, per tower, 20,000 occupants (with each occupant averaging 20 square meters of floor area). This population estimate is somewhat lower than the 25,000 referred to in some reports of the incident but higher than would be predicted based on studies of actual occupancy of office buildings in North America (where actual office occupants, as opposed to assigned workstations, would average approximately 25 square meters of floor area per person). The prediction is based on three exit stairs in each tower having a combined width of approximately 4.3 meters and an effective width (as defined in the literature) of 3.4 meters. Assuming optimum flow conditions and optimum stair-use capability by each occupant, the towers could be totally evacuated by stairs in a *minimum* time of approximately 80 minutes. Note that, assuming a slow-to-moderate descent speed of three stories per minute, a relatively fit person starting from the 110th floor would require about 37 minutes to descend to the ground level. This means that, even in the best of conditions, many people -- especially in upper portions of the building -- would spend a significant portion of the total evacuation time simply waiting to make use of the heavily queued stairs. (New York City Fire Department Captain Downey, 1993,

reported personnel requiring up to four hours to *ascend* the stairs to the top floor during the February 1993 incident.)

Actual Evacuation Conditions and Times. Unfortunately, no reliable estimates have been found in the published literature of the actual crowd movement characteristics and evacuation times in the February 1993 evacuation. There is abundant information about the suboptimal, indeed abysmal, conditions in the exit stairwells during the several hours it took to clear the two 110-story towers. For example, there were (overall in the Center) on the order of 1,000 injured occupants; the stairways had some unusual configurations at some levels and they were not familiar to occupants; the stairwells lacked lighting and were completely dark in many areas; the stairwells were contaminated with smoke; there was extensive counterflow on the stairs as many firefighters and other emergency responders had to ascend the stairs to perform their duties; and some people required physical assistance -- including various carries -- thereby slowing travel in both directions. In the first published account of a small study, interviewing evacuees with disabilities, evacuation times for the small sample of 27 persons ranged from under one hour to over nine hours, with an average of just over three hours (Juillet 1993).

Crucial, Uncollected Data on Evacuations. As outlined above, from a scientific and practical perspective one would want to have data on *who, what, where, when* and *why.* Many of these data are "committed" (to use a phrase coined by John Archea) by

evacuees and others using the stairs at locations that do not lend themselves to easy observation in an emergency such as the post-bomb evacuation of the World Trade Center. However there are, in each tower (and in buildings generally), a few easily observed positions where immensely useful data are "committed," namely at the exit discharge doors at the base of the stairwells. Two or three, continuously operating video cameras here, feeding into video recorders, could have provided immensely useful data. (Such cameras and recording systems are often installed for security purposes.) For example, the total number of evacuees and the total number of emergency responders using the stairs at this point would be directly available, thus eliminating ambiguity about actual number of evacuees. Also, the exact *chronology* of outflow and inflow -- plus data that could be used to identify each person, and thus identify where he or she came from -- would be obtainable. (In evacuation drill studies by the author in Canada during the early 1970s and in Australia in 1985, such data were collected, sometimes even without using video recorders; the data proved to be of immense value in understanding what happens in evacuations. See, for example, Pauls and Jones 1980.) Such information-gathering systems -- combined with a time-logged record of crucial communications by emergency responders and supervisory staff within the building -- would be the equivalent of the black boxes and cockpit voice recorders which are commonly used in aircraft and which have been crucial in crash investigations. Given the ever-decreasing cost of the technology, why can such systems not be provided in large buildings which could be

occupied by tens of thousands of people as opposed to the few hundreds, at most, occupying a large commercial airliner?

Research on Occupant Behavior. Turning from the research that could have been to that which might be, two very small studies have begun on occupant behavior in the World Trade Center incident. The first, based on videotaped interviews of 27 of the occupants who reported some physical disability which affected their evacuation, has been reported in very preliminary form by Juillet (1993). The videotapes of the interviews could, ultimately, be analyzed in a variety of ways; however, as this paper is prepared, this does not appear to be the case. The second small study involved some 1600 mailback questionnaires distributed to selected World Trade Center occupants by the National Fire Protection Association (NFPA) several months after the bombing. Reportedly, about 400 or so were returned for analysis (to be done by Fahy of NFPA and Proulx of the National Research Council of Canada). The four-page questionnaire did not go into detail on crowd movement conditions in the stair. At least there was not the focus on this topic to the extent there was in earlier questionnaires used in 1970 in Canada and 1985 in Australia to augment observations of evacuation drills in tall office buildings. In these earlier studies, a ten-page mailback questionnaire was employed and return rates were about 90 percent. Some findings from the one in 1970, in a 21-story office building, were reported by Pauls and Jones, 1980.

