NIST NCSTAR 1-7

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Occupant Behavior, Egress, and Emergency Communications

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NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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U.S. Department of Commerce
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Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is "voluntarily provided safety-related information" that is "not directly related to the building failure being investigated" and that "disclosure of that information would inhibit the voluntary provision of that type of information" (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

This report describes the occupant evacuation of World Trade Center (WTC) 1 and WTC 2 on September 11, 2001. Multiple sources of information were collected and analyzed: over 1,000 new interviews with survivors (including 803 telephone interviews, 225 face-to-face interviews, and 5 focus groups); over 700 published interviews; 9-1-1 emergency calls; transcripts of emergency communications, historical building design drawings, memoranda, and calculations; formal complaints filed with the Occupational Safety and Health Administration; and other relevant materials.

The egress system, including stairwells and elevators, was described and compared to requirement of both contemporary and current code requirements. This report documents the emergency procedures, both as they were designed to be implemented, as well as how they were actually implemented on September 11, 2001.

The population in WTC 1 and WTC 2 on September 11, 2001, at 8:46:30 a.m. was enumerated and described, where the characteristics of the population were relevant to the subsequent evacuation, including training, experience, mobility status, among others. The progress of the evacuation of both towers was described in a quasi-chronological manner from 8:46:30 a.m. when WTC 1 was attacked, until 10:28:22 a.m., when WTC 1 collapsed.

Causal models were built to explore the sources of evacuation initiation delay (why people did not immediately start to leave the building) as well as normalized stairwell evacuation time (how long the average occupant spent in the stairwells per floor). Issues identified as contributing to either speeding or aiding the evacuation process were explored. Egress simulations provided context for estimating how long WTC 1 and WTC 2 would have taken to evacuate with different populations, using different models, and subject to different damage to the building.

Keywords: Building fires, egress, egress modeling, emergency communication, evacuation, human behavior, interviews, World Trade Center.

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Acronyms

ASTM	ASTM International
BPS	Building Performance Study
CATI	Computer Assisted Telephone Interview
ESU	Emergency Services Unit
FEMA	Federal Emergency Management Agency
FDNY	City of New York Fire Department
IBC	International Building Code
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NYC	New York City
NYPD	New York City Police Department
OSHA	Occupational Safety and Health Administration
PANYNJ	Port Authority of New York and New Jersey
PAPD	Port Authority Police Department
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
ft	foot
ft^2	square foot
in.	inch
L	liter
m	meter
µm	micrometer
min	minute
s	second

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METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
ENERGY (includes WORK)		
kilowatt hour (kW · h)	joule (J)	3.6 E+06
quad (1015 BtuIT)	joule (J)	1.055 056 E+18
therm (U.S.)	joule (J)	1.054 804 E+08
ton of TNT (energy equivalent)	joule (J)	4.184 E+09
watt hour (W · h)	joule (J)	3.6 E+03
watt second (W · s)	joule (J)	1.0 E+00
FORCE		
dyne (dyn)	newton (N)	1.0 E-05
kilogram-force (kgf)	newton (N)	9.806 65 E+00
kilopond (kilogram-force) (kp)	newton (N)	9.806 65 E+00
kip (1 kip=1,000 lbf)	newton (N)	4.448 222 E+03
kip (1 kip=1,000 lbf)	kilonewton (kN)	4.448 222 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
HEAT FLOW RATE		
calorieth per minute (calth/min)	watt (W)	6.973 333 E-02
calorieth per second (calth/s)	watt (W)	4.184 E+00
kilocalorieth per minute (kcalth/min)	watt (W)	6.973 333 E+01
kilocalorieth per second (kcalth/s)	watt (W)	4.184 E+03

To convert from	to	Multiply by
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01
PRESSURE or STRESS (FORCE DIVIDED BY AREA)		
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) ($kip/in.^2$)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) ($kip/in.^2$)	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00

To convert from	to	Multiply by
TEMPERATURE		
degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15
TEMPERATURE INTERVAL		
degree Celsius (°C)	kelvin (K)	1.0 E+00
degree centigrade	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556 E-01
degree Fahrenheit (°F)	kelvin (K)	5.555 556 E-01
degree Rankine (°R)	kelvin (K)	5.555 556 E-01
VELOCITY (includes SPEED)		
foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01
VOLUME (includes CAPACITY)		
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch ($in.^3$)	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely voluntecred their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

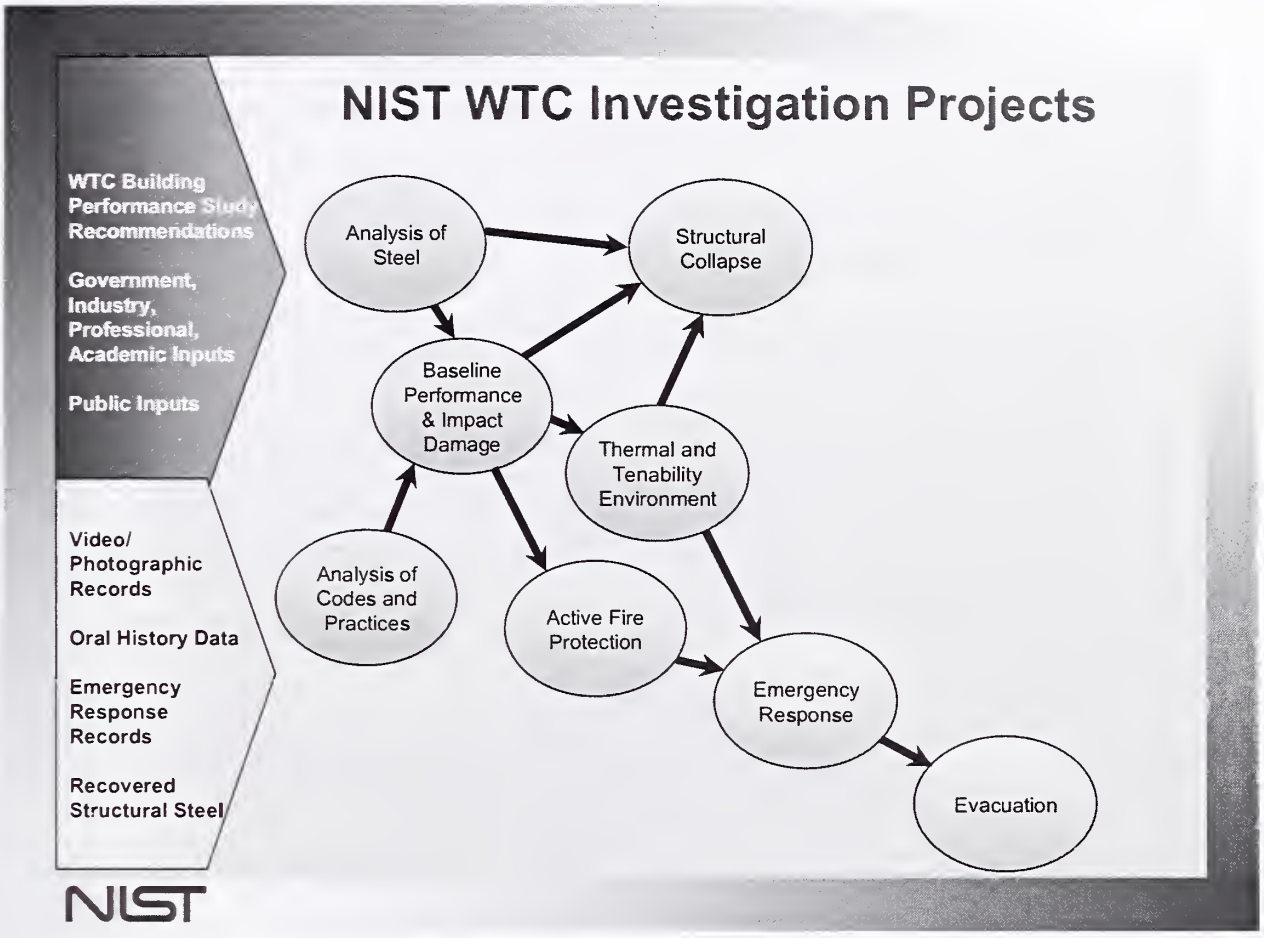

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers*. NIST NCSTAR 1. Gaithersburg, MD, September.

NIST (National Institute of Standards and Technology). 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of World Trade Center 7*. NIST NCSTAR 1A. Gaithersburg, MD.

Lew, H. S., R. W. Bukowski, and N. J. Carino. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Design, Construction, and Maintenance of Structural and Life Safety Systems*. NIST NCSTAR 1-1. National Institute of Standards and Technology. Gaithersburg, MD, September.

Fanella, D. A., A. T. Derecho, and S. K. Ghosh. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Design and Construction of Structural Systems*. NIST NCSTAR 1-1A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Ghosh, S. K., and X. Liang. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Comparison of Building Code Structural Requirements*. NIST NCSTAR 1-1B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Fanella, D. A., A. T. Derecho, and S. K. Ghosh. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Maintenance and Modifications to Structural Systems*. NIST NCSTAR 1-1C. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., and D. A. Johnson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Protection and Life Safety Provisions Applied to the Design and Construction of World Trade Center 1, 2, and 7 and Post-Construction Provisions Applied after Occupancy*. NIST NCSTAR 1-1D. National Institute of Standards and Technology. Gaithersburg, MD, September.

Razza, J. C., and R. A. Grill. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Comparison of Codes, Standards, and Practices in Use at the Time of the Design and Construction of World Trade Center 1, 2, and 7*. NIST NCSTAR 1-1E. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., D. A. Johnson, and D. A. Fanella. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Comparison of the 1968 and Current (2003) New*

York City Building Code Provisions. NIST NCSTAR 1-1F. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., and D. A. Johnson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Amendments to the Fire Protection and Life Safety Provisions of the New York City Building Code by Local Laws Adopted While World Trade Center 1, 2, and 7 Were in Use*. NIST NCSTAR 1-1G. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., and D. A. Johnson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Post-Construction Modifications to Fire Protection and Life Safety Systems of World Trade Center 1 and 2*. NIST NCSTAR 1-1H. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., D. A. Johnson, and D. A. Fanella. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Post-Construction Modifications to Fire Protection, Life Safety, and Structural Systems of World Trade Center 7*. NIST NCSTAR 1-1I. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., and D. A. Johnson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Design, Installation, and Operation of Fuel System for Emergency Power in World Trade Center 7*. NIST NCSTAR 1-1J. National Institute of Standards and Technology. Gaithersburg, MD, September.

Sadek, F. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Baseline Structural Performance and Aircraft Impact Damage Analysis of the World Trade Center Towers*. NIST NCSTAR 1-2. National Institute of Standards and Technology. Gaithersburg, MD, September.

Faschan, W. J., and R. B. Garlock. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Reference Structural Models and Baseline Performance Analysis of the World Trade Center Towers*. NIST NCSTAR 1-2A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Kirkpatrick, S. W., R. T. Bocchieri, F. Sadek, R. A. MacNeill, S. Holmes, B. D. Peterson, R. W. Cilke, C. Navarro. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Analysis of Aircraft Impacts into the World Trade Center Towers,* NIST NCSTAR 1-2B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Gayle, F. W., R. J. Fields, W. E. Luecke, S. W. Banovic, T. Foecke, C. N. McCowan, T. A. Siewert, and J. D. McColskey. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Mechanical and Metallurgical Analysis of Structural Steel*. NIST NCSTAR 1-3. National Institute of Standards and Technology. Gaithersburg, MD, September.

Luecke, W. E., T. A. Siewert, and F. W. Gayle. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Contemporaneous Structural Steel Specifications*. NIST Special Publication 1-3A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Banovic, S. W. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Steel Inventory and Identification.* NIST NCSTAR 1-3B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Banovic, S. W., and T. Foecke. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Damage and Failure Modes of Structural Steel Components.* NIST NCSTAR 1-3C. National Institute of Standards and Technology. Gaithersburg, MD, September.

Luecke, W. E., J. D. McColskey, C. N. McCowan, S. W. Banovic, R. J. Fields, T. Foecke, T. A. Siewert, and F. W. Gayle. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Mechanical Properties of Structural Steels.* NIST NCSTAR 1-3D. National Institute of Standards and Technology. Gaithersburg, MD, September.

Banovic, S. W., C. N. McCowan, and W. E. Luecke. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Physical Properties of Structural Steels.* NIST NCSTAR 1-3E. National Institute of Standards and Technology. Gaithersburg, MD, September.

Evans, D. D., R. D. Peacock, E. D. Kuligowski, W. S. Dols, and W. L. Grosshandler. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Active Fire Protection Systems.* NIST NCSTAR 1-4. National Institute of Standards and Technology. Gaithersburg, MD, September.

Kuligowski, E. D., D. D. Evans, and R. D. Peacock. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Post-Construction Fires Prior to September 11, 2001.* NIST NCSTAR 1-4A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Hopkins, M., J. Schoenrock, and E. Budnick. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Suppression Systems.* NIST NCSTAR 1-4B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Keough, R. J., and R. A. Grill. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Alarm Systems.* NIST NCSTAR 1-4C. National Institute of Standards and Technology. Gaithersburg, MD, September.

Ferreira, M. J., and S. M. Strege. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Smoke Management Systems.* NIST NCSTAR 1-4D. National Institute of Standards and Technology. Gaithersburg, MD, September.

Gann, R. G., A. Hamins, K. B. McGrattan, G. W. Mulholland, H. E. Nelson, T. J. Ohlemiller, W. M. Pitts, and K. R. Prasad. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Reconstruction of the Fires in the World Trade Center Towers.* NIST NCSTAR 1-5. National Institute of Standards and Technology. Gaithersburg, MD, September.

Pitts, W. M., K. M. Butler, and V. Junker. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Visual Evidence, Damage Estimates, and Timeline Analysis.* NIST NCSTAR 1-5A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Hamins, A., A. Maranghides, K. B. McGrattan, E. Johnsson, T. J. Ohlemiller, M. Donnelly, J. Yang, G. Mulholland, K. R. Prasad, S. Kukuck. R. Anleitner and T. McAllister. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Experiments and Modeling of Structural Steel Elements Exposed to Fire.* NIST NCSTAR 1-5B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Ohlemiller, T. J., G. W. Mulholland, A. Maranghides, J. J. Filliben, and R. G. Gann. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Tests of Single Office Workstations.* NIST NCSTAR 1-5C. National Institute of Standards and Technology. Gaithersburg, MD, September.

Gann, R. G., M. A. Riley, J. M. Repp, A. S. Whittaker, A. M. Reinhorn, and P. A. Hough. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Reaction of Ceiling Tile Systems to Shocks.* NIST NCSTAR 1-5D. National Institute of Standards and Technology. Gaithersburg, MD, September.

Hamins, A., A. Maranghides, K. B. McGrattan, T. J. Ohlemiller, and R. Anleitner. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Experiments and Modeling of Multiple Workstations Burning in a Compartment.* NIST NCSTAR 1-5E. National Institute of Standards and Technology. Gaithersburg, MD, September.

McGrattan, K. B., C. Bouldin, and G. Forney. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Computer Simulation of the Fires in the World Trade Center Towers.* NIST NCSTAR 1-5F. National Institute of Standards and Technology. Gaithersburg, MD, September.

Prasad, K. R., and H. R. Baum. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Structure Interface and Thermal Response of the World Trade Center Towers.* NIST NCSTAR 1-5G. National Institute of Standards and Technology. Gaithersburg, MD, September.

Gross, J. L., and T. McAllister. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Structural Fire Response and Probable Collapse Sequence of the World Trade Center Towers.* NIST NCSTAR 1-6. National Institute of Standards and Technology. Gaithersburg, MD, September.

Carino, N. J., M. A. Starnes, J. L. Gross, J. C. Yang, S. Kukuck, K. R. Prasad, and R. W. Bukowski. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Passive Fire Protection.* NIST NCSTAR 1-6A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Gross, J., F. Hervey, M. Izydorek, J. Mammoser, and J. Treadway. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Resistance Tests of Floor Truss Systems.* NIST NCSTAR 1-6B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Zarghamee, M. S., S. Bolourchi, D. W. Eggers, Ö. O. Erbay, F. W. Kan, Y. Kitane, A. A. Liepins, M. Mudlock, W. I. Naguib, R. P. Ojdrovic, A. T. Sarawit, P. R Barrett, J. L. Gross, and

T. P. McAllister. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Component, Connection, and Subsystem Structural Analysis.* NIST NCSTAR 1-6C. National Institute of Standards and Technology. Gaithersburg, MD, September.

Zarghamee, M. S., Y. Kitane, Ö. O. Erbay, T. P. McAllister, and J. L. Gross. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Global Structural Analysis of the Response of the World Trade Center Towers to Impact Damage and Fire.* NIST NCSTAR 1-6D. National Institute of Standards and Technology. Gaithersburg, MD, September.

McAllister, T., R. W. Bukowski, R. G. Gann, J. L. Gross, K. B. McGrattan, H. E. Nelson, L. Phan, W. M. Pitts, K. R. Prasad, F. Sadek. 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Structural Fire Response and Probable Collapse Sequence of World Trade Center 7.* (Provisional). NIST NCSTAR 1-6E. National Institute of Standards and Technology. Gaithersburg, MD.

Gilsanz, R., V. Arbitrio, C. Anders, D. Chlebus, K. Ezzeldin, W. Guo, P. Moloney, A. Montalva, J. Oh, K. Rubenacker. 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Structural Analysis of the Response of World Trade Center 7 to Debris Damage and Fire.* (Provisional). NIST NCSTAR 1-6F. National Institute of Standards and Technology. Gaithersburg, MD.

Kim, W. 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Analysis of September 11, 2001, Seismogram Data.* (Provisional). NIST NCSTAR 1-6G. National Institute of Standards and Technology. Gaithersburg, MD.

Nelson, K. 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: The Con Ed Substation in World Trade Center 7.* (Provisional). NIST NCSTAR 1-6H. National Institute of Standards and Technology. Gaithersburg, MD.

Averill, J. D., D. S. Mileti, R. D. Peacock, E. D. Kuligowski, N. Groner, G. Proulx, P. A. Reneke, and H. E. Nelson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Occupant Behavior, Egress, and Emergency Communication.* NIST NCSTAR 1-7. National Institute of Standards and Technology. Gaithersburg, MD, September.

Fahy, R., and G. Proulx. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Analysis of Published Accounts of the World Trade Center Evacuation.* NIST NCSTAR 1-7A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Zmud, J. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Technical Documentation for Survey Administration.* NIST NCSTAR 1-7B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Lawson, J. R., and R. L. Vettori. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: The Emergency Response Operations.* NIST NCSTAR 1-8. National Institute of Standards and Technology. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

E.1 OVERVIEW

While most attention has properly focused on the nearly three thousand people who lost their lives at the World Trade Center (WTC) site on September 11, 2001, five times that many people successfully evacuated from the WTC towers due to heroic efforts of occupants, as well as emergency responders. Understanding why many, yet not all, survived the WTC attacks was one of the four objectives of the Federal building and fire safety investigation of the WTC disaster led by the National Institute of Standards and Technology (NIST).

Success in evacuating a building in an emergency can be characterized by two quantities: the time people needed to evacuate and the time available for them to do so. To the extent the first time exceeded the second, it follows that there will be casualties. When the second time exceeds the first, perhaps by some suitable margin, nearly all should be able to evacuate the building.

For the WTC towers, the times available for escape were cataclysmically established by the collapses of the buildings. Those times were not known in advance by the building occupants or the responders. The times were also considerably shorter, by a factor of three or four, than the time needed to clear the tenant spaces of WTC 1 following the 1993 bombing and an additional factor of two shorter than the time needed to clear the last person from the elevators in the building. Further, some occupants would have been unable to evacuate the buildings given any amount of time due to injuries, entrapment, and/or toxic exposure.

NIST examined the design of the building, the behavior of the people, and the evacuation process in detail to ascertain the factors that factored prominently in the time needed for evacuation.

In order to accomplish this objective, numerous sources of data were collected and analyzed, including: over 1,000 new interviews with survivors; a collection of over 700 published interviews with WTC survivors; 9-1-1 emergency calls; transcripts of emergency communication among building personnel and emergency responders; historical building design drawings, memoranda, and calculations; building modifications and upgrades; formal complaints filed with Occupational Safety and Health Administration; and other relevant material.

There were three forms of interviews with survivors: 803 telephone interviews, over 225 face-to-face interviews, and 6 focus groups. The telephone interviewees were randomly selected using independent proportionate stratification from a list of occupants who had badges to enter WTC 1 or WTC 2 on September 11, 2001. In other words, each occupant of a particular tower had an equal probability of being selected. Roughly 400 occupants in each tower were interviewed in order to achieve a high level of statistical precision within each tower. Reported percentages from tower-specific survey data (n=400) exhibited sampling errors no greater than 2.5 percentage points, and 95 percent confidence intervals of percentages are no greater than ± 5 percentage points. This level of precision was more than adequate for examining characteristics of occupants and egress attributes. With telephone interview results, primary statistical analyses were in the form of tabulations and linear statistics (e.g., reporting of percentages and

average/means). The telephone interview results enabled a scientific projection of the population and distribution of occupants in WTC 1 and WTC 2, as well as causal modeling and multivariate regression analysis to explore fundamental egress issues such as sources of evacuation delay.