It is unfortunate that there is not much support from safety organizations for more-thorough and timely surveys using either questionnaires or interviews or both to learn what actually happened -- *from the building occupants' point of view* -- in evacuations such as that at the World Trade Center.

In what was described as the largest emergency evacuation to date, there was an estimated 100,000 (or more) person-hours of evacuation behavior, entailing some five million person-flights of stair use (not counting that by emergency responders). As noted earlier, this amounts to a lot of "data being committed." Experience of those researchers who have taken the effort to survey evacuees after such an event is that people want to share their experiences and they are capable of doing so in an evocative, information-rich fashion.

Two small examples from the World Trade Center might help make the case for greater attention to what happens in a major evacuation in a multistory building. Some interviews apparently revealed that evacuees with walking difficulties were told to keep to the right side of the exit stairs to facilitate traffic including counterflow by emergency responders. However, on all three stairs in Tower 1 the right side of the stairs is the outer side of the dogleg (switchback) stair configuration where the handrails do not extend the full length of the flights! The inside -- the left side for a person descending -- has full length handrails including horizontal extensions terminating at newel posts. Of course people had even more

difficulty than should have been the case and, apparently, at least one person's fall was attributed to this. Surely here is the kind of nitty-gritty information that is needed to help design future buildings better; retrofit existing ones; and manage evacuations with more attention to simply-understood, but important, human factors.

The second example is a more general observation based on a comparison of reports prepared for publication by fire service personnel and those prepared by someone involved with the 27 interviews of people with disabilities. From the latter we learn that there was much social interaction among the occupants including all forms of assistance in coping with the situation (e.g., physical assistance in getting down the dark, smokey, crowded stairs). But a reading of the many accounts (in the special issue of *Fire Engineering)* by fire service personnel could easily lead one to think that only firefighters provided assistance. Yes, there were important acts of rescue performed by firefighters but that is their job for which they receive some training (which could be the subject of another paper dealing with ergonomics of assistance techniques). Why can we not document better all the other assistance provided long before firefighters even arrive on the scene, especially on the upper floors of a very tall building? Note that an officer of the New York City Fire Department, responsible for operations in one of the Center's 110-story towers, suggested allowing "approximately two to three hours for a climb to the 60th floor" (Burns 1993).

Blame the Victim. Occasionally, as in other areas, the prime victims of an emergency are blamed for doing something that, in hindsight, is judged to be less effective than some other activity could have been. They might even be accused of doing something judged to be detrimental to themselves or others. For example, various fire service accounts of the World Trade Center bombing and evacuation imply criticism of occupants who -- lacking information from building authorities and the fire service -- initiated their own evacuation shortly after the bomb blast sent smoke to upper floors of the two 110-story towers. In the fire service accounts of the incident, where this is referred to as "self evacuation," there almost seems to be an implication that this amounts to *unauthorized* evacuation. One account by New York City's Fire Department Chief Fusco (1993) notes, "people opening doors in stair shafts allowed smoke to migrate from floor to stair shaft or vice versa." Relative to other routes -- notably elevator shafts -- stairs were less important to smoke migration. Indeed, door openings could easily have had the effect of making the stairs more tenable by diluting smoke to less-damaging concentrations. Also, with lighting circuits de-energized because of overall power failure, the open doors were a means of getting some light into the otherwise dark stairs. Most important, neither the fire services nor anyone else offered the occupants any other options that appeared workable given their perceptions of the event. Moreover, after the firefighters had sized up the situation, they too focused efforts on evacuation.

Furthermore, on the theme of *not* providing information to building occupants, how many office workers in New York City are aware of the Fire Department's possible use of one of the two or three exit stairs in a building as "attack stairs," i.e., stairs that will be used extensively by firefighters, possibly entailing smoke logging of that stair either intentionally or unintentionally? In this matter, as well as in others, there appears to be some myopia on the part of firefighters; they focus so much on their operations in the incident and fail to recognize the needs, motivations and activities of the very people they are supposed to protect. Chief among these needs is that for information.