The objective of the face-to-face interviews was to gather first-hand accounts and observations of the activities and events inside the buildings on the morning of September 11. This approach identified unknown information, aided in the evaluation of technical hypotheses, and explored motivations for occupant behaviors, while allowing for comparisons to the telephone interview data. There was no recording of the face-to-face interviews, other than random selections, with consent of respondents, for quality control purposes. A typical face-to-face interview averaged approximately two hours. The methodology for the face-to-face interviews was a synthesis of two established methodologies, designed to assist survivors in providing comprehensive and accurate accounts of their evacuation, given the latency between experience and interview. Some groups of occupants were specifically sought in order to explore targeted unknowns. These included occupants near the floors of impact, witnesses to fireballs, mobility-impaired occupants, floor wardens, building personnel with emergency response responsibilities, family members who spoke to an occupant after 8:46:30 a.m., and occupants from regions of the building not addressed by other groups in order to ensure adequate interview coverage for all areas of both towers.

Six focus groups were conducted in order to elicit accurate group representations of specific events or themes and complement the findings of the telephone and face-to-face interviews. The focus groups and the corresponding objectives were:

1. Occupants located near the floors of impact: to explore the extent of the building damage and how the damage influenced the evacuation process.

2. Floor wardens: to explore the implementation of the floor warden procedures and the effect those actions had on the evacuation of the occupants on a floor and the evacuation of the floor warden.

3. Mobility-impaired occupants: to explore the effect of a disability on the evacuation of the occupant and any other individuals who may have assisted or otherwise been affected by the evacuee.

4. Persons with building responsibilities: to capture the unique perspective of custodians, security, maintenance, or other building staff.

5. Randomly selected evacuees in WTC 1: to further explore the variables from the causal modeling which best explained evacuation delay and normalized stairwell evacuation time, including environmental cues, floor, and activities.

6. Randomly selected evacuees in WTC 2: to further explore variables used in the causal modeling that best explained evacuation delay, including environmental cues, floor, risk perception, and use of elevators.

NIST documented the WTC egress system, including the location of the three primary stairwells, exit doors, core hallways, transfer corridors, wall construction, location and layout of the 100+ elevators in each tower, and emergency communication devices. The design of the egress system was compared to

building code requirements of the New York City Building Code, National Fire Protection Association 101 (Life Safety Code), and International Building Code.

NIST documented the emergency procedures, both as they were planned to be carried out, as well as how they were actually implemented on September 11, 2001. The procedures included responsibilities for tenant safety through the floor warden system; pre-planned content of public address system announcements (which varied from public address system announcements made on September 11, 2001); responsibilities of the fire safety director, deputy fire safety director, building security, and supervisors of various contractors (including mechanical, vertical transportation, and electrical). Additionally, interaction among responding agencies such as the Port Authority of New York and New Jersey, the Port Authority Police Department, the New York City Police Department (NYPD), the New York City Fire Department, and contract security were documented.

NIST estimates that there were 8,900 ± 750 people in WTC 1 at 8:46:30 a.m. on September 11, 2001. Similarly, NIST estimates that there were 8,540 ± 920 people inside WTC 2 at 8:46:30 a.m. New York City officially announced 2,749 fatalities at the WTC complex, including emergency responders, airplane passengers and crew (but not hijackers), and bystanders. NIST estimated that of the 17,400 ± 1,180 occupants inside WTC 1 and WTC 2 at 8:46:30 a.m., 2,146 to 2,163 perished. No information could be found for 17 persons. More than twice as many occupants were killed in WTC 1 as WTC 2, largely due to the fact that occupants in WTC 2 used the 16 minutes between the attacks on WTC 1 and WTC 2 to begin evacuating, including the use of elevators by some occupants in WTC 2.

The demographic characteristics of the evacuees was explored where the characteristics were relevant to the evacuation on September 11, 2001. Few differences in the characteristics of WTC 1 or WTC 2 were observed. Men outnumbered women roughly two to one. The average age was mid-forties. The mean length of employment at the WTC site was almost 6 years, while the median was 2 and 3 years for WTC 1 and 2, respectively. Sixteen percent of 2001 WTC evacuees were also present during the 1993 bombing, although many other occupants were also knowledgeable about the 1993 evacuation. Two-thirds of the occupants had participated in at least one fire drill during the 12 months immediately prior to September 11, 2001. Eighteen percent did not recall whether they had participated in a fire drill during that time period and 18 percent reported that they did not participate in a fire drill during that time period.

In WTC 1, all three stairwells and the elevators were destroyed in the impact region, extending as low as floor 92. No occupant evacuated from above the 91st floor, although some survived until the building collapsed after 102 minutes. Helicopter rescue from the roof was considered by an NYPD aviation unit, but deemed not possible due to the heat and smoke from the building fire. Occupants of both towers delayed initiating their evacuation after WTC 1 was hit. In WTC 1, the median time to initiate evacuation was 3 minutes for occupants from the ground floor to floor 76, and 5 minutes for occupants near the impact region (floors 77 to 91). Occupants observed various types of impact indicators throughout the building, including wall, partition, and ceiling damage and fire and smoke conditions. The most severe damage was observed near the impact region, fatally trapping some occupants. Announcements in WTC 1 were not heard by the occupants, despite repeated attempts from the lobby fire command station to order an evacuation. Damage to critical communications hardware prevented announcement transmission. Evacuation rates reached a peak, steady-state in approximately 5 minutes, and remained roughly constant until the collapse of WTC 2, when the rate in WTC 1 slowed to about one-fifth of the

peak, steady-state. WTC 1 collapsed at 10:28:22 a.m., resulting in approximately 1,500 occupant deaths, 107 of which were estimated to be below the 92nd floor.

The evacuation of WTC 2 was markedly different from the evacuation of WTC 1. There was a 16 minute period after WTC 1 was attacked, but before WTC 2 was attacked. During this time period, occupants were forced to decide whether to remain inside WTC 2, and if they decided to leave, they had to choose between using one of the three stairwells or using an elevator. Further complicating this decision process were multiple, conflicting announcements around 9:00 a.m., first instructing occupants to return to their offices, and then within one minute of impact, instructing them to begin an evacuation if conditions on their floor warranted that decision. Over 90 percent of WTC 2 survivors started to evacuate the building prior to its being attacked. Sixteen percent of the survivors used elevators to evacuate. Approximately 75 percent of the occupants who were above the 78th floor (the lowest floor of impact) descended to at least below the impact region prior to the attack on WTC 2. Over 40 percent of the survivors had left WTC 2 prior to 9:02:59 a.m. After WTC 2 was attacked, at least 18 individuals used Stairwell A, located in the northwest corner and furthest from the impact damage, to descend below the 78th floor to evacuate the building. Additional public address announcements were made after the airplane strike on WTC 2, although occupants who survived generally did not hear those announcements. After the initial peak in evacuation rate, the rate reached a steady-state similar to the rate observed in WTC 1 until approximately 20 minutes prior to collapse of WTC 2. The evacuation rate during the final 20 minutes dropped significantly, likely due to a decreased number of occupants remaining in the egress system below the 78th floor. NIST analysis indicated only 11 occupants initially below the 78th floor were killed when WTC 2 collapsed at 9:58:59 a.m. Overall, NIST estimated that 630 occupants of WTC 2 perished.

Using the statistical power of the telephone interview results, causal models were constructed to explain both evacuation initiation delay and average stairwell travel time per floor. The factors that best predicted evacuation initiation delay in WTC 1 were (1) which floor the respondent was on when WTC 1 was attacked, (2) whether occupants encountered environmental cues, and (3) seeking additional information (or milling) about the nature of the event. In WTC 2, the same process occurred as in WTC 1, except that perceived risk (sense of immediate danger) was a predictor of seeking additional information (along with floor and environmental cues). Analyses explored factors that affected time spent in the stairwells in WTC 1 exiting the building. The floor an occupant was on when WTC 1 was attacked (distance to safety) increased the probability of encountering an environmental cue (smoke, damage, fire, etc). Additionally, being on a higher floor predicted greater evacuation initiation delay times and encountering environmental cues, which predicted higher normalized stairwell travel time. Independently, interrupting evacuation for any reason increased the normalized stairwell travel time.

Constraints or aids to the evacuation progress were documented. Building announcements were cited by many in WTC 2 as a constraint to their evacuation, principally due to the 9:00 a.m. announcement instructing occupants to return to their work spaces. Crowdedness in the stairwells, firefighter counterflow, lack of instructions and information, as well as injured or disabled evacuees in the stairwells were the most frequently reported obstacles to evacuation. The most commonly mentioned forms of aid were assistance from coworkers and emergency responders and the photoluminescent markings in stairwells. Six percent of survivors in WTC 1 and WTC 2 reported a mobility impairment which slowed their evacuation. Sometimes the evacuation speed of others in the immediate area slowed down occupant evacuation speed. Recent pre-existing injuries, medications, or medical treatments were the most commonly reported mobility impairments, while a small number used wheelchairs, were pregnant, or

were elderly. A rest station for mobility-impaired occupants was established in WTC 1 somewhere between floors 12 and 20. Less than 10 minutes prior to the collapse of WTC 1, the occupants and helpers on the floor were ordered to evacuate, although it remains unclear whether all rest station residents survived.

Minutes prior to the collapse of WTC 2, an NYPD Emergency Services Unit (ESU) officer radioed from a floor in the 20s to the outside that he was having trouble ascending the stairwell due to the large number of occupants descending (Interview 24 NYPD [NIST 2004]). While the origin of the occupants remains unknown, only 11 occupants who started evacuating below the impact region were known not to have survived.

Multiple evacuation models were used to simulate different WTC tower evacuations, subject to a number of assumptions. The goal of the modeling was to frame an understanding of actual evacuation findings on September 11, 2001. Simulations demonstrated that a phased evacuation (also known as defend-in-place, whereupon occupants on the fire floor and the immediately surrounding floors descend to three floors below the fire floor) would have taken between 4 minutes to complete (without delays in evacuation initiation) and 11 minutes to complete (with evacuation initiation delays between 0 and 10 minutes). Total evacuation of a tower assuming a full occupant load without visitors (19,800) would have required as few as 92 minutes to 112 minutes. With visitors (total population 25,500 people) total evacuation would have required as little as 114 minutes to 142 minutes. The ranges reflect two different model outputs, each assuming two different delay times (no delay and a 10 minute distribution of delay times). An evacuation simulation for 8,800 people (approximately the number present in each tower on September 11, 2001) in the absence of any damage to the building, would have required at least 52 minutes to 71 minutes, depending on the model or the delay times. Finally, the EXODUS model was 'calibrated' to approximate the gross evacuation rates observed in WTC 1 and WTC 2 on September 11, 2001. Once the model input necessary to approximate the observables was determined, additional occupants were added in order to estimate how many occupants might have been unable to evacuate on September 11, 2001 (given the damage to the building and observed delay times) if the buildings had had larger occupant loads. NIST estimated that approximately 14,000 occupants would have been unable to evacuate from WTC 1 and WTC 2 on September 11, 2001, had the starting building population been 19,800 in each building.

E.2 REFERENCE

NIST (National Institute of Standards and Technology). 2004. NIST WTC Emergency Responder Interview Data Set. Gaithersburg, MD.

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Chapter 1
BACKGROUND AND INTRODUCTION

On the morning of September 11, 2001, the World Trade Center (WTC) in New York City was attacked by hijacked commercial airplanes. The collision with each tower (WTC 1 at 8:46:30 a.m. and WTC 2 at 9:02:59 a.m.) produced significant structural damage. The impact generated a large, luminous external fireball that consumed a portion of the jet fuel, with the remaining fuel acting as an ignition source for the combustible material within each tower. At 9:58:59 a.m., 56 minutes after it was struck, WTC 2 collapsed due to a combination of the aircraft impact damage and subsequent fire. WTC 1 stood until 10:28:22 a.m.

This report provides an analysis of the overall evacuation of WTC 1 and WTC 2. The two towers were nearly identical buildings in height, geometry, and architectural features. The evacuation processes in these two buildings displayed both distinct similarities and differences. This report also focuses on the behaviors of the occupants, actions of the building personnel and emergency responders (covered more completely in NIST NCSTAR 1-8[1]), and the interactions among all three. This report documents the performance of the emergency egress system.

This chapter begins with a discussion of significant egress events. It then reviews the design of the WTC egress system and emergency procedures, and outlines the National Institute of Standards and Technology (NIST) data collection methodology. The events of September 11, 2001, are detailed as they relate to the evacuation, including the moments prior to 8:46:30 a.m. Finally, an analysis of the events establishes key evacuation findings and conclusions. Note that individuals shown in photographs in this report may have been blurred to protect their identities.

1.1 HISTORICAL INCIDENTS IN WHICH EGRESS WAS SIGNIFICANT

Although the World Trade Center building collapses are arguably the most significant building events where building egress played a critical role, concern about the ability of occupants to escape from large buildings is hardly new. Indeed, many earlier lessons were based on analyses of high-rise fires in New York City. In 1911, the Triangle Shirtwaist Fire spread through the top three floors of a 10-story fire-resistant building in New York (Fire Engineering 1977). The fire started in a corner of the eighth floor of the building and quickly spread over the entire floor as well as the floors above by the windows, stairs, and elevator shafts. There were 145 fatalities in the fire, all but one from the ninth floor of the building. While many of the fatalities were located on the ninth floor, approximately 40 jumped from the building to the street below to escape the flames, and another 10 perished when an exterior fire escape collapsed. The fire was extinguished with hose lines from two standpipe risers in the stairwells and was under control within 18 min. The upper three floors were a complete loss. Significant issues identified from the fire investigation included the fact that there was limited access to the stairwells due to partially-blocked, non-fireproof doors that opened inward, as well as exterior cast-iron fire escapes which loosened from the

[1] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

wall due to heat from the fire. Subsequent recommendations promoted fireproof egress stairways and automatic sprinklers for buildings taller than 18 m (60 ft).

The Equitable Building fire in New York City in January 1912 is an early example of building collapse following fire (NFPA 1912). The Equitable Building was a group of five linked buildings, the tallest being 10 stories tall. Erected beginning in 1869, the buildings were constructed of so-called fireproof construction with wood floors on brick or tile arches supported by wrought-iron and steel I-beams resting on columns made mostly of cast iron. The fire originated in the basement of one of the buildings from a discarded match and spread quickly to a tile-enclosed shaft containing two elevators and eleven small dumbwaiters enclosed in wood. Within 45 minutes, the fire had spread throughout the upper floors of the buildings and downward through numerous unprotected floor openings. Except for a few areas, the building was completely gutted by the fire. Three separate sections of the building collapsed, with the largest collapse involving all of the floors down to the basement on one side of the building. Since the fire occurred before business hours, loss of life was limited to three employees on the upper floors and three additional deaths attributed to collapse of cast-iron columns. Firefighter loss was limited to a single fatality, as all personnel were ordered out of the building prior to the first collapse. Egress and firefighter access was through a single continuous stairway from the basement level to the top floor, deemed inadequate for escape in the subsequent investigative report. Recommendations included the need for protection of floor openings, corridor partitions, and structural metal work, and inclusion of sprinklers in all portions of office buildings where fire is most likely to occur. Two remote stairways enclosed in fireproof shafts with fire doors at each floor were deemed necessary. Additional stairways were recommended such that travel distance to a stairway was limited to 27 m (90 ft).

In 1945, a U.S. Army Air Force B-25 crashed into the Empire State Building in New York City resulting in a significant fire on parts of the 78th and 79th floors from an estimated 3 m^3 (800 gal) of gasoline sprayed from the plane crash (Hayne 1945). The crash and resulting fire caused 14 deaths and approximately 25 injuries. The crash occurred on a Saturday morning when few building occupants were present, and much of the office space surrounding the crash site was unoccupied. Several occupants of the 79th floor took refuge in a metal and glass partitioned office and were later rescued by the fire department. According to the investigation report, the stairwells remained tenable throughout the incident and provided fire department access and a safe means of egress for occupants of the upper floors not involved with the initial gasoline fire. Fire department access was accomplished via elevator to the 65th floor and by stairwell the remaining 13 to 14 floors. The fire was extinguished approximately 35 minutes after the first fire department notification. Building design, timing of the fire on a Saturday morning, and fire department response were credited with limiting the resulting damage and loss of life. Important issues related to building egress identified in the investigation report include (1) limiting use of elevators as a means of egress from upper floors, since the crash of one of the elevators to the sub-basement might create apprehension of the dependability of the remaining elevators; (2) an understanding that damage to stair shafts may be sufficient to prevent their use as a means of egress from the crash floor and floors above; and (3) a realization that fire resistive building construction does not preclude damage by fire involving building contents.

In August 1970, a fire at the 50-story One New York Plaza building extensively damaged the 33rd and 34th floors and spread significant smoke throughout the building (Powers 1970). The fire was first detected in the concealed ceiling space of the 33rd floor and spread to exposed polystyrene insulation in the south and west walls of the 33rd floor. The building was only partially occupied at the time of the

fire, with some of the floors above the fire unoccupied. Occupants evacuated either by elevators or down the stairwells. Heavy smoke conditions were noted on many floors of the building. Two security guards and two firefighters died from the fire, and 30 injuries resulted. Fire department access was accomplished via elevators to the 30th floor and by stairs to the fire. The fire was controlled within 5 h. Reducing the fire load of building contents, the need for automatic sprinkler systems, and the protection of steel members by materials that cannot be readily removed or damaged were important issues identified from the investigation. New York City Local Law No. 5, Fire Safety in High-Rise Buildings, resulted in large part from a reaction to this and several other high rise-fires in New York at the time. Among other provisions, Local Law 5 requires building compartmentation, with an exception for sprinklered spaces (New York City 1973).

In February 1972 and February 1974, major high-rise fires occurred in Brazil, causing more than 200 casualties. In February 1972, a fire in the 31-story Andraus Building in São Paulo resulted in 16 fatalities and more than 375 injuries (Willey 1972). The fire developed on four floors of a department store and then spread up the exterior facade of the building, involving 28 floors of the building within 25 minutes. The fire gutted most areas of the building and damaged structural supports. The department store occupied the lower seven floors above grade and was served by four open stairways and two elevators. The remainder of the building was of office occupancy with a single 1 m (39 in.) wide enclosed masonry spiral stairwell and five elevators. Door construction in the office stairwell was of hollow-core, wood, or metal construction. Combustible interior finish and exterior façade were credited for the rapid fire spread throughout all but the upper four floors of the building. It was reported that some people used elevators to egress the building, while others used the single stairwell. Once a stairwell door on the fifth floor failed, leaving the lower floors of the stairwell untenable, occupants fled toward the roof of the building. Approximately 300 people reached the roof level heliport, while another 200 became trapped in the stairwell. Rescue operations for those trapped in the stairwell included ladders from nearby buildings on the fifteenth and sixteenth floor. The use of areas of refuge by nearly 500 occupants was aided by stairway ventilation and wind velocity.

An unfortunately similar fire two years later, which started on the 12th floor of the 25 story Joelma Building in São Paulo, and resulted in 179 deaths, 300 injuries, and total destruction of the building contents (Sharry 1974). Inability of helicopters to rescue occupants trapped on the roof of the building, inadequate means of egress from the building (a single 1.2 m (47 in.) unenclosed stairwell), lack of fire protection, and presence of combustible contents within the building were noted as significant in the fire. The majority of survivors of the fire made their escape through the use of the building's four elevators. While this method was not recommended due to the possibility that occupants may become trapped, the success of the evacuation was attributed to two factors: the use of elevator operators allowed the elevators to be operated in an express mode (stopping only at desired floors), and the elevator power supply was unaffected early in the fire.

In June 1989, a fire occurred in a 10-story office building in Atlanta, Georgia (Isner 1990). The Peachtree 25th building was an H-shaped building with two connected 10-story towers and a population of approximately 1,500 people. Each tower measured approximately 76 m by 20 m, with the connection measuring 21 m by 24 m. The fire began on the 6th floor of the south tower at approximately 10:30 a.m. The ignition of the fire was attributed to an electrician working on an electrical switchbox. While the worker was attempting to return power to a section of the floor by replacing a 200-ampere fuse, severe arcing occurred. The arcing had sufficient energy to melt metal and ignite the interior-finish materials in

the hallway. The electrician was severely injured and later died, although not as a direct result of the arc, which was estimated as having lasted 60 seconds or more. The fire growth rate was extremely high, and the fire spread was rapid. Multiple layers of wall covering promoted extraordinary fire spread rates, which was not an unfamiliar fire hazard to fire investigators (Bouchard 1982; Demers 1980). The wall coverings had completely burned out when the fire department arrived on the floor, only seven minutes after notification. The intense black smoke quickly trapped about 40 occupants on the floor of origin. Most occupants found a room and closed the door behind them, breaking out windows to vent incoming smoke and waited to be rescued. At some point, one woman jumped from a 6th floor window and sustained severe injuries. The fire department was not notified until an occupant of the building from a remote floor activated a manual pull-station at approximately 10:30 a.m. Several occupants of the fire floor were leaning out of a window in order to breathe when the fire department arrived on the scene at approximately 10:34 a.m. Fourteen occupants were rescued via ladder truck, and 14 people were rescued using the stairwells. In all, five people died because of this fire, the first multiple fatality high-rise office building fire in the United States in 17 years (Isner 1990).

Several failure modes contributed significantly to the severity of the fire. There were no automatic sprinklers, which allowed the fire to spread. The electrician did not follow proper procedure when changing the fuse, resulting in the arc that ignited the wall linings and electrical equipment. The ignition source was so severe that a fire in the electrical room was inevitable, however. Multiple-layer, combustible interior-finishes also contributed to the rapid spread of the fire.

In many instances, these significant egress events resulting from fires in buildings have shaped building codes requirements related to the egress system. Requirements for stairwell design, placement, and capacity all evolved as a result of significant past fire incidents.

1.2 PREVIOUS FIRES AND EVACUATION INCIDENTS IN THE WORLD TRADE CENTER

In February 1975, a fire in WTC 1 began on the 11th floor and ultimately spread from the 10th to the 19th floor extending through telephone closets on each floor (Powers 1975). Although not important from an egress perspective, the fire provides an appropriate background for what occurred in the later terrorist attacks in 1993 and 2001. The fire was initially reported by manual alarm at 11:35 p.m. Automatic alarms from smoke detectors on the 11th floor through the 19th floor responded at about 1 min intervals after the manual alarm. It was believed that the fire originated in an executive office on the 11th floor and spread to upper and lower floors through 0.30 m by 0.45 m (12 in. by 18 in.) openings in the floors of utility closets on each floor. Four steel floor trusses were distorted slightly. Approximately 800 m^2 (9,000 ft^2) of the 11th floor was damaged, destroying about half of the contents and damaging the remaining contents in this area. Virtually all combustibles, including fire retardant-treated wood paneling on the telephone closet walls of the 10th and 12th floors, were destroyed. Limited quantities of combustible furnishings on the 12th and 13th floors limited the spread of fires from the telephone closets on these floors. Recommendations resulting from the fire included (1) provisions for automatic sprinklers in areas where highly combustible material or large accumulations of combustibles are present, (2) the installation of detectors in return air shafts on each floor to purge the return air and stop the supply of fresh air to the fire area, and (3) fire stopping of all openings in floors or walls as well as in any wiring installations. It was noted that sprayed fire-resistive material may not adhere properly to surfaces or may be dislodged as other building services are installed.

On August 3, 1977, two Fuerzas Armadas de Liberacion Nacional (F.A.L.N.) terrorist bombs exploded in midtown Manhattan, killing one person and injuring seven others. When a specific threat against the World Trade Center was phoned into a local TV news station at 9:45 a.m. (Breasted 1977), both WTC towers were evacuated, although not until after 12 noon. An employee of Windows on the World at the time, described the situation:

> "We were all scared. I started to shake. The ride down seemed to take two hours. I'm part of a team that was trained for fire drills, but I have no idea of what do if there was a bomb. This was more frightening than a fire because we are all equipped for a fire." (Ivins 1977)

An estimated 35,000 people were evacuated from WTC 1 and WTC 2, both of which reopened the same day, shortly after 3:00 p.m. (Ivins 1977). Overall, more than 100,000 people evacuated buildings in Manhattan that day (Breasted 1977). Many people, however, were reluctant to leave after having been docked wages after previous incidents for evacuating the building (Ivins 1977).

At 12:18 p.m. on February 26, 1993, a terrorist attack resulted in an explosion in a sublevel parking garage in the World Trade Center complex, immediately killing six people (Isner and Klem 1993a; Isner and Klem 1993b) and causing an estimated $300 million damage. The explosion of at least 450 kg (1,000 lb) of explosive material caused extensive damage to several sublevels of the building and an intense fire that spread varying amounts of smoke in four of the seven buildings in the complex. Most of the complex's estimated 150,000 occupants evacuated the buildings as a result of the incident, including approximately 50,000 from the affected towers.[2] According to the NFPA Investigation, 1,042 people were injured in the incident, including 15 who received blast-related injuries. At the peak of the incident, the fire reached 16 alarms and involved more than 700 firefighters (approximately 45 percent of the New York City Fire Department's on-duty personnel) (Isner and Klem 1993a). As a comparison, on September 11, 2001, 22 alarms were called prior to the collapse of WTC 2, in addition to a 10-60 alarm (unique to special operations for large incidents) and a three alarm which staged additional units nearby. This resulted in the involvement of more than 1,000 firefighters being at the World Trade Center.

The explosion significantly damaged floors, walls, and doorways in subgrade levels and forced large amounts of smoke well away from the immediate area. In one report, visibility was reduced to 0.3 m (1 ft) within about 1 min at the 44th floor of WTC 1, largely through the spread of smoke in elevator and stairwell shafts (Isner and Klem 1993b). Before beginning evacuation, many occupants experienced smoke on occupied floors and encountered even heavier smoke as they descended the buildings in the stairwells. Since the explosion disabled the emergency communication systems in the buildings, occupants responded to the event without the planned central guidance. Even without guidance, many occupants began evacuation early in the event. Egress was further complicated by a total loss of electrical power to emergency stairwell lighting within about 1 hour and 15 min. It was estimated that it took occupants from 1½ hours to 3 hours to exit the building from the upper floors of the towers. Fortunately, the scarcity of combustibles in the subgrade levels and dilution of the fire gases limited the toxic potency of the resulting smoke. Although most of the injuries were smoke related, no fatalities due to smoke inhalation were noted even with prolonged exposure to dense smoke.

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[2] Text of undated presentation by Ted Stam, General Property Manager, World Trade Center. WTCI-619-P.

Fire crews were assigned responsibility for searching five floor subsectors. Since the elevators were not operational, firefighters climbed the stairwells. It took more than two hours for crews to climb to the 100th floor. By 4:00 p.m., approximately 4 hours after the blast, all occupants had evacuated tenant floors. Some elevator cars, however, had stopped in elevator shafts, portions of which had no doors leading from that section of the shaft (such as express elevators). Locating and evacuating the trapped elevator occupants was such a high priority that, rather than wait for the stairwells to empty to send the elevator technicians up into the building by stairwells, the technicians were delivered to the roof by helicopter. Even with that measure, it took approximately 5 hours to locate and free a group of kindergarten students and several adults trapped in an elevator in WTC 2 (Isner and Klem 1993b). By 8:00 p.m., approximately 8 hours after the explosion, the last occupants trapped in elevators were evacuated.

1.3 SCOPE OF OCCUPANT BEHAVIOR, EGRESS, AND EMERGENCY COMMUNICATIONS PROJECT FOR THE NIST WORLD TRADE CENTER INVESTIGATION

The purpose of this project was to determine the behavior and fate of occupants and responders - both those who survived and those who did not - by collecting and analyzing information on occupant behavior, human factors, egress, and emergency communications in WTC 1, WTC 2, and WTC 7, and evaluating the performance of the evacuation system on September 11, 2001.

This project was divided into six tasks as follows:

Task 1—Gathered baseline information on the evacuation of the WTC buildings on September 11, 2001, through a comprehensive, systems-oriented, and interdisciplinary data collection effort focused on occupant behavior, human factors, egress, and emergency communications (including instructions given, interpretation of instructions, and response to instructions). This involved the collection of new data from people affected by the WTC attacks (e.g. building occupants, building operators, and emergency responders via direct accounts from survivors and families of victims), especially those who had to evacuate the buildings. Experts in human behavior and statistical sampling were retained to assist in developing a data acquisition strategy that considered various data collection methods, such as interviews and questionnaires. Inputs and suggestions were obtained from individuals with an interest in the data collection effort. Additionally, written accounts, transcripts of (emergency) communications, published accounts, and other sources of egress related information were obtained, in coordination with other data collection efforts for the overall investigation.

Task 2—Collected archival records from prior WTC evacuation incidents (e.g., 1975 fire, 1977 blackout, 1980 bomb scare, 1990 power outage, and 1993 bombing) and practice evacuations, including oral history data from floor wardens and fire safety directors. These records were compared and contrasted with the September 11, 2001, evacuation. Changes made to the evacuation procedures following the earlier incidents and in recent years were evaluated in the context of the experience on September 11, 2001.

Task 3—Documented pre-event data for WTC Buildings 1, 2, and 7. This information included physical aspects of building egress components, such as stairs (width, number, location, vertical continuity), evacuation lighting, back-up power, elevators (number, operational before and after impact, role in evacuation), and active fire protection systems (sprinklers, manual suppression, fire alarms, smoke

control). Building plans, emergency plans, type and frequency of evacuation drills, occupancy level and distribution on the morning of September 11th, and communications also constituted pre-event data. This information provided a baseline for evaluating the performance of the egress system.

Task 4—Stored the information collected in task 1 in a database. Additionally, information from third-party sources, such as published media accounts, were assembled and analyzed in the database.

Task 5—Analyzed the data to study the movement of people during the evacuations, decision-making and situational awareness, and issues concerning persons with disabilities. A timeline of the evacuation was developed using the results of these analyses together with other data sources. This timeline was compared with the timeline of the structural response, data on the development of the interior conditions (fire and smoke), as well as information on the activation of the active fire protection systems. The observed evacuation data was compared with results obtained using alternate egress models to better understand occupant behavior and identify needed improvements to existing egress models. In addition, the evacuation experience was compared with previous evacuation incidents in these buildings. The results were reviewed in the context of occupant protection practices for tall buildings, including the consideration of total evacuation and phased evacuation strategies.

Task 6—Report preparation. The results of this project were synthesized into this report to describe the occupant behavior, egress, and emergency communications in WTC 1 and WTC 2, and the performance of the evacuation system.

1.4 REPORT ORGANIZATION

This report investigates the occupant behavior, egress, and emergency communications at the World Trade Center on September 11, 2001.

This chapter explores historical fire incidents where egress played a significant role, as well as previous significant fire or evacuation incidents at the World Trade Center complex. It also describes the scope of the overall project.

Chapter 2 describes the design of the World Trade Center egress system, including the stairwells, elevators and emergency communication systems. Emergency procedures, including the roles of building managers is described. Finally, changes to the egress system as a result of the 1993 bombing are detailed.

Chapter 3 documents the overall technical approach of the project, including discussion of the collection and analysis of first-person accounts (face-to-face, telephone, and focus group interviews), collection and analysis of published media accounts, and collection and analysis of other relevant data, including audio, video, photographic, and design records.

Chapters 4 through 9 chronologically detail the overall progression of the evacuation of WTC 1 and WTC 2, including occupant activities, observations, and reactions.

Chapter 4 enumerates the occupants of WTC 1 and WTC 2, describes their basic characteristics as it relates to evacuation, and discusses the emergency preparedness of the occupants prior to the attacks.

Chapter 5 documents the occupants' awareness of and reaction to the impact of the first airplane with WTC 1, as well as observations of local damage and phenomena.

Chapter 6 describes the period of time from immediately after WTC 1 was attacked until just prior to the attack on WTC 2. The overall evacuation rate, actions of the building managers, and occupant activities and behaviors are discussed.

Chapter 7, paralleling Chapter 5, documents the impact of the second airplane with WTC 2, including awareness and reaction on the part of the occupants.

Chapter 8 tracks the progress of the evacuation and overall emergency response in both towers until immediately prior to the collapse of WTC 2.

Chapter 9 examines the collapse of WTC 1 and WTC 2, including an analysis of where the occupants likely were as each building collapsed.

Chapter 10 discusses the important egress issues raised by the events of September 11, 2001, at the World Trade Center. Included are causal models, summary statistics on the overall building evacuation rates, egress modeling, and in-depth analysis of specific issues that affected the evacuation, including the role of alarms, announcements, mobility impairments, emergency responders, authorities, information flow, activities, evacuation experience, and constraints/aids to evacuation.

Chapter 11 summarizes the key findings of this report and highlights the most important findings to consider in response to the evacuation of WTC 1 and WTC 2.

Chapter 2
DESIGN OF THE WORLD TRADE CENTER EGRESS SYSTEM

The provision of access to and egress from buildings under emergency conditions relies on four primary components: stairwells, elevators, communication systems, and emergency responders (broadly defined to include the City of New York Fire Department (FDNY), New York City Police Department (NYPD), Port Authority Police Department (PAPD), Port Authority personnel, building security, fire safety directors, floor wardens, and other individuals with formal response responsibilities). These are subsequently grouped into building systems and the human component.

2.1 OVERALL BUILDING DESCRIPTION

By 2001, the World Trade Center (WTC) complex had become an integral part of Manhattan. It was composed of seven buildings (here referred to as WTC 1 through WTC 7) on a 16 acre site, located near the southwest tip of the island, shown in Figure 2–1. Whether viewed from close up, from the Statue of Liberty across the Upper Bay or from an airplane descending to LaGuardia Airport, the WTC towers were a sight to behold. WTC 1 (often referred to as the North Tower) and WTC 2 (often referred to as the South Tower), were each 110 stories high, dwarfing the other skyscrapers in lower Manhattan and seemingly extending to all Manhattan the definition of "tall" set by midtown's Empire State Building. Groundbreaking for the towers was in 1966, while construction began in 1968. WTC 1 was first occupied in 1970; WTC 2 in 1972.

Additionally, there was a six-story subterranean structure, largely below the WTC Plaza with connections to WTC 1, 2, 3, 4, 5, and 6, which included a shopping mall and the WTC PATH station. This was surrounded by a 3 ft (0.9 m) thick concrete wall that extended from ground level down 70 ft (21 m) to bedrock. Holding back the waters of the Hudson River, this wall had enabled rapid excavation for the foundation and served to keep the groundwater from flooding the underground levels. Commuter trains brought tens of thousands of workers and visitors to Manhattan from Brooklyn and New Jersey into the WTC station. A series of escalators and elevators took the WTC employees directly to an underground shopping mall and to the Concourse Level of both towers.

WTC 3 (Marriott Hotel) was 22 stories. WTC 4 (South Plaza Building) and WTC 5 (North Plaza Building) were both 9-story office buildings. WTC 6 (U.S. Customs House) was an 8-story office building. These six buildings were built around a 5 acre plaza, named for Austin J. Tobin, and the centerpiece of which was a large globe art object. WTC 7, located north of the other six WTC buildings and separated by Vesey Street, was a 47-story office building. WTC 7 was completed in 1987 and was operated by Silverstein Properties, Inc., as an air rights building.

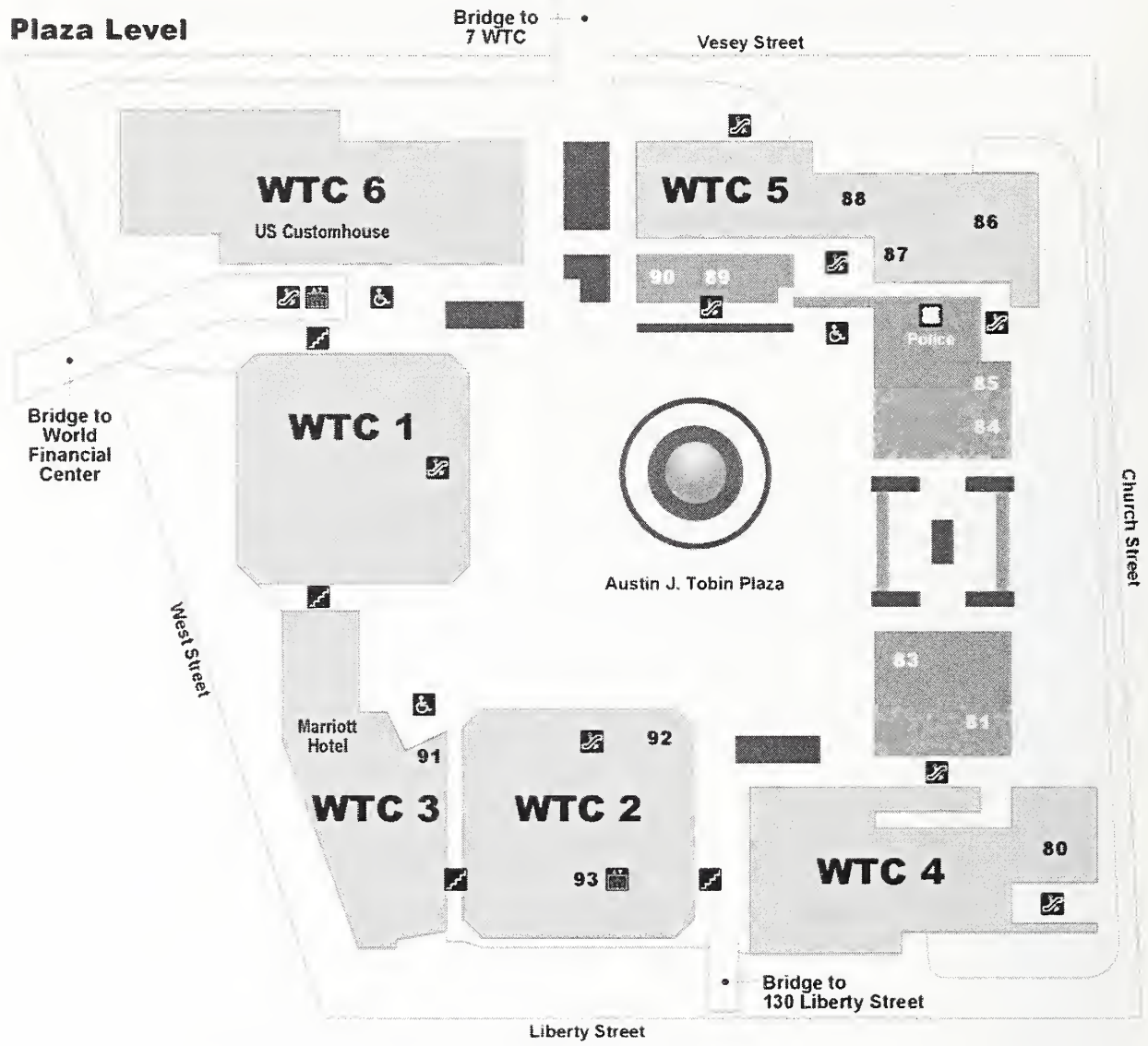

Figure 2–1. WTC site plan.

2.1.1 Description of the Towers

WTC 1 and WTC 2 each consisted of 110 stories above the Concourse Level (or 109 stories above the plaza / Mezzanine Level) structure. There were also six basement levels below the Concourse Level. Although the towers were similar, they were not identical. The height of WTC1 at the roof level was 1,368 ft (418 m) above the Concourse Level (6 ft taller than WTC 2), and WTC 1 additionally supported a 360 ft (110 m) tall antenna on the roof for television and radio transmission. Each tower had a square plan with the side dimension of 207 ft 2 in. (63.2 m). The corners of the tower were chamfered 6 ft 11 in. (2.1 m). Each tower had a core service area of approximately 135 ft x 87 ft (41 m x 27 m), although the core space changed on tenant spaces throughout the towers. A typical architectural floor plan in the tower is shown in Figure 2–2. As can be seen in this figure, placing all service systems within the core provided column-free floor space of roughly 31,000 sq ft (2,900 m^2) per floor outside the core. The long axis of the

core in WTC 1 was oriented in the east-west direction while the long axis of the core in WTC 2 was oriented in the north-south direct.

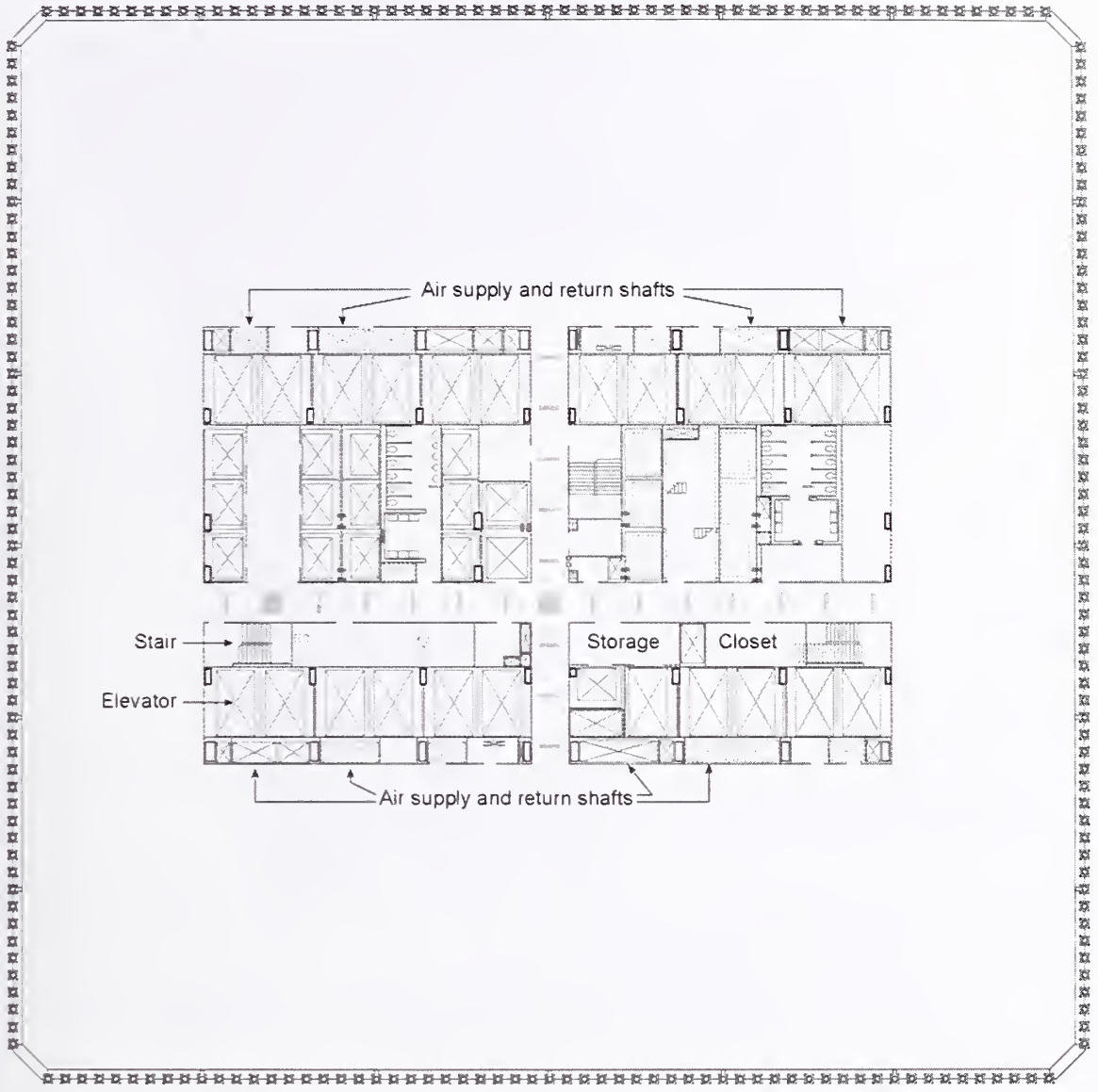

Figure 2–2. Typical WTC tower architectural floor plan.

The superb vistas from the top of such buildings virtually demanded public space from which to view them, and the Port Authority responded. The 107th floor of WTC 1 housed a gourmet restaurant and bar with views of the Hudson River and New Jersey to the west, the skyscrapers of midtown Manhattan to the north, the East River and Queens to the east, the Statue of Liberty to the southwest, and the Atlantic Ocean to the south. Similar views could be seen from observation decks on the 107th floor and the roof of WTC 2.

Table 2–1 shows the use of the floors, which was similar but not identical in the two towers:

Table 2–1. Use of floors in the WTC towers

Floor(s)	WTC 1	WTC 2
Roof	Antenna space and window washing equipment	Outdoor observation deck and window washing equipment
110	Television studios	Mechanical equipment
108, 109	Mechanical equipment	Mechanical equipment
107	Windows on the World	Indoor observation deck
106	Catering	Tenant space
79 through 105	Tenant space	Tenant space
78	Skylobby, tenant space	Skylobby, tenant space
77	Tenant space	Tenant space
75, 76	Mechanical equipment	Mechanical equipment
45 through 74	Tenant space	Tenant space
44	Skylobby, kitchen, tenant space	Skylobby, tenant space
43	Cafeteria	Tenant Cafeteria
41, 42	Mechanical equipment	Mechanical equipment
9 through 40	Tenant space	Tenant space
7, 8	Mechanical floors	Mechanical floors
Concourse through 6	6-story lobby	6-story lobby

The Port Authority had managed the operation of the two towers since their opening three decades earlier. Silverstein Properties acquired a 99-year lease on the towers in July 2001.

At the beginning of the workday, many of the roughly 40,000 people who worked in the towers and visited to tour or to conduct business emerged from PATH trains in the massive subterranean station. They would take escalators and elevators to a large shopping concourse. Walking a few hundred feet led occupants to the spacious, 6-story-high lobby on the Concourse Level where they would cross paths with those who arrived on foot or by bus and cab. Figure 2–3 shows the layout of the shopping mall, located underneath the WTC plaza. Figure 2–4 shows the lobby configuration for WTC 1. Figure 2–5 shows the layout of the WTC 2 lobby. The WTC 1 and WTC 2 lobbies were at the same level as the underground shopping mall, often collectively referred to as the Concourse Level. The WTC outdoor plaza and the WTC 1 and WTC 2 Mezzanine were one story higher than the Concourse Level, often referred to as either the Mezzanine or plaza level.

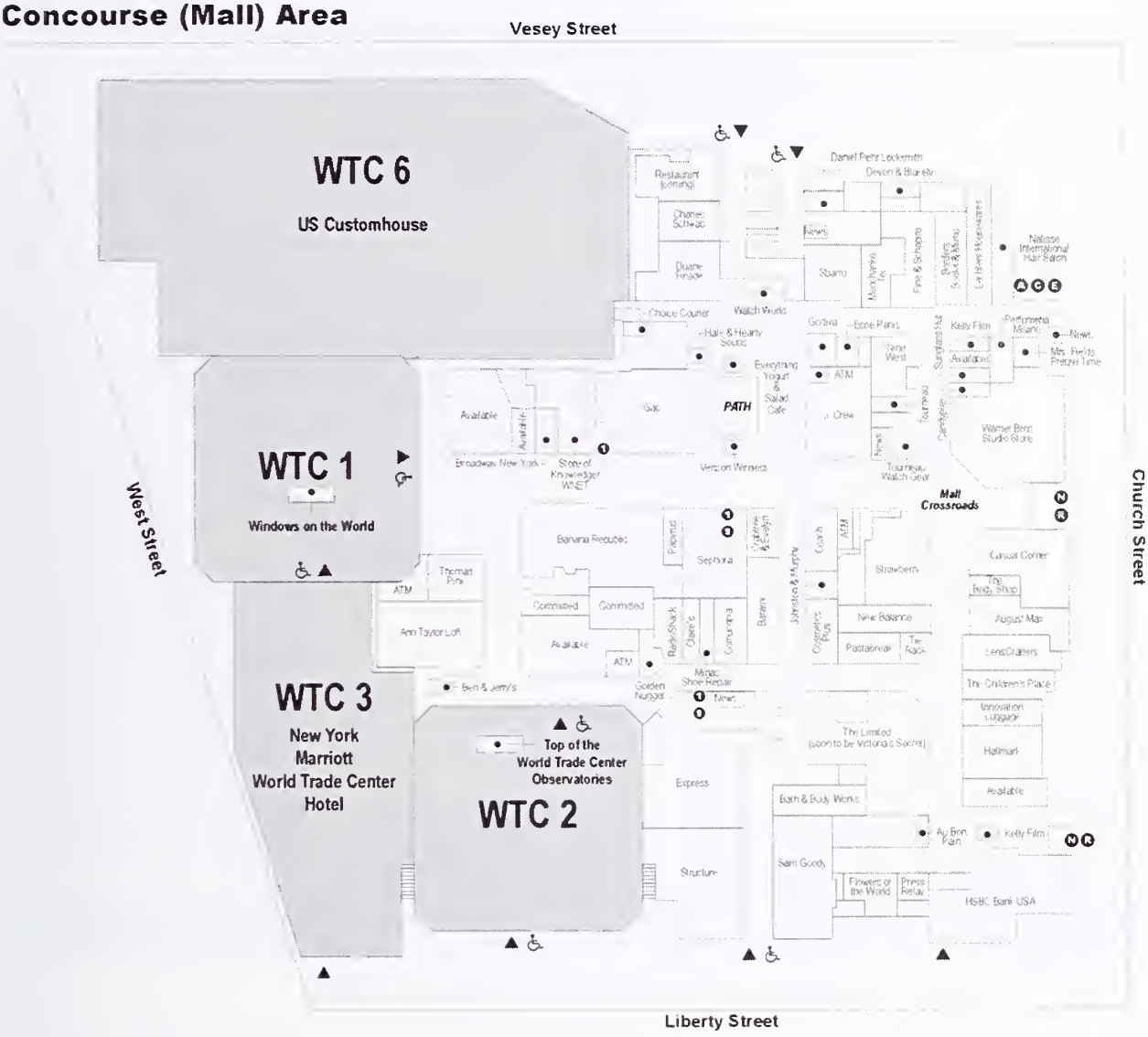

Figure 2–3. Shopping mall layout underneath WTC plaza.

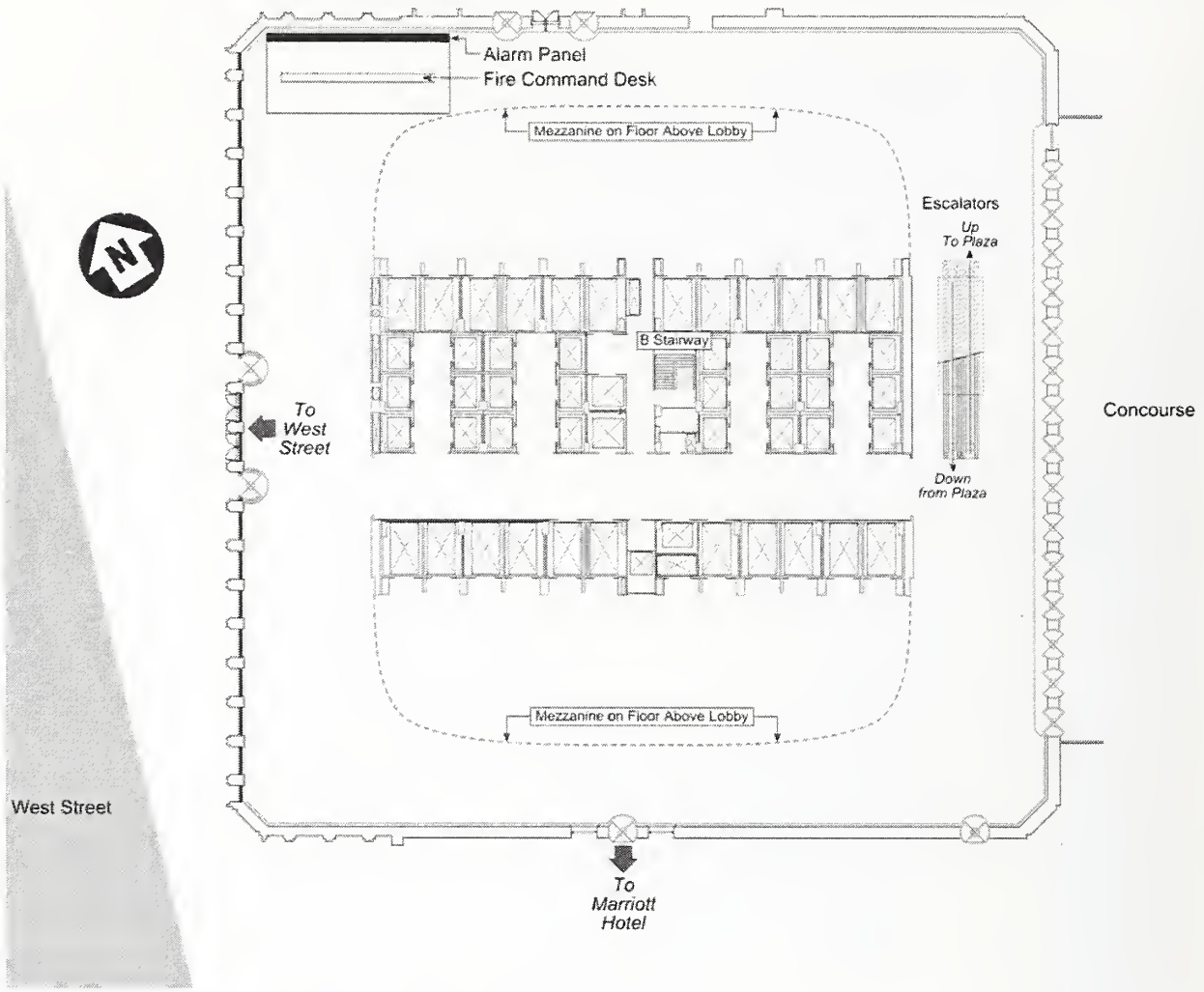

Figure 2–4. WTC 1 lobby (concourse) level.

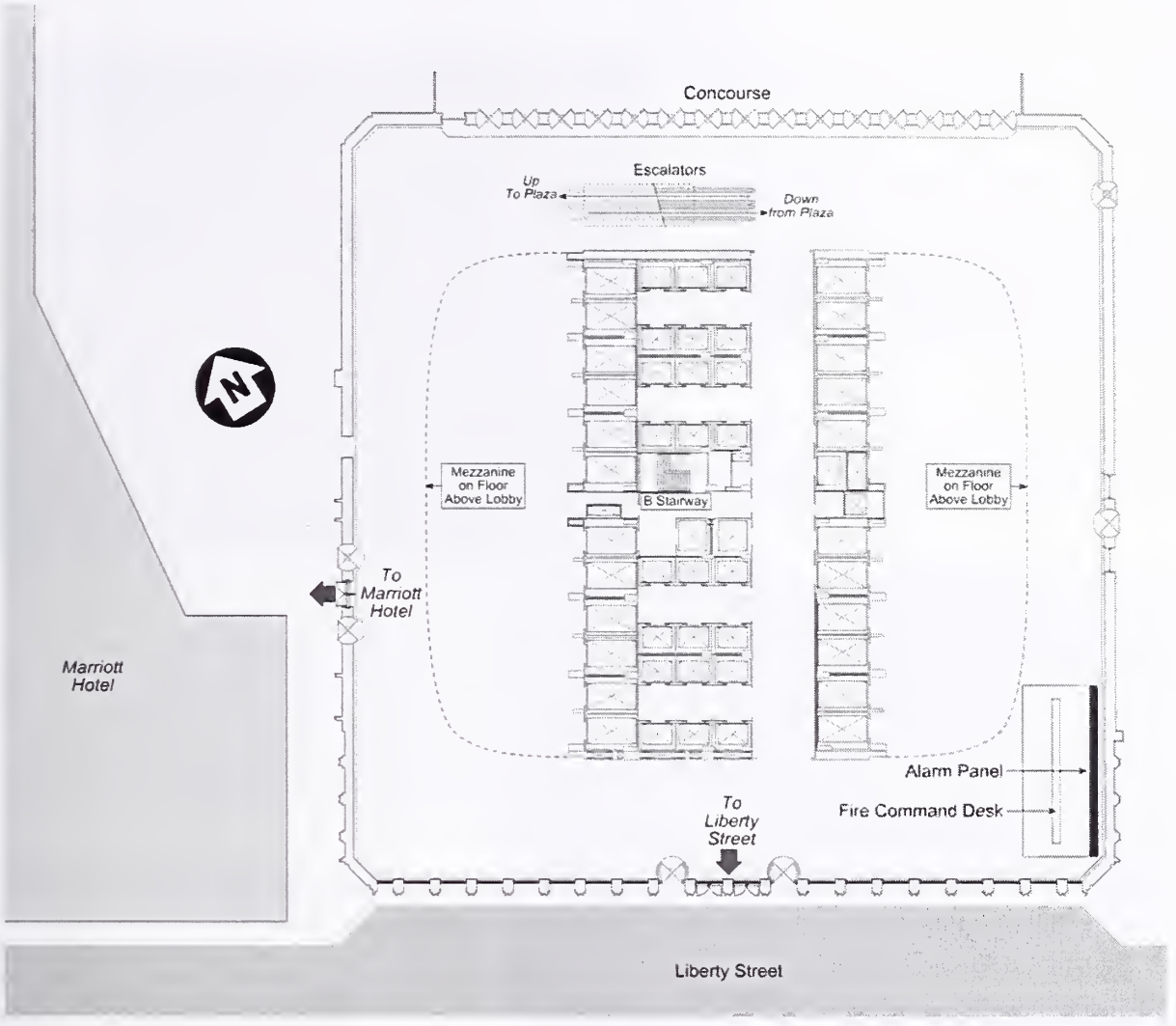

Figure 2–5. WTC 2 lobby (concourse) level.

Getting tens of thousands of people from the Concourse to their offices was no small task. This was accomplished by a then-novel array of 106 express and local elevators located within the building core (as shown later in Figure 2–14). Section 2.2.3 discusses the elevators system in WTC 1 and WTC 2.

Also within the core were three sets of stairs that extended the full height of the tower. Section 2.2.2 discusses the stairwells in each tower. However, upon entering a stairwell at an upper floor, one did not find a continuously descending staircase leading to the lobby. Principally at the mechanical floors, there were enclosed horizontal corridors that led around the massive elevator hardware. These corridors ranged in length from about 10 ft to about 100 ft. After traversing each of these, the pedestrians would resume their descent.

Upon exiting the elevators (or stairs, for those who chose the more strenuous route), one was faced with a view typical of high-rise buildings. Surrounding the rectangular core corridor was a mixture of blank walls, door entries to firms, and glass-front reception areas. Above was a standard drop ceiling.

Many of the floors had but a single tenant, and some of these tenants occupied multiple floors. By 2001, most of these companies, which had moved in since the installation of automatic sprinklers, had taken advantage of Yamasaki's design concept of a vast space that was virtually obstruction-free. The open landscaping included as many as 200 or more individual workstations, often clustered in groups of six or eight (Figure 2–6). Trading floors had arrays of long tables with multiple computer screens (Figure 2–7). Some of these floors had a few executive offices in the corners and along the perimeter. Many also had walled conference rooms. It was common for the multiple-floor tenants to have installed convenience stairs internal to their space.

Other floors were subdivided to accommodate as many as 20 firms. Some of the smaller firms occupied space in the core area, reclaimed as elevator shaft space from local elevators was phased out throughout the towers.

With so many workers and visitors in the buildings, there needed to be food available. The Port Authority maintained a cafeteria on the 43rd floor of WTC 1. A number of the companies maintained kitchen areas where catered food was brought in daily, making it unnecessary for their staff even to leave their floor for lunch. The underground Concourse Level mall also provided may options for eating. In addition, there were hundreds of restrooms, in both the tenant and the core spaces.

Figure 2–6. Typical WTC tenant spaces.

Source: Photos courtesy of The Port Authority of New York and New Jersey.

Figure 2–7. A WTC 4 trading floor.

Source: Photo courtesy of The Port Authority of New York and New Jersey.

2.2 BUILDING SYSTEMS

2.2.1 Egress Calculations

Determining the Number and Width of Stairwells

In 1965, architects and engineers designing the World Trade Center towers were faced with an impending change to the NYC Building Code. The draft building code language had a significant impact on the design of emergency egress systems. In 1965, the Port Authority directed its designers to adopt the draft version of the new code for their final designs. Some of the advantages of the new draft code were noted to be the following (Levy 1965):

- Fire towers[3] could be eliminated;
- Provisions for exit stairs were more "lenient;" and
- Criteria for partition weights were more "realistic."

It was not certain whether all the changes being proposed to the 1938 code would be incorporated into the final version of the new code. Thus, in 1966, the Chief Engineer of the Port Authority suggested that the "architect/engineers prepare a listing of the elements of the design which do not conform to old code requirements, but are acceptable under the new. With this list in hand, we could initiate discussions, at top level in the Building Department, to see if we can secure agreement to go along with our design" (Kyle 1966).

A one-page document, dated "2/15/67", with the initials "CKP" listed the following items:[4]

- Fire tower corridors [sic] eliminated.
- Number of stairs reduced from 6 to 3. (Old plans had 5 stairs at 3'-8" and 1 stair at 4'-8" for a total population of 390.[5] New plans have 2 stairs at 3'-8" and 1 stair at 4'-8" allowing a population of 390.)
- The size of doors leading to the stairs are [sic] changed from 3'-8" to 3'-0".
- All stairs exit through a lobby. Old plans had fire tower stair exiting through a fire enclosed corridor.
- Shaft walls are changed from a 3 h rating to a 2 h rating.
- Corridors are limited to a 100 ft dead end and with a 2 h rating.

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[3] A fire tower is an exterior stairwell of incombustible construction terminating at grade level designed to ensure that smoke conditions from an interior fire do not contaminate the fire tower. The fire tower was provided for firefighter ingress and did not count as a required stairwell for occupant egress. (NYC Building Code 1938)

[4] See appendix of NCSTAR 1-1 for a reproduction of this memo.

[5] The 1938 NYC Building Code allowed 30 person per unit of exit width, while the 1968 NYC Building Code allowed 60 persons per unit of exit width, effectively halving the egress capacity of new construction. Population calculations are per floor.

- Additional (word(s) missing) changed from 20 pounds per ft^2 to 6 pounds per ft^2 (based on partition weight of 50 pounds to 100 pounds per linear foot).

Apparently, this list represented elements of the WTC design that would not have satisfied the 1938 code, but did satisfy the then-current draft version of the new code. Ultimately, WTC 1 and WTC 2 were designed with three stairwells, two 3'-8" (44 in.) wide and one 4'-8" (56 in.) wide, as discussed below.

A unit of exit width in the 1968 NYC Building Code was (and continues to be) 22 in. (0.56 m). The NYC Building Code table specifying exit and access requirements (Table 6–1) required that for a business occupancy, the stairs would accommodate 60 persons per unit of exit width. As the WTC 1 and WTC 2 tenant floor design occupancy load was 365 persons per floor[6] (Solomon 1968), this required 6.5 units of exit width. Twelve in. (0.3 m) was the minimum half-width acceptable in the code, therefore, three stairwells (two with two units of exit width (44 in. [1.1 m]) and one with 2.5 units (56 in. [1.4 m])) satisfied the minimum requirements of the 1968 NYC Building Code. Table 2–2 shows the location of the stairwells, core perimeter, and transfer hallways for occupied floors in WTC 1 and WTC 2.

Egress Provisions from Windows on the World

The 106th and 107th floors of WTC 1 (North Tower) contained the Windows on the World complex, consisting of the Windows on the World restaurant, the Greatest Bar on Earth, numerous banquet and function rooms, kitchens and support areas, and management offices for the dining complex. While the configuration of the space may have changed over the life of the building, these functions were all present from the time Windows on the World first opened in April 1976.[7]

Restaurants, bars, and function rooms are classified in building codes as assembly use, which carries a significant increase in occupant load and consequent provisions for egress. The design occupant load for such assembly space is 15 ft^2 per occupant as opposed to the 100 ft^2 per occupant for the office use space in most of the rest of the buildings. Thus, while the design number of occupants on an office floor was 365 to 390 (depending on the calculation method), the design number of occupants for these floors was over 1,000 each (the exact number depends on the area of kitchens, dishwashing, and office space on the floor, all of which is at 100 ft^2 per occupant).

Locating assembly space high in a building poses particular challenges to egress design because the capacity of an egress component is not permitted to be decreased in the direction of travel. Thus, where more or wider stairs are provided to meet capacity requirements these must be continued all the way down through the building which affects space utilization for the entire structure.

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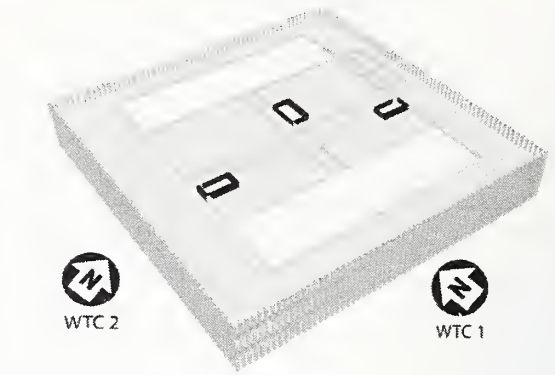
[6] A January 25, 1968 memo from J. Solomon (Emory Roth and Sons) to M. Levy (PANYA) subsequent to a NYC Building Department plan review, documents that the "largest floor area is about 36,500 ft^2 on the 106th floor. At one person per 100 ft^2 there will be 365 persons per floor, well within the permissible maximum" of 390 persons based upon stairwell capacity. WTCI-477-P Note that this calculation did not account for the use of the 106th floor as an assembly space.

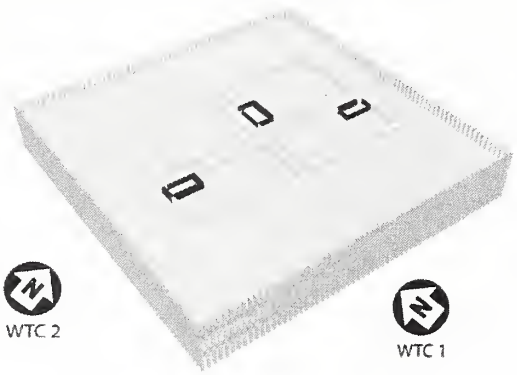
[7] PANYNJ response to formal NIST question, March 25, 2005.

Table 2–2. Plan view of stairwells in WTC 1 and WTC 2.

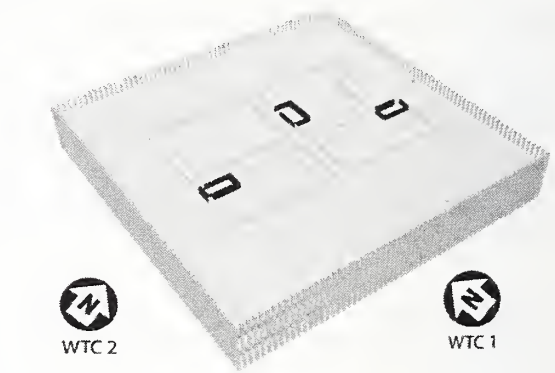
Lobby (Concourse) Level Layout
Only Stairwell B Serviced the Concourse Level



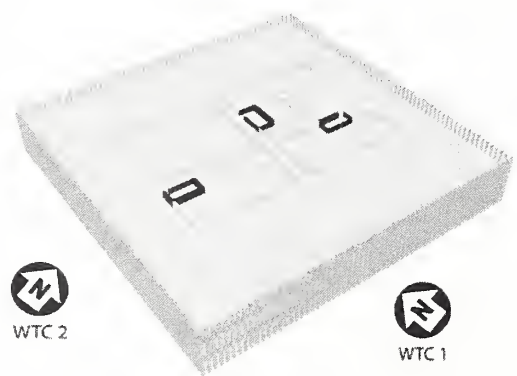
Mezzanine (Plaza) Level Layout
Only Stairwell B Serviced the Concourse Level



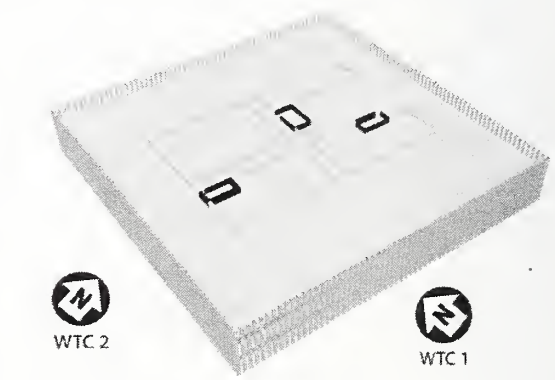
Floors 9 – 19
Stairwells A was East in WTC 1, North in WTC 2.



Floors 20 – 26
Core space previously used by the elevators in the northeast quadrant became leasable tenant space.

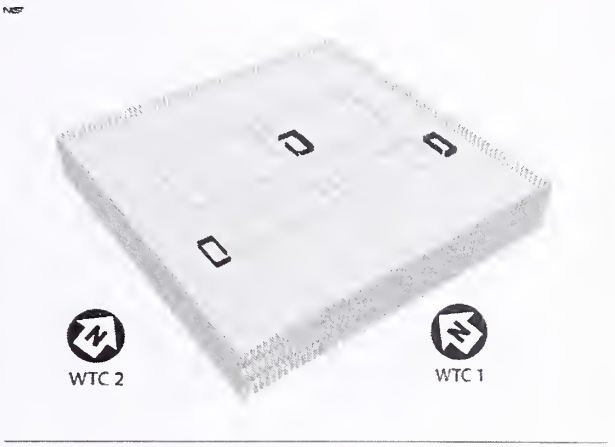


Floors 27 - 34

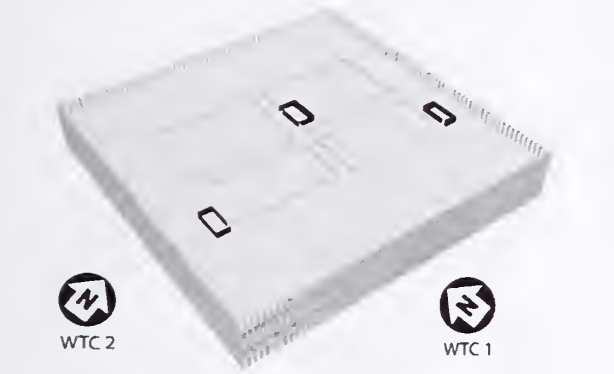


Floors 35 - 41

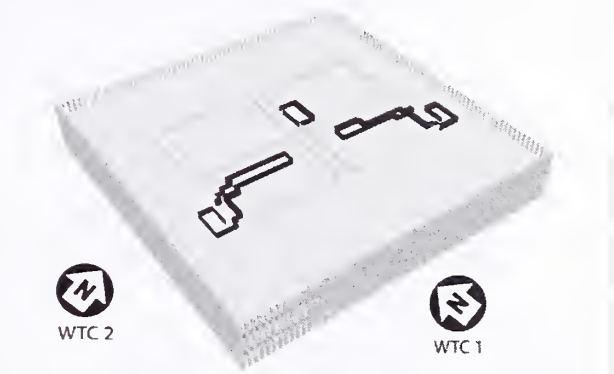
Floor 42
Stairs A and C transferred outside the core.



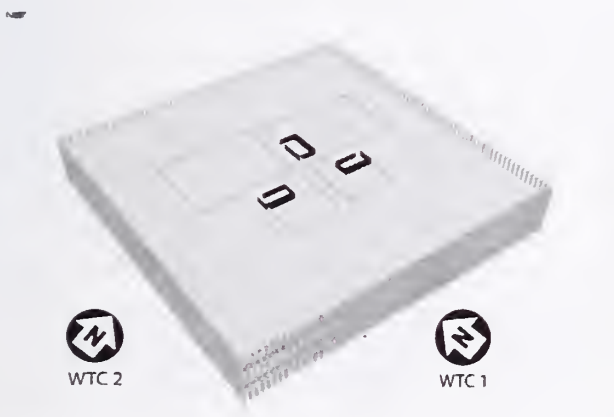
Floors 43, 45 – 47
There was an escalator connecting floors 43-44 (skylobby).



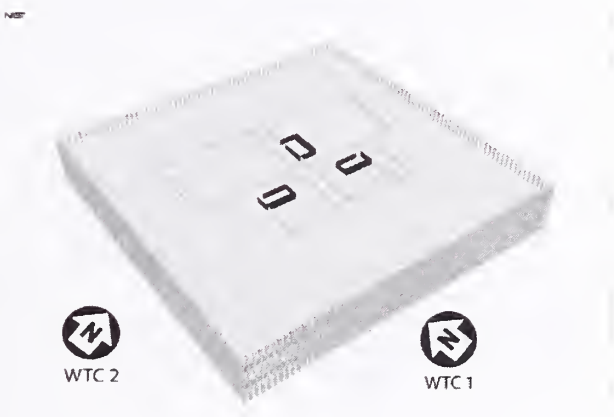
Floor 44 (Skylobby)



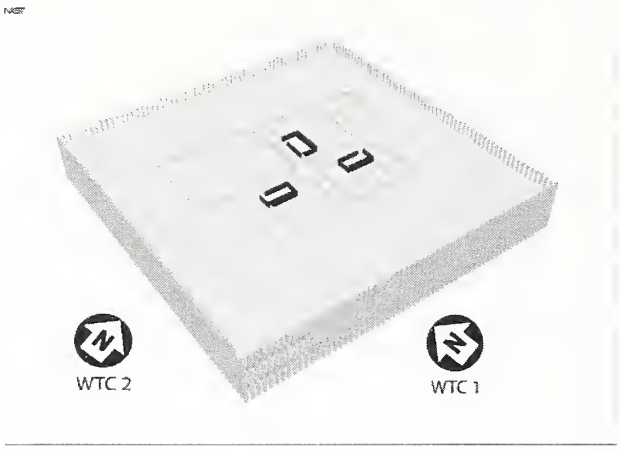
Floor 48
Stairs A and C transferred back inside the core.



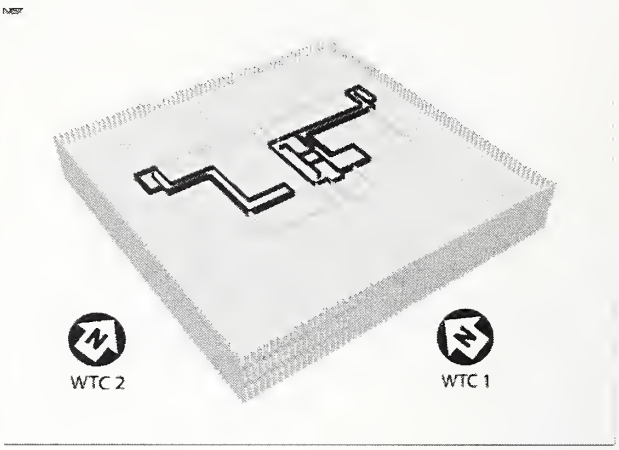
Floors 49 – 54



Floors 55 - 56



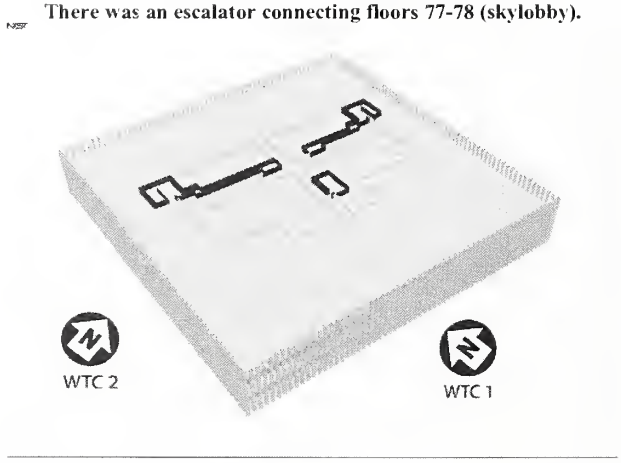
Floors 57 – 75
There was a slight change in Stairs A, C between floors 66-68.



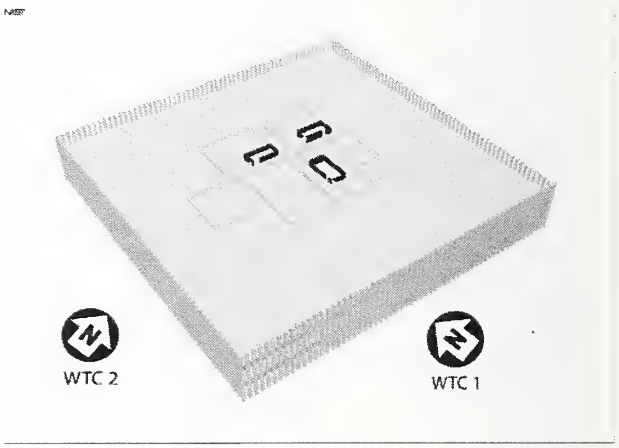
Floor 76
Stairs A, B, and C transferred, with Stairwells A and C moved outside the core.

Floors 77, 79, 80, 81
There was an escalator connecting floors 77-78 (skylobby).

Floor 78



Floor 82
Stairs A and C transferred back inside the core.



Floors 83 - 95

Floors 96 - 102

Floors 103 – 104

Floors 105 - 106

Floor 107

The document record contains a letter dated January 27, 1995, from Eugene Fasullo (PANYNJ) to Richard Visconti (Deputy Commissioner, NYC Department of Buildings [DOB]) confirming the results of a meeting on December 6, 1994, at which they reached agreement on a plan to address egress requirements from the 106th and 107th floors (Fasullo 1995). The details of the agreed solution are summarized below. The Deputy Commissioner, DOB, signed the letter to show concurrence with the agreed solution.[8]

It remains unclear what conditions existed from the date Windows on the World first opened to the time the agreed solution was implemented in 1995. The dates suggest that the issue was identified as a result of the Memoranda of Understanding (MOU) between PANYNJ and the NYC DOB and FDNY executed in 1993, in response to the bombing. A Windows on the World refurbishment after the 1993 bombing included these egress system changes.[9]

The basis for the agreed solution was to divide each floor into three areas of refuge (consistent with Section 27-372 [NYC Building Code]) to provide additional capacity to the existing stairs in accordance

[8] Fasullo, E., PANYNJ, to R. Visconti, NYC Department of Buildings, "Variance Granted by Memorandum of Understanding with Buildings Department, Windows on the World," January 27, 1995.

[9] PANYNJ response to formal NIST question, March 25, 2005.

with Section 27-367 (NYC Building Code). These identical provisions existed in the version of the 1968 NYC Building Code in effect when the buildings were built as sections C26-604.5 and C26-603.3, respectively (the NYC Building Code was renumbered) (NYCBC 1968).

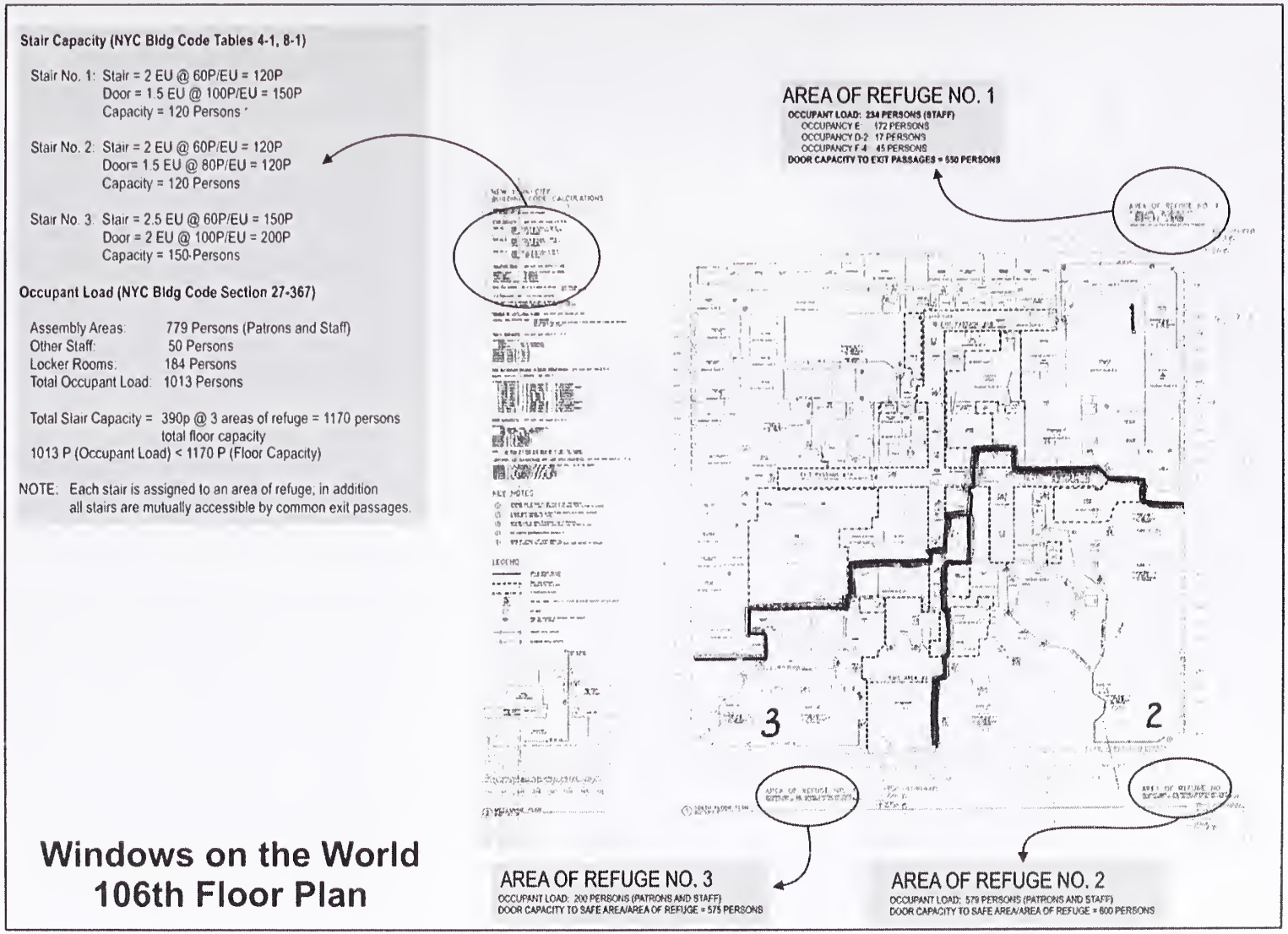
These code provisions allow for a doubling of allowed stair capacity when one area of refuge is provided on a floor and tripling the stair capacity for two or more areas of refuge on a floor. These areas of refuge must be separated by 2 h construction, be large enough for the expected occupant load at 3 ft^2 per occupant, each contain at least one stair, and have access to at least one elevator (above the 11th floor). Since three, distinct areas of refuge were provided on each floor, tripling of the capacity of each of the three stairs resulted in a maximum permitted occupant load of 1,170 people per floor (6.5 units of egress x 60 persons per unit x 3).

Attached to (and referenced in) the letter were two plans entitled "106th Floor Egress Plan" and "107th Floor Egress Plan" (shown in Figure 2–8 and Figure 2–9, respectively) that detailed the arrangement,. The 2 h separation walls snaked across the floors and were not aligned on the two floors. Some areas that needed to remain open to free passage were protected with Won doors (accordion doors that are fire rated and are closed automatically on activation of the fire alarm system). Details of the egress system design calculations and corresponding NYC Building Code requirements were included on the plans to demonstrate they met code requirements.

By comparison, current model building codes, including the ICC 2003 International Building Code (IBC) and National Fire Protection Association (NFPA) 5000, both permit a doubling (but not tripling except in IBC Type I-2 and I-3 institutional uses) of the stair capacity for the provision of a horizontal exit on a floor. The horizontal exit must consist of a 2 h fire rated separation, contain at least one stair on each side, and have sufficient space for the expected occupant load at 3 ft^2 per person. A horizontal exit must be continuous down through the building to grade[10] (NFPA 11.2.4.3.1 and IBC 1021.2), unless the floor assemblies are at least 2 h with no unprotected openings.

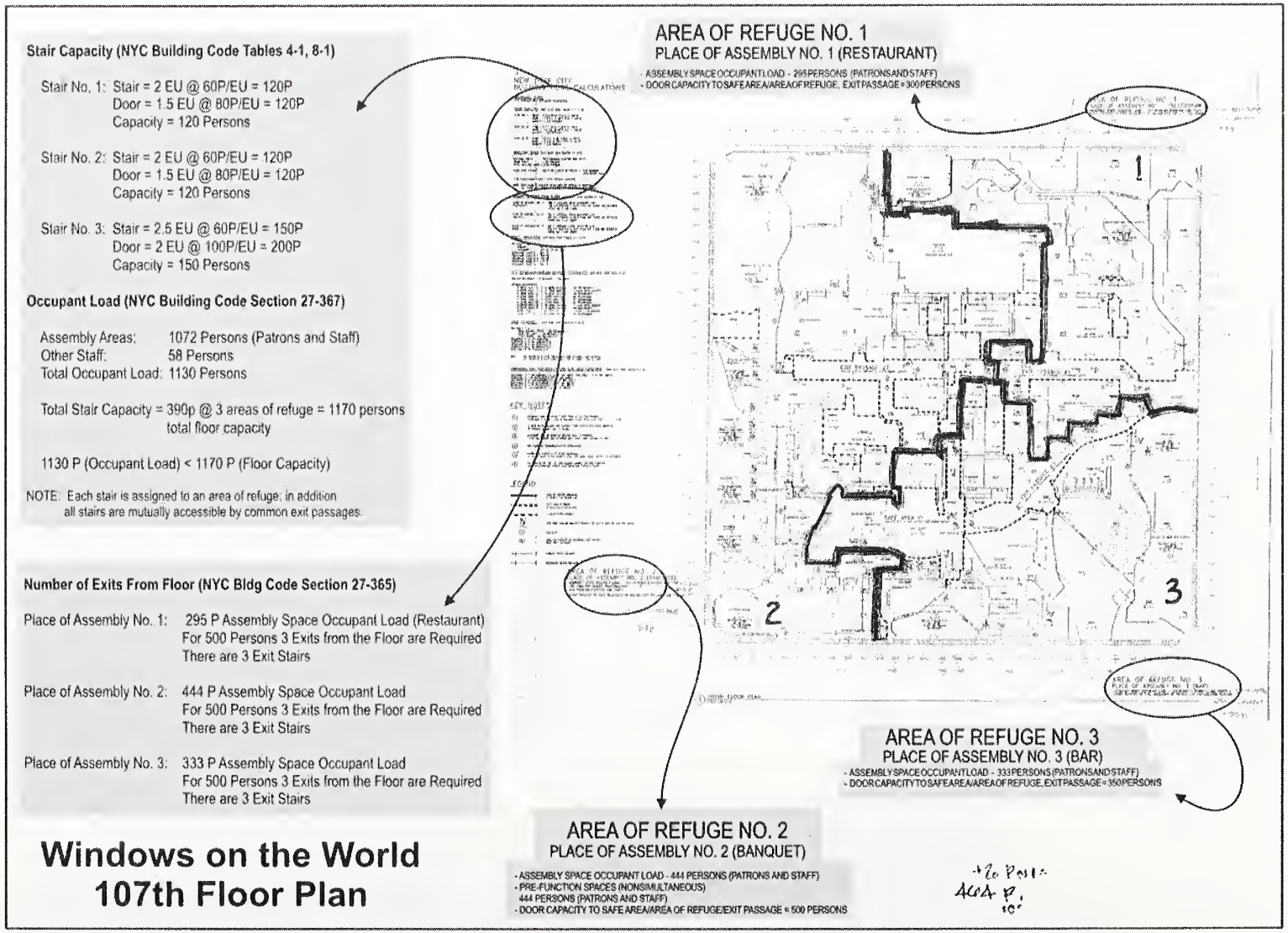
The solution to the egress problem was to provide a protected space in which occupants could wait to enter stairs that did not have adequate capacity for the numbers of people. Since the attacks took place in the morning (a non-peak time), NIST estimated that there were 188 occupants trapped in the Windows on the World floors. If the attacks had occurred when the facility was loaded near its capacity, as many as 2,000 occupants could have lost their lives on those two floors alone, since there were no survivors above the impact floors of WTC 1.

[10] In other words, the stairway may not contain unprotected openings (such as opening out to a floor) until the occupant exits the building.



Source: Reproduced with permission of The Port Authority of New York and New Jersey. Enhancement by NIST.

Figure 2–8. 1993 Windows on the World egress calculation, floor 106.



Source: Reproduced with permission of The Port Authority of New York and New Jersey. Enhancement by NIST.

Figure 2–9. 1993 Windows on the World egress calculation, floor 107.

A similar condition existed on the 107th floor of WTC 2, commonly referred to as the Observation Deck. A tenant alteration application submitted by Ogden Entertainment (the tenant) to PANYNJ in late 1995 and early 1996 utilized the areas of refuge provisions referred to previously with respect to the Windows on the World space.[11] Taking advantage of a NYC Building Code provision which permits a lower basis for occupant load, the PANYNJ permitted a maximum occupant load of 1,170 persons on the floor (Indoor Observation Deck and Outdoor Observation Deck, combined), which was enforced by the lessee with periodic oversight by PANYNJ.[12]

2.2.2 Stairwells

WTC 1 and WTC 2 each had three primary stairwells designed for emergency egress, designated as A, B, and C. There were additional stairwells located in the basement levels (B1 – B5), convenience stairs for tenants leasing multiple floors, and mechanical room stairs. These secondary stairs are not considered part of the emergency egress system and are not described here. Stairwells A and C were 1.1 m (44 in.) wide and extended from floor 2 (plaza or Mezzanine Level) to floor 110 (lower mechanical space). The stairwell landings by the exit door were 92 in (2.3 m) wide by 78 in (2.0 m) deep. Figure 2–10 shows a 44 in. (1.1 m) stairwell in WTC 1 taken on September 11, 2001, by John Labriola during his evacuation. Note the photoluminescent paint on the stair edge and landing. Stairwell B was 56 in. (1.4 m) wide and ran from the subgrade 6 levels below ground to floor 107 including the Concourse (main lobby); there was no exit from Stairwell B onto the 2nd floor (plaza / Mezzanine Level). The stairwell landings by the exit door for Stairwell B were 116 in (2.9 m) wide by 78 in (2.0 m) deep.

Figure 2–10. 44 in. stairwell in WTC 1 taken on September 11, 2001.

The 1968 NYC Building Code has requirements for the number and capacity of stairs and for the assumed occupant load that are similar to requirements in the other contemporaneous codes (see NIST NCSTAR 1-1, Appendix A). Codes of that time required that multiple stairs be located "as remote from each other as practicable." NYC permitted scissor stairs,[13] and the code required the exit doors to be at least 4.6 m (15 ft) apart. Local Law 16 (1984) first imposed a remoteness requirement of 30 ft or one-

[11] Ogden Entertainment. 1996. Port Authority work number W96-2103-01. WTCI-180-P.

[12] PANYNJ response to formal NIST question. "Re: Question for PA." March 25, 2005. S. Bohl to S. Sunder.

[13] Scissor stairs are two separate stairwells with two separate stairwell access doors, which share a common shaft space, often winding around each other. This results in an efficient use of space, but places the stairwells in direct contact (in other words, there is not a barrier separating the stairwells), thus allowing smoke or other threats to affect two stairwells simultaneously.

third the maximum travel distance of the floor (whichever is greater). This requirement was not retroactive, so it did not apply to WTC 1 and WTC 2. However, this requirement did apply to WTC 7.

The 1968 NYC Building Code also states that, " ...vertical exits should extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway or street floor lobby ..." (C26-602.4). The 1965 BOCA Basic Building Code and 1966 NFPA 101 contained similar language, but not the 1964 New York State Building Construction Code or the 1966 Municipal Code of Chicago. Current model code language (2003 IBC, section 1003.6) defines continuous as: not " ... interrupted by any building element other than a means of egress component."

The exit discharge language was the subject of discussion in that the stairs in WTC 1 and WTC 2 discharged onto the Mezzanine Level, which was not at street level but rather at the Plaza level. The Port Authority took the position that the concourse was like an underground street, and the arrangement met the intent of the Code, as demonstrated by a February 18, 1975 letter from Joseph Solomon (Emory Roth and Sons) to Malcolm Levy (PANYNJ), which covered six points. "We [Emory Roth and Sons] were instructed by the Port Authority to deviate from the code [1968 NYC Building Code]." The fourth point listed the "treatment of concourse level as 'Underground Street' noted by letter to the Port Authority on April 6, 1971, January 11, 1972, and May 7, 1973" (Solomon 1975).

Transfer Hallways

The WTC 1 and WTC 2 stairwells were occasionally routed horizontally around equipment on mechanical floors, through what were called transfer hallways, as shown in Figure 2–11. Table 2–2 shows the overall layout of the stairwells in WTC 1 and WTC 2, including the basic core perimeter.[14] Stairwell B required a horizontal transfer at floor 76. For all other floors, stairwell B maintained vertical alignment through the building. Stairwells A and C required horizontal transfers (some longer than others) at floors 42, 48, 66, 68, 76, and 82. Horizontal transfer distances ranged from several feet (floors 66 and 68) to over 100ft (33 m), including smoke doors (which were closed but not locked) and multiple right angles turns in the transfer on floors 42, 48, 76, and 82 for Stairwells A and C. Note that the mechanical floors were located on floors 41-42, 75-76, and 108-109. One problem with the horizontal transfers was that they extended the total evacuation time, when compared to a similar design without horizontal transfers. The World Trade Center Review Committee, formed by the New York City Building and Fire Commissioners in response to the 1993 WTC Bombing, found that "the occupants of the towers encountered changes in the path of egress that were unfamiliar, [contributing] to the general confusion during the evacuation process (New York City 1995)." Figure 2–12 shows a photograph of a horizontal transfer hallway in WTC 1 or WTC 2 taken after the 1993 bombing, including photoluminescent markings.

[14] Core is defined in this report as the boundary of non-leasable common space, including egress hallways, stairwells, elevator shafts and lobbies, HVAC, plumbing and other mechanical spaces. This definition of core may differ from a structural definition of core, defined by the location of core columns, which did not change location in WTC 1 or WTC 2 on different floors.

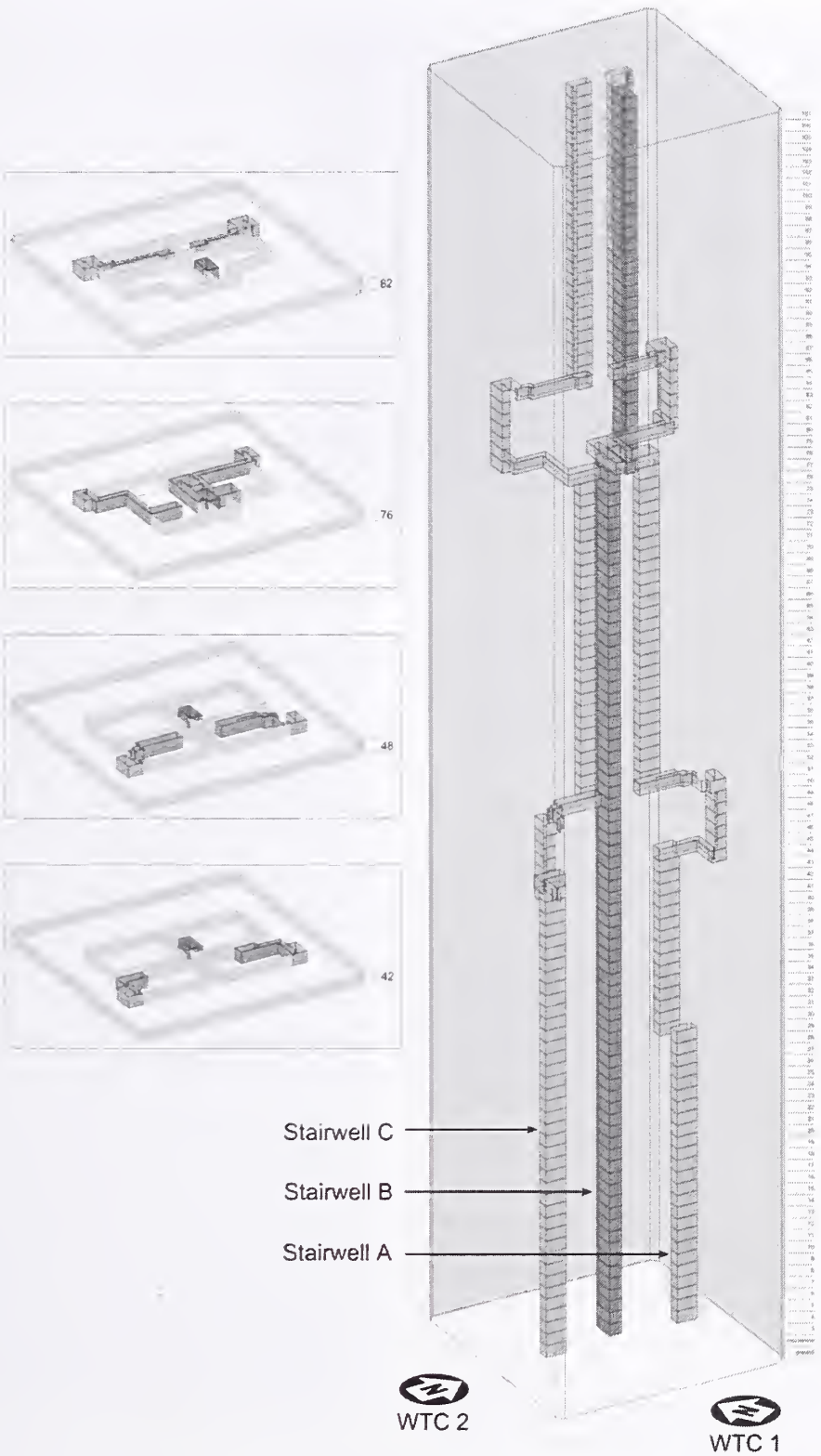


Figure 2–11. Stairwells in the WTC towers.

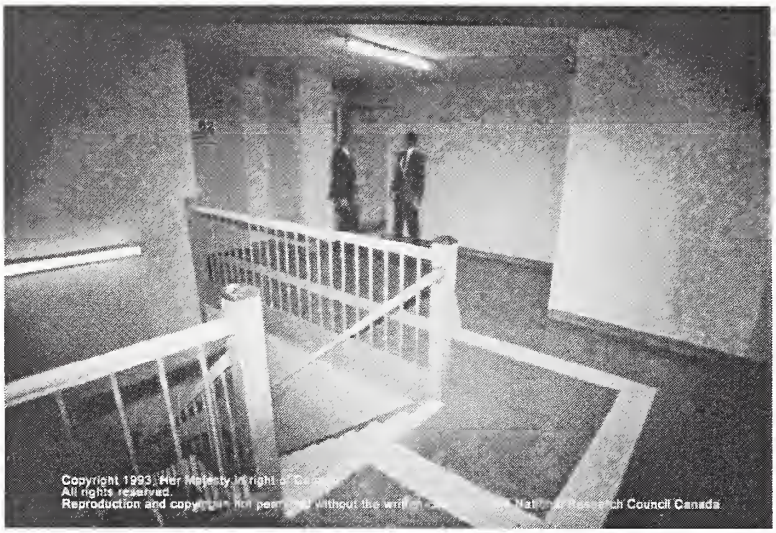


Figure 2–12. Horizontal transfer floors in the WTC towers.

Each stairwell had signage on both sides of the stairwell access doors indicating the letter designation of the particular stairwell. A sign on the inside of the stairwell indicated the floor number, the stairwell designation, and whether the floor was a "re-entry" or "non-re-entry" floor. Figure 2–13 shows a photograph of this signage taken after the 1993 bombing. A non-re-entry floor was a landing in the stairwell where the door to the floor was locked from the stairwell side. If the particular floor was not a re-entry floor, the sign indicated the location of the nearest re-entry location, every fourth floor (in the case of Figure 2–13, floors 74 and 78). The stairwell doors were required to be always open every fourth floor by the NYC Building Code. Door locks leading to mechanical spaces and the roof were controlled electronically at the Security Command Center (SCC) on floor 22. The NYC Building Code also required that, in the event of a power outage, the re-entry locking mechanism would default to the open position.

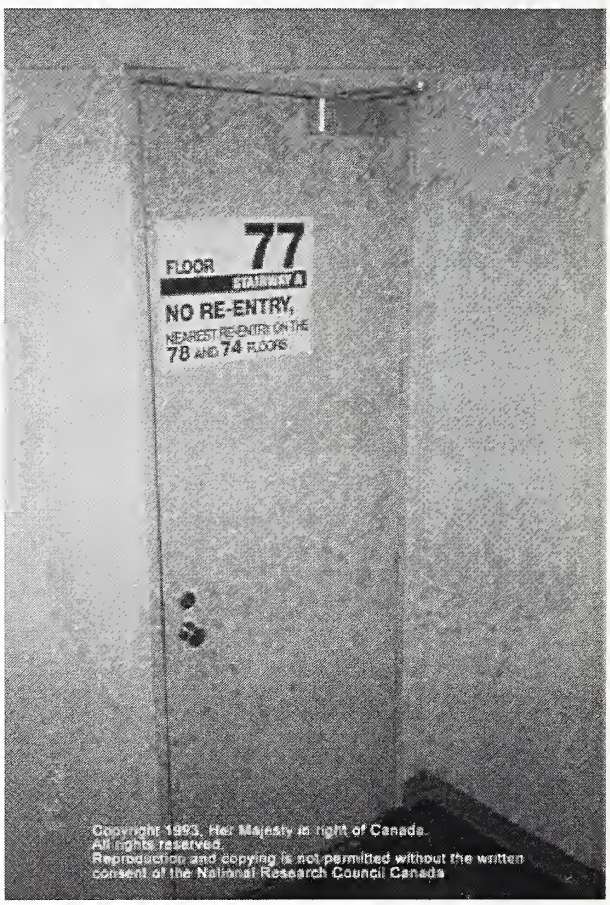


Figure 2–13. Stairwell door signage as seen from inside stairwell A.

Compartmentation

The design of WTC 1 and WTC 2 featured large, open office spaces devoid of columns due to the innovative structural design. Tenants could (and often did) utilize open plan office layouts that permitted impressive views of the Manhattan skyline out the perimeter windows.

The NYC Building Code and PANYNJ practice required partitions to separate tenant spaces from one another and from common spaces such as the corridors that served the elevators, stairs, and other common spaces in the building core. Fire rated partitions are intended to limit fire spread on a floor and to prevent spread of fire in one tenant space to that of another. Partitions separating tenant space from exit access corridors were permitted to be 1 h, although PANYNJ specified them to be 2 h (Kyle 1966). This allowed dead ends to extend to 100 ft (rather than 50 ft with 1 h partitions), which permitted more flexibility in tenant layouts. Partitions separating tenant spaces (so-

called demising walls) were required to be 1 h. Enclosures for vertical shafts, including stairways and transfer corridors, elevator hoistways, and mechanical or utility shafts were required to be of 2 h fire rated construction. Protection of vertical shafts was intended to limit the spread of fire and smoke from floor to floor.

Another influence on compartmentation of the buildings was the adoption of Local Law 5 (New York 1973) (LL 5) amending the NYC Building Code. While it did not (legally) apply to the WTC buildings, PANYNJ policy was to follow the requirements voluntarily. LL 5 required compartmentation of unsprinklered spaces in existing office buildings over 100 ft in height "having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located" to be subdivided by 1 h fire separations into spaces or compartments not to exceed 7,500 ft^2. Floor areas could be increased up to 15,000 ft^2 if protected by 2 h fire resistive construction and smoke detectors. Regardless of the floor area, compartmentation is not required when complete sprinkler protection is provided (LL 5, Section 6).

Shortly after the adoption of LL 5, PANYNJ began to add the required compartmentation as a part of new tenant layouts as evidenced by several subsequent tenant alteration contracts from this time. Following the 1975 fire a fire safety consultant report recommended to PANYNJ that the buildings be retrofitted with sprinklers to address possible smoke problems, which would also obviate the need for compartmentation and permit the unobstructed views for which the buildings were known. The decision left the interior WTC floor arrangements with only partitions separating tenant spaces from one other and from exit access corridors or common spaces in the core, and with shaft enclosures.[15]

Construction of Partitions and Shaft Enclosures

Vertical shafts surrounding stairs, mechanical shafts (carrying supply and return air), elevator hoistways, and utility shafts were all contained within the building core of the WTC towers, and were enclosed by gypsum planking similar to fire separations commonly used today in single-family attached housing. These gypsum planks were 2 in. thick and 2 ft wide, reportedly with metal tongue and groove channels attached to the long sides. These were likely two 1 in. panels held together by the metal channels. Their length in WTC 1 and WTC 2 is unknown, but similar panels today are available in 8 to 14 foot lengths. The planks were placed into metal H-channels at the top and bottom and secured by drywall screws.

The 1978 edition of the Gypsum Association (GA) Fire Resistance Design Manual lists several similar shaft wall constructions utilizing 2 in. gypsum planks consisting of two 1 in. gypsum core board panels with "metal channels on long edges." The GA Manual lists shaft walls of a single 2 in. metal edged plank (WP7015) having a 1 h fire rating, a single 2 in. metal edged plank with one layer of Type X gypsum board on the unexposed side (WP7112) having a 2 h fire rating, and a single 2 in. metal edged plank with two layers of Type X gypsum board on the unexposed side (WP 7575) having a 3 h fire rating.

Partitions separating tenant spaces on the same floor were constructed of two layers of 5/8 in. Type X gypsum board on steel studs and ran slab to slab. This construction is commonly recognized as a 2 h fire separation. Above the ceiling, penetrations for ducts or to allow for return air flow were fitted with rated fire dampers to preserve the fire rating.

[15] PONYA 1976 – Complete report reproduced in NIST NCSTAR 1-1H.

Interior partitions not separating spaces occupied by different tenants were constructed of single or double layers of 5/8 in. Type X gypsum board on steel studs, and ran from the slab to the suspended ceiling but not above. Double layers of gypsum board were used when the tenant desired additional sound attenuation. These partitions were not required to be fire rated and fire rated doors were not used. However, a single layer of 5/8 in. Type X gypsum board on steel studs (16 in. on center) is generally considered to have a 1 h fire rating and two layers of 5/8 in. Type X gypsum on steel studs (16 in. on center) is considered to have a 2 h fire rating. For a ceiling-high partition to be considered as having a fire rating, the ceiling itself would have to be rated as well. The ceiling system used throughout these buildings was not fire rated.

2.2.3 Elevators

Getting thousands of people from the ground level to the offices, observation levels, and restaurants, some as high as a quarter-mile, was no small task. Thus, elevators were the primary mode of movement between floors of the World Trade Center. The World Trade Center complex contained more than 240 elevators, with 99 elevators serving the above-ground levels in each of the two main towers and an additional 7 elevators serving primarily the sub-grade basement levels. In the towers, the elevators were arranged to serve the buildings in three sections divided by skylobbies, which served to distribute passengers among express and local elevators. Figure 2–14 shows an elevator riser diagram for WTC 1 and WTC 2 for passenger elevators.

- People traveling to floors 9 through 40 entered a bank of 24 local elevators at the Concourse Level. These were divided into four groups, with each stopping at a different set of eight or nine floors (9 through 16, 17 through 24, 25 through 31, and 32 through 40).

- Those going to floors 44 through 74 took one of eight express elevators to the 44th floor skylobby before transferring to one of 24 local elevators. These 24 were stacked on top of the lower bank of 24, providing additional transport without increasing the occupied floor space.

- Those going to floors 78 through 107 took one of 10 express elevators from the Concourse Level to the 78th floor before transferring to one of 24 local elevators. These were also stacked on the lower banks of 24.

- Dedicated express elevators served the restaurant, bars, and meeting rooms on floors 106 and 107 of WTC 1, as well as the observation deck in WTC 2.

An occupant traveling to the 91st floor, for example, would have taken an express elevator from the lobby to the 78th floor and then would have had to transfer to another elevator to arrive at the 91st floor.. The elevator trip would have taken several minutes travel time, depending upon the wait at the elevators. While providing an acceptable rate of people movement, this three-tier system also used less of the building footprint than the usual systems in which all elevators run from the entrance to the top of the building. Further, leasable floor space was reclaimed near the top of a given zone. At the top of each elevator bank, the machinery to lift the cabs occupied the next higher floor. From the next higher floor up to the bottom of the next elevator bank, there was no need for an elevator shaft. The concrete floor was extended into this space, providing additional rentable floor area for offices, conference rooms, storage, etc. Figure 2–14, for example, shows that the space taken by Elevator Bank A (Elevators 24 – 29) in

order to serve floor 9 to floor 16, was reclaimed for tenant use on floors 19 to 42. This resulted in a reclamation of approximately 750 ft^2 per floor. A calculation for reclaiming unused floor space above elevator banks A, B, and C for all three zones, reveals that roughly 100,000 ft^2 of potentially leasable office space could be recovered. Assuming $55 per ft^2 per year as a rental rate for a downtown Manhattan office building over 600,000 ft^2 (BOMA 2001), the reclamation could theoretically yield nearly $6 million per year of rental income. At the time WTC was built, the concept of skylobbies, served by express elevators and serving only one zone of the building, was innovative. Other tall buildings now use this concept.

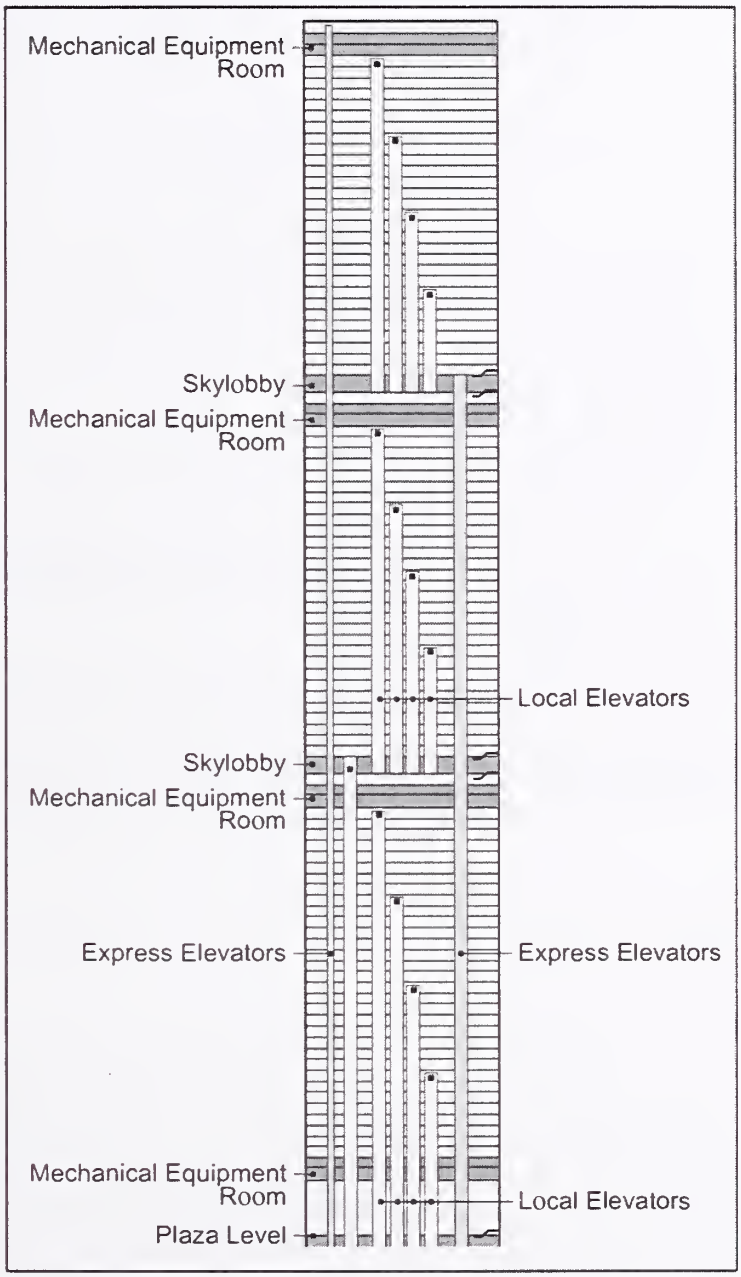


Figure 2–14. Elevator riser diagram for WTC 1 and WTC 2.

In addition to the passenger elevators, there were seven freight elevators in each tower; most served a particular zone, while Car 50 served every floor.

- Car #5: B1-5, 7, 9-40, 44
- Car #6: B1-5, 44, 75, 77-107 (Dual-use express, see below)
- Car #17: B1-1, 41, 43-78
- Car #48: B1-7, 9-40
- Car #49: B1-5, 41-74
- Car #50: B6-108
- Car #99: 107-110[16]

There were two express elevators (#6 and #7) to Windows on the World (and related conference rooms and banquet facilities) in WTC 1 and two to the observation deck in WTC 2. There were five local elevators in each building: three that brought people from the subterranean levels to the lobby, one that ran between floors 106 and 110, and one that ran between floors 43 and 44, serving the cafeteria from the skylobby. All elevators had been upgraded to incorporate firefighter emergency operation requirements.

Local Law 5 (New York 1973) requires that elevators be provided with an emergency recall system. This requirement was incorporated subsequently into the American Society of Mechanical Engineers (ASME) A17.1, Safety Code for Elevators and Escalators, which governs elevator design and operation in all present U.S. building codes. The ASME Code required that:

- All passenger elevators be marked with signs stating that they cannot be used during a fire;
- Fire detectors installed in every elevator lobby and machine room be arranged to initiate a recall of the elevators to the ground floor where the doors open and the elevator is taken out of service; and
- Fire service personnel can use a special key to operate any individual car in a manual mode as long as they feel it is safe to do so.
- At least one elevator serving every floor be connected to emergency power.

Currently, there are no national model codes that permit elevators to be used as a means of occupant egress in emergencies, and national standard ASME A17.1 (ASME 2000) requires signs at all elevators warning that they should not be used in fires. There are some recent exceptions to this requirement, but these are limited to special cases. For example, NFPA 5000 permits protected elevators as a secondary means of egress for air traffic control towers, and the City of Las Vegas accepted elevators as a primary means of occupant egress from Stratosphere Tower based on a performance-based design (Bukowski 2003).

[16] PANYNJ WTC Fire Safety Plan (Towers One and Two), 1995, WTCI-13-NYC.

U.S. building codes (including NYC Building Code) require *accessible elevators* as part of a means of egress that may be used by the fire service to evacuate people with disabilities. These elevators must comply with the emergency operation requirements of ASME A17.1 (Phase II emergency operation by the fire service), be provided with emergency power, be accessible from an area of refuge or a horizontal exit (unless the building is fully sprinklered), and operate in a smoke protected hoistway. Phase II operation involves the use of an elevator by a firefighter for fire service access or for rescue of people with disabilities performed under manual control (with the use of a special key).

In the event of a fire in WTC 1 or WTC 2, or other emergency requiring evacuation where the stairwells are unusable or cut off by fire and/or smoke, consideration of using elevators for occupant egress may be given in accordance with the following PANYNJ guidelines:

- Elevators may not be used if they also service the fire floor, except under specific instructions from the fire safety director or Fire Department;
- If the elevators do not service the fire floor and their shafts have no opening to the fire floor, they may be used at the direction of the fire safety director or fire department;
- Elevators under the direction of the fire department or trained building personnel may be used.[17]

Every elevator lobby contained a sign reading, "IN CASE OF FIRE USE STAIRS UNLESS OTHERWISE INSTRUCTED." The sign also included a diagram indicating the location of the sign and the location and letter designation of each stairwell serving the particular floor.[18]

2.2.4 Emergency Communication System

WTC emergency procedures specified that all building-wide announcements were to be broadcast from the fire command station of each WTC tower, in coordination with the fire safcty director or life safety and security supervisor. The deputy fire safety director was likely to make all announcements. Appendix J of the World Trade Center Emergency Guidelines[19] provided prepared text for a varicty of emergency scenarios, including power failures, fires, and service interruptions. Prior to all emergency announcements, the following pre-announcement was made:

> "Your attention please, your attention please. An important public address announcement will be made in the main corridor of your floor in a few moments."

Evacuation for any reason, including fire or smoke, would have gencrated the following announcement, enabling a phased evacuation:

> "Your attention please. We are experiencing a smoke condition in the vicinity of your floor. Building personnel have been dispatched to the scene and the situation is being addressed. However, for precautionary reasons, we are conducting an orderly evacuation of floors _____.

[17] World Trade Center Emergency Procedures Manual 2001 – Confidential. Port Authority of New York and New Jersey.
[18] The Port Authority of NY & NJ World Trade Center Fire Safety Plan (Towers One and Two). 1995. WTCI-13-NYC.
[19] World Trade Center Emergency Procedures Manual 2001 – Confidential. Port Authority of New York and New Jersey.

> Please wait until we announce your floor number over the public address system. Then follow the instructions of your fire safety team. We will continue to keep you advised. We apologize for the inconvenience and we thank you for your cooperation."

The standard evacuation announcement for a particular floor was:

> "Your attention please. It is now time for your floor to be evacuated. In accordance with the directions from your fire safety team, please take the exit stairs nearest to your location. We remind you that communications, emergency lighting and other essential services are in service. We will continue to keep you advised. We apologize for the inconvenience and we thank you for your cooperation."

According to the Guidelines, however, the information and instructions broadcast to the building occupants could be modified to suit the nature of the emergency, at the discretion of the fire safety director.[20] NIST NCSTAR 1-4 addresses the fire alarm systems in WTC 1 and WTC 2.

Fire Command Station

The fire command station, located in the lobbies of both WTC 1 and WTC 2, provided a command post for building personnel to orchestrate the response. The NYC Building Code requires that the computer screen in the fire command station monitor and display information regarding:

- Manual fire alarms
- Smoke detection
- Sprinkler water flow
- Elevator lobby smoke detectors
- Fire signal activation
- Central office notification
- Fan system status
- Fail safe locked door status

[20] World Trade Center Emergency Procedures Manual 2001 – Confidential. Port Authority of New York and New Jersey.

- Fire system trouble
- Fire signal trouble
- Tamper switch alarm
- Power source
- Test/normal mode
- Other information as desired, including the status of elevators.

Figure 2–15. Fire command station in lobby of WTC on September 11, 2001, as seen from mezzanine escalator, looking west.

The primary value of the fire command station was its role as a convening point for key building personnel responding to a building incident. The roles of many of the key personnel are described in the following section. Figure 2–15 shows the fire command station in the lobby of WTC 1 on September 11, 2001, seen from the east end of the Mezzanine Level. The fire command station appears in the back right corner of the picture.

2.3 THE HUMAN ELEMENT

PANYNJ produced and regularly updated an emergency procedures manual for building personnel to follow in the event of a building incident,[21] at least until Silverstein Properties formally had become leaseholder several months prior to September 11, 2001. While Silverstein Properties was formally managing WTC 1 and WTC 2, PANYNJ staff continued to be significantly involved in property management during the transition. The latest update to the manual was completed earlier in 2001. Note that PANYNJ was not responsible for responding to fires or alarms in WTC 3 (Marriott Hotel), WTC 6 (US Customs House), or WTC 7.

The fourteen chapters in the 2001 manual addressed such possibilities as bomb threats, fires, floods, gas leaks, elevator emergencies, power failures, medical emergencies, chemical and fuel releases, structural integrity, and political demonstrations, among other potential problems. Aircraft impact was not specifically addressed. Individual responsibilities for key personnel were enumerated, including interactions with non-PANYNJ personnel (including, as appropriate, FDNY, NYPD, and others). The following subsections of Chapter 2.3, are derived primarily from The 2001 WTC Emergency Procedures Manual, Chapter 7, entitled "Fire Emergencies."

[21] World Trade Center Emergency Procedures Manual 2001 – Confidential. Port Authority of New York and New Jersey.

2.3.1 Responsibilities of the Fire Safety Director

The fire safety director was a position required by Local Law 5 (New York 1973). Local Law 5 required all buildings (new or existing) occupied by more than 100 persons above or below the street level, or more than 500 people in the entire building to have a fire safety director, deputy fire safety director, and building evacuation supervisor. Each such building is required to have one employee designated as fire safety director and one or more employees designated as deputy fire safety director, who possess certificates of fitness from the commissioner qualifying the individual to conduct fire drills, evacuations, and related training. A certified individual is required to be on duty during normal working hours. Consistent with Local Law 5, the primary responsibility of a fire safety director at the WTC (according to the formal emergency procedures manual) was overall emergency management for a building incident (PANYNJ 2001b). The fire safety director reports to the Fire Command Station, or scene, and assumes the following duties:

- Verify that FDNY has been notified and coordinate activities of FDNY and other emergency response personnel;
- Confer with floor wardens of affected floor(s) to determine conditions on the floor and identify areas to be evacuated, route of evacuation, stairwells available, and potential refuge floors;
- Initiate evacuation procedures;
- Direct public address announcement(s), as necessary;
- Deploy security officers to restrict access to affected and secure areas;
- Dispatch "key runs";[22]
- Ensure appropriate notifications are initiated;
- Maintain a chronological record of the event;
- Direct the Operations Control Center (OCC) to arrange for emergency elevator service;
- Investigate cause of fire (in coordination with the FDNY Bureau of Fire Investigation, prepares appropriate reports).

2.3.2 Responsibilities of the Deputy Fire Safety Director

The role of the deputy fire safety director assigned to the Fire Command Station in the lobby was to execute and direct the fire safety plan, including:

- Notify fire safety director, operations control center, and police desk (WTC 5) of incident;
- Maintain communications with floor wardens and other members of the fire safety team;

[22] A "key run" is a security officer charged with distributing and retrieving master key rings and Fire Department portable radios. These keys provided access to secure areas for emergency responders or building personnel during an incident.

- Assist with crowd control and evacuation, as necessary;
- Request that the elevator starter or OCC contact the elevator(s) to respond to the Lobby and await Fire Department personnel:
- Complete necessary fire alarm notification forms.

2.3.3 Responsibilities of the Operations Control Center Supervisor

Upon notification of a fire event, the supervisor on duty at the Operations Control Center was to first ensure that the fire command station and the fire safety director were notified. Next, the supervisor was to issue a general broadcast of information over all WTC radio channels, monitor all channels and ensure that radio silence is observed unless directly related to the ongoing incident, arrange for elevator service, update units with relevant information as necessary, and notify managers of Windows on the World (WTC 1) and Top of the World (WTC 2) of incident in order to "reduce anxiety to tenants, visitors, guests, etc. when numerous emergency vehicles respond." The Operations Control Center was located in the B1 Level of WTC 1 and was a backup Fire Command Center.

2.3.4 Responsibilities of the Operations and Maintenance Management

Building operators and maintenance personnel were mobilized in order to provide emergency response assistance should the need arise. The duty supervisor established contact with the fire safety director, fire safety coordinator, or life safety and security supervisor and responded to the fire command station to assist as required. The operations group supervisor, who may have required self contained breathing apparatus, was assigned to respond to one floor below the scene of the incident, established communication with the fire command station using the floor warden telephone, assisted with the evacuation, and kept in contact with the fire command station.

The supervisor of the mechanical contractors was to dispatch staff to the fire pumps in order to "stand by" for further instructions, dispatched staff to operate the smoke purge system as requested by the fire safety director or Fire Department, and dispatched staff to secure sprinkler water shutoff valves.

The supervisor of electrical contractors was assigned to dispatch one contract electrician to one floor below the affected floor in order to assist should the incident involve electrical closets or fixtures, two electricians to the nearest sub-station below the affected floor, and a supervisor to the fire command station. Further, the electrical supervisor was to ensure that staff was standing-by in order to secure electrical power, if necessary, and that portable electrical power was available, as needed, and played a significant role in post-incident restoration of smoke detectors and/or alarm panels. In the event of a major disaster, all staff electricians were to report to the electrical shop/office.

The elevator maintenance contract supervisor was to report to the fire command station in order to assist, as needed, as well as dispatch elevator mechanics to their appropriate posts to assist, as needed. Figure 2–16 shows a WTC official (denoted by the vest identifying WTC Officials) attempting to communicate with elevator occupants in WTC 1 on September 11, 2001, from the fire command station in the lobby.

Figure 2–16. Elevator communication panel in the fire command station of WTC 1, as operated on September 11, 2001.

2.3.5 Floor Warden System

The WTC Emergency Procedures (PANYNJ 2001b) requires each floor of a high-rise building to designate a floor warden to coordinate the evacuation of the floor, consistent with NYC Building Code. Assisting the floor warden were deputy floor wardens and searchers, which constitute a tenant fire safety team. On multi-tenant floors, each tenant identified a floor warden for their space. Once the order to evacuate a floor was given, those with building authority had specific responsibilities to insure an orderly evacuation:

- In the event of an emergency, the floor warden was responsible for ensuring that an alarm was transmitted by either telephoning the police desk or activating a manual pull station. The floor warden reported the incident in detail to the Fire Command Station, and relayed instructions to building occupants.

- The floor warden was responsible for notifying occupants of the floor that there was a fire and ensure that the occupants executed the fire safety plan (PANYNJ 1995). In an emergency, searchers would round up employees, and the deputy fire warden would move them into the corridors and make sure all occupants were accounted for. In the event occupants were reluctant to evacuate, searchers were not required to force evacuation.

- In coordination with the Fire Safety Director, floor wardens selected the safest stairwell to use on the basis of the location of the fire, including checking the environment in the stair, and notifying the fire command station which stairwell was utilized.

2.3.6 Occupant and Tenant Training

WTC policy was to conduct fire drills every 6 months, consistent with NYC Local Law 5,[23] or shortly after move-in for all new tenants in WTC 1 and WTC 2. Written procedures specified a three day

[23] Local Law 5-73. §C19-161.2.a.4.

advance notice prior to the drill for tenants, through the floor warden and deputy floor warden. The floor warden then notified all occupants of the floor.

Immediately prior to the fire drill, the public address system would be used to announce that the drill was about to occur. Occupant attendance at drills was mandatory, with a small "skelcton staff" permitted for business continuity. An occupant who missed a fire drill as "skeleton staff" was required to attend the next fire drill. The occupants were required to assemble outside a designated stairwell.

During the fire drill training, the fire alarm was sounded. The floor warden, deputy floor warden, and searchers ensured that occupants gathered in the central hallway, near a stairwell. The fire safety team then instructed the occupants not to attempt to fight fires, not to use the elevators, to obey all instructions from the deputy fire safety director, and what phone number to call if there was a problem. The location of the nearest stairwell was identified and the procedures for phased-evacuation (move three floors below the fire floor, as instructed by the floor warden and/or deputy fire safety director) (PANYNJ 1996).

The standard instruction to the occupants was to evacuate downward (to three floors below the incident floor). The training did not explicitly instruct occupants not to evacuate upward or attempt to access the roof. Stairwells A and C went to the 110th floors, but only to serve as egress points to descend from the 110th floor or the roof. The 110th floor was not a re-entry floor, and thus, occupants without an authorized badge or a key would have been unable to reach the door that led to the roof. Had the 110th floor been accessible, actually reaching the roof would have been prevented by two additional doors, in accordance with Federal Communication Commission regulations.[24] The first door to access the stairwell to the roof was protected by an access card reader. Upon opening the first door, the individual would enter a vestibule where, upon showing ID to a closed-circuit television monitored at the Operations Control Center (OCC), the door would be electronically unlocked from the OCC. Access to the roof was, thus, limited to a small number of people certified to enter through a radio frequency hazard awareness class.[24]

Floor wardens, deputy floor wardens, and searchers were required as part of their training, to watch a video, prepared by PANYNJ. The video entitled "WTC Fire Safety" and provided to NIST by PANYNJ, reviewed the emergency procedures, building fire safety systems, and the responsibilities of the members of the fire safety team (PANYNJ 1996).

2.4 CHANGES TO THE EGRESS SYSTEM AFTER THE 1993 BOMBING

The February 26, 1993, World Trade Center bombing precipitated a $250 million[25] repair and life safety upgrade to the complex, including (PANYNJ undated):

- Radio repeaters on the roof of WTC 5 for Fire Department communications.
- Circulation improvements.

[24] The roof housed critical communications equipment, including broadcast facilities for major television stations, paging transmitters, FDNY transmitters, numerous mobile transmitters. [Information derived from Port Authority response to formal NIST question, April 2004]

[25] Public Comments to Draft Version of NCSTAR 1-7. PANYNJ. 2005.

- New North (to Vesey St.) and South (to Liberty St.) corridors for faster evacuation from the Concourse (mall).
- Two escalators from the Concourse (mall): one to the plaza at WTC 5 and one up to WTC 4 and onto Church St.
- Photoluminescent paint on handrails, stair treads, and stair centerline.
- Multiple power sources for stairwell lighting: 2 normal feeds, back-up generator, and a back-up from the PATH system; battery backup for every other stairwell fixture (up to 90 minutes).
- LED exit signs for extra brightness and visibility through smoke conditions.
- Fluorescent signs inside stairwells at all stair reentry doors along with raised porcelain type Braille.
- Fire Command Stations in main lobbies.
- Two sealed beam (with battery back-up) elevator lights and bells, in addition to normal lighting.
- Upgraded elevator intercom system, monitored at Fire Command Station.
- New decentralized Fire Alarm System (Style 7), with three separate data risers to transponders located every three floors; redundant control panels and electronics; multiple control station announcement capability.
- Fire alarm system powered by normal emergency power, battery back-up, and tertiary power to equipment.
- New modernized Operations Control Center with the capability to monitor all HVAC systems and elevators.
- Elevators modernized to current code, including replacing relay system with microprocessor based system (only 50 percent complete on September 11, 2001).
- Sprinkler installation accelerated to completion, including Concourse.
- Fire wardens equipped with flashlights, whistles, hats and special training.
- Fire drills conducted in conjunction with the Fire Department.

In addition, PANYNJ purchased evacuation chairs, which were provided free to building tenants upon request, for use by mobility-impaired occupants during emergency evacuation. Further discussion of the changes to WTC 1 and WTC 2 subsequent to the 1993 bombing can be found in NIST NCSTAR 1-1.

2.5 BUILDING CODE ANALYSIS

NIST NCSTAR 1-1 addresses the building codes relevant to WTC, including provisions for egress system design. For most buildings constructed in the United States, building codes adopted by local jurisdictions establish minimum requirements for design and construction. However, because the PANYNJ is an interstate agency, which was established in 1921 under a clause in the U.S. Constitution, its construction projects are not required to comply with any local or national model building code. For the design of the WTC towers, which began in 1962, the Port Authority in May 1963 instructed the architect and engineers to prepare their designs of WTC 1 and WTC 2 to comply with the NYC Building Code.[26] While not specifically stated in the 1963 letter to the architect, the 1938 edition of the Code was in effect at that time. In areas where the Code was not explicit or where technological advances made portions of the 1938 Code obsolete, the Port Authority also directed the architect and engineers to propose designs "based on acceptable engineering practice." When such situations occurred, the Port Authority required the architect and engineers to inform the Planning Division of the WTC. The Port Authority established a special WTC office that reviewed and approved plans and specifications, issued variances, and conducted inspections during construction instead of the city agencies that would normally perform these duties.

In September 1965, the Port Authority instructed the architect and engineers to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the NYC Building Code that was under development and to undertake any design modifications necessary to comply with the new code provisions.[27] Prior to issuance of this instruction, the Port Authority recognized that the draft version of the new New York City Building Code had incorporated advanced techniques and that the Port Authority favored the use of advanced techniques in the design of the WTC towers.[28] By adopting the draft versions of the new NYC Building Code, WTC 1 and WTC 2 were classified as Type 1-B Construction instead of Type 1-A Construction (see Sect. 9.1.3 for definition and fire protection requirements of Construction Type), and several architectural features related to egress were modified in the final design (see Sect. 10.1 of NIST NCSTAR 1-1). This relaxation of code requirements allowed the Port Authority to gain economic advantage.[29] The new NYC Building Code (NYCBC 1968) was enacted by the City Council on October 22, 1968, approved by the Mayor on November 6, 1968, and became effective on December 6, 1968.

2.5.1 Egress in the Building Codes

The ability to evacuate thousands of occupants from buildings as massive as WTC 1 and WTC 2, was a function of three primary variables: how many stairs, how wide the stairs were, and where the stairs were located. Each of those three factors, in the context of building code requirements, are evaluated below.

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[26] Letter dated May 15, 1963 from Malcolm P. Levy (Chief, Planning Division, World Trade Department, PANYNJ) to Minoru Yamasaki (architect, Minoru Yamasaki & Associates) (See Appendix A of NCTAR 1-1).

[27] Letter dated September 29, 1965 from Malcolm P. Levy (Chief, Planning Division, World Trade Department, PANYNJ) to Minoru Yamasaki (architect, Minoru Yamasaki & Associates) (See Appendix A of NCSTAR 1-1).

[28] Memorandum dated June 22, 1965 from John M. Kyle (Chief Engineer, PANYNJ) to Malcolm P. Levy (Chief, Planning Division, World Trade Department, PANYNJ) (See Appendix A of NCSTAR 1-1)

[29] Memorandum dated January 15, 1987 from Lester S. Feld (Chief Structural Engineer, World Trade Department) to Robert J. Linn (Deputy Director, Physical Facilities, World Trade Department) (See Appendix A of NCSTAR 1-1)

Building codes largely relate required egress capacity to the size of the area served and the nature of the use of the area served. WTC 1 and WTC 2 were square buildings (roughly 207 ft by 207 ft, measured internally), with a gross square footage for each tenant floor approximately 42,850 ft^2 (3,990 m^2). The floor areas in the towers were typically one of two use categories: business or assembly. The distinction is important for calculating egress requirements as the number of people allowed in a given space would be significantly fewer if the space is used for office (business) activities, than if the same space were used for assembly activities (such as a restaurant or meeting space). The width and number of stairwells are then specified to equal or exceed the number of occupants on a floor.

The size of the 'core' varied significantly throughout WTC 1 and WTC 2. Note that the size of the structural core (as defined by the location of interior load-bearing columns) did not change significantly from floor to floor. As discussed earlier in Chapter 2.2.3, however, on any given floor, the core space used for local elevators was reclaimed for leasable office space on successively higher floors within a zone. For example, while floors 42 to 48 had a core area of approximately 12,000 ft^2 (1,100 m^2), floor 105 had a core area of 6,800 ft^2 (630 m^2), or 57 percent of the core area of floors 42 through 48.

The size of the core was important because some building codes (including the NYC Building Code) calculate occupant load on a net basis rather than a gross basis. A net basis reduces the square footage of a floor by an amount equal to the unoccupied space on a floor, such as elevator or machinery shafts, and common areas such as hallways. The logic of using net as a calculation basis rather than gross is that there does not need to be egress capacity provided for floor area where no occupants would be located. As an example, while floors in WTC 1 and WTC 2 had a gross square footage of approximately 42,850 ft^2 (3,990 m^2), floor 105 had a net square footage of approximately 36,500 ft^2 (3,400 m^2), which yielded an occupant load of 365 persons. Floors 106 and 107 in WTC 1 were designated an assembly space for Windows on the World and were discussed previously in Chapter 2.2.1. By comparison, the occupant load on floors 42 – 48 would have been approximately 313 when calculated using 100 persons per ft^2 net. Generally, however, the floor with the largest occupant load dictates the overall design of an egress system.

In addition to local changes in the size of the core space, the stairwells in the WTC towers changed floor location throughout the building, as well. This meant that the remoteness (or the distance the stairwells are located apart from one another) of stairwells varied, as well. The greatest separation distance between any two of the three stairwells, as measured by a walking path measurement (assuming that the building is fully sprinklered, which WTC 1 and WTC 2 were) determines the stairwell remoteness. At the two extremes of remoteness found in WTC 1 or WTC 2, floors 83 and higher had Stairwell A and Stairwell B located about 70 ft (21 m) apart, while on floors 77 – 82, Stairwell A and Stairwell C were located approximately 175 ft – 200 ft (54 m – 63 m) apart (depending upon the walking path on a particular floor). Coincidentally, WTC 1 was most heavily damaged on floors in the 90s (where the stairwells were the closest together) and all three stairwells were destroyed, while WTC 2 was attacked in a region where the stairwells were the most remote (floors 78 through 82) and one stairwell remained passable. The angle of the airplane impact, the length-wise orientation of the core, and the presence of elevator machinery near the passable stairwell may also have been contributing factors to the stairwell survivability, however. For context, most current codes require that two exits be located a distance apart no less than one-third of the diagonal distance of the area served (if the floor has full sprinkler protection) or no less than one-half of the diagonal distance of the area served (if the floor is not fully covered by sprinkler protection). One-half of the diagonal distance of the area served was 147 ft (45 m) and one-

third of the diagonal distance was 98 ft (30 m). Thus, in separate areas within the same building, stairwell remoteness distances would have been less than that required for sprinklered buildings, as well as greater than that required for unsprinklered buildings.

As described earlier in Chapter 2.2, WTC 1 and WTC 2 had three stairwells, two 44 in. wide and one 56 in. wide. The 44 in. stairwells were served by doors on each floor measuring 34 in. (1 m), while the 56 in. stairwell was served on each floor by a door measuring 44 in. The NYC Building Code was selected due to the PANYNJ instruction to architects and engineers to adhere to the NYC Building Code. IBC and NFPA 5000 and NFPA 101 were selected because they are national model codes. See NIST NCSTAR 1-1 for further discussion of building codes.

2.5.2 New York City Building Code (1968)

Table 6-2 in §C26-601 required 100 ft^2 per occupant (net) for business occupancies, yielding a nominal occupant floor load of 365 persons per floor, based upon the largest net square footage (36,500 ft^2). In order to provide sufficient capacity for 365 persons, six and one-half units of exit width (at 60 people per 22 in. unit) would have been required, yielding an allowable floor load of 390 people for business occupancies. A minimum of two stairwells would have been required for an occupant load less than 500 people [§C26-602 Exits from Floors], each equally sized, as no more than 50 percent of the occupants can be served by a single exit. Two equally sized stairwells would have been 78 in. wide each. Three stairwells, two 44 in. wide and one 56 in. wide, would also provide the minimum egress capacity for business occupancy floors.

Floors 106 and 107 in WTC 1 and floor 107 in WTC 2, having had occupant loads of over 1,000 persons each, would have required four stairwells to serve each floor. Thus, the 1968 NYC Building Code would have required theses spaces be served by a minimum of four stairwells (as the occupant load was greater than 1,000 persons).[30] The number of stairwells was not allowed to decrease in the direction egress travel, therefore, the entirety of WTC 1 and WTC 2 was required to have four stairwells. In 1995, once these spaces were considered formally between PANYNJ and NYC DOB, three stairwells were shown to provide adequate total capacity of 1,170 using the NYC Building Code exit reduction clause in §C27-367 (Fasullo 1995). There was no mention, however, of the requirement for a fourth stairwell in either tower (which existed and continues to exist as a requirement in §C27-366), nor whether the floor and ceiling system satisfied the area of refuge requirement for a 2 h fire rating.

Each stairwell would be required to have a door at least 0.9 m (36 in.) wide. The sum of two risers and one tread depth was required to be not less than 0.61 m (24 in.) nor greater than 0.65 m (25.5 in.).[31] (Thus, the 'standard' 7 in. riser and 11 in. tread depth would satisfy this formula, at 25 in. [7 in. + 7 in. + 11 in.]). According to Table 6-4 in the NYC Building Code, however, the stair rise, may not exceed

[30] Egress calculation performed in 1995 (contained as figures in Chapter 2.2.1) show a calculated egress capacity of 1,170 persons for both floors 106 and 107 in WTC 1 and a calculated occupant load of 1,013 and 1,030 persons for floor 106 and 107, respectively. Note that there was no mention in this memo of a fourth stairwell.

[31] From the NFPA Life Safety Code Handbook (2003 Edition), this note was made about the formula formerly used by NFPA and currently used by NYC: "This requirement was deleted because it was based on a 300-year-old French formula in which an inch was a slightly larger unit of measure than it is today. Moreover, people's feet and stride length – the basis of the formula – were somewhat smaller at that time. Also, the requirement was originally intended only for stairs of moderate steepness or pitch."

0.2 m (7.75 in.) and the tread depth must be greater than 0.24 m (9.5 in.). In 1968, the location of a floor exit was required to be as remote from the others as practicable.

2.5.3 New York City Building Code (October 2003)

As it pertains to the narrow scope of this egress analysis, the requirements related to the egress system in 2003 would be identical to the requirements of 1968, with one significant exception: stairwell remoteness. In 1968, the location of a floor exit was required to be as remote from the others as practicable. New York City Local Law (LL) 16 (1984) imposed a remoteness requirement (not retroactive to an exiting building such as WTC 1 or WTC 2) of 9 m (30 ft) or one-third the maximum travel distance of the floor (55 m [180 ft]), whichever is greater, which for WTC 1 and WTC 2 was 55 m (180 ft). Thus, all floors of WTC 1 and WTC 2 had stairwell separations that exceeded the minimum separation distance requirement of New York City LL 16 (1984).

2.5.4 International Building Code (2000)

Chapter 10 of the 2000 International Building Code (IBC) require 100 ft^2 per occupant (gross), yielding a nominal occupant floor load of 429 persons per floor. A minimum of two stairwells would have been required (for occupant load less than 500 persons [Table 1005.2.1]), each equally sized. As WTC 1 and WTC 2 were fully sprinklered, Table 1003.2.3 requires a minimum of 0.005 m per occupant (0.2 in. per occupant) totaling 2.2 m (87 in.) of total stairwell width, or two 1.1 m (44 in.) stairwells.

Floors 106 and 107 in WTC 1 and floor 107 in WTC 2, having occupant loads of over 1,000 persons each, would require four stairwells to serve each floor. The four stairwells would be required to be maintained to grade, as the number of stairwells shall not decrease in the direction of egress travel. Additionally, the floor system would be required to have at least a 2 h fire rating. If two areas of refuge were built on floors 106 and 107 (each area holding at least one stairwell), the IBC would permit four 44 in. stairwells.

Section 1003.3.1 requires that each stairwell have a door at least 0.8 m (32 in.) wide. Section 1004.2.2.1 requires that for fully sprinklered buildings, the stairwell doors be located a distance of no less that one-third the length of the maximum overall diagonal dimension of the building or area to be served (30 m [98 ft] for WTC 1 and WTC 2). This requirement was met on some floors, but not all floors, as discussed previously.

2.5.5 NFPA 5000 and NFPA 101 – Life Safety Code (2003)

The gross square footage for each WTC tower was 42,850 ft^2 (3,990 m^2). Table 7.3.1.2 requires 100 ft^2 per occupant (gross) for a business occupancy, yielding a nominal occupant floor load of 429 persons per floor. A minimum of two stairwells would be required (for occupant load less than 500 persons [Section 7.4]), each equally sized. Table 7.3.3.1 required a minimum of 0.0076 m per occupant (0. 3 in. per occupant) totaling 3.3 m (129 in.) of total stairwell width, which may be satisfied by two 1.7 m (65 in.) stairwells, or three stairwells, sized at 1.1 m (44 in.) each. Section 7.2.1.2 requires that each stairwell have a door at least 0.8 m (32 in.) wide.

Floors 106 and 107 in WTC 1 and floor 107 in WTC 2, having occupant loads of over 1,000 persons each, would require four stairwells to serve each floor (Section 7.4.1.2). Four stairwells would be maintained to grade, as the number of stairwells shall not decrease in the direction of egress travel.

Section 7.5.1.3 addresses the remoteness of stairwells, with the purpose "to minimize the possibility that more than one has the potential to be blocked by any one fire or other emergency condition." Additionally, Section 7.5.1.3.3 requires that for fully sprinklered buildings, the stairwell doors be located a distance of no less that one-third the length of the maximum overall diagonal dimension of the building or area to be served (30 m (98 ft) for WTC 1 and WTC 2). This