Information. Repeatedly in studies of disasters and smaller-scale emergencies the importance of information and communication is emphasized. Early in the work by Canter, Breaux and Sime (1980) on human behavior in fires, they summarized the situation as follows:

> The studies . . . support the view that fire is experienced as a complex, rapidly changing event, which, in its early stages at least, is usually highly ambiguous, providing little positive information to act upon.

Concluding Comments

Given the information needs of people in emergencies, how can we continue to ignore the opportunities presented to research what actually happens during a building evacuation? Not only do emergency responders appear to operate without a clear understanding of occupant evacuation, the building occupants face rude surprises when an emergency occurs. For example, occupants might not properly appreciate that, in a total evacuation, queuing and very long total evacuation times are inherent in our traditional and current approaches to means of egress design in tall buildings. Furthermore, they might not appreciate that, to optimize flow down a stair, one need not rush; rather, efficient evacuation is a combination of moderate speed -- which will be within the capabilities of all but a few percent of occupants -- and moderate densities with the closest person ahead of you about one arm's length away and to the side.

These insights have been gained in some of the very few studies that have examined vertical evacuation in detail using relatively simple tools to simply record *what* happened, *where* and *when.* Somewhat more sophisticated techniques, involving interviews and questionnaires, begin to give us insights related to *who* and *why.*

It is unfortunate that the major bomb incident and total evacuation of the World Trade Center in February 1993 will not add much to our meager collection of information about vertical evacuation. It is possible -- given slightly different smoke

generation and movement -- that the incident could have turned out much worse than it did (in terms of catastrophic life-loss in at least one of the two 110-story towers). On the other hand, perhaps it could have been a less upsetting and injurious event for the tens of thousands of people who, collectively, spent on the order of 100,000 hours searching for information and a way out (partly by traversing some five million person-flights of stairs). We cannot even say the event was an expensive lesson in terms of new insights into evacuation; it was merely expensive.

Some would argue that we learned the importance of communication -- and information generally. However, anyone involved with studies of the behavior of people in disasters and other emergencies already knows that lesson well. And, just as information is important during the impact stage of a disaster, it is important long before disaster strikes. Thus it is ironic that, although (as the old Chinese proverb puts it) running away is the best way to escape danger, we still do not have much information on what evacuation in buildings actually entails and we appear disinclined either to improve this situation or to apply more effectively what little we do know.

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Paul, here follows an excerpt from my 1994 paper which is provided in complete form as an attached Word file.
Jake

The following comments on the World Trade Center come from the paper, Vertical Evacuation in Large Buildings: Missed Opportunities for Research, Disaster Management, Vol. 6, No. 3, 1994, pp. 128-132, by Jake Pauls.

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"However there are, in each tower (and in buildings generally), a few easily observed positions where immensely useful data [can be easily obtained], namely at the exit discharge doors at the base of the stairwells. Two or three, continuously operating video cameras here, feeding into video recorders, could have provided immensely useful data. (Such cameras and recording systems are often installed for security purposes.) For example, the total number of evacuees and the total number of emergency responders using the stairs at this point would be directly available, thus eliminating ambiguity about actual number of evacuees. Also, the exact chronology of outflow and inflow -- plus data that could be used to identify each person, and thus identify where he or she came from -- would be obtainable. . . . Such information-gathering systems -- combined with a time-logged record of crucial communications by emergency responders and supervisory staff within the building -- would be the equivalent of the black boxes and cockpit voice recorders which are commonly used in aircraft and which have been crucial in crash investigations. Given the ever-decreasing cost of the technology, why can such systems not be provided in large buildings which could be occupied by tens of thousands of people as opposed to the few hundreds, at most, occupying a large commercial airliner? . . . It is unfortunate that the major bomb incident and total evacuation of the World Trade Center in February 1993 will not add much to our meager collection of information about vertical evacuation. It is possible -- given slightly different smoke generation and movement -- that the incident could have turned out much worse than it did (in terms of catastrophic life-loss in at least one of the two 110-story towers). On the other hand, perhaps it could have been a less upsetting and injurious event for the tens of thousands of people who, collectively, spent on the order of 100,000 hours searching for information and a way out (partly by traversing some five million person-flights of stairs). We cannot even say the event was an expensive lesson in terms of new insights into evacuation; it was merely expensive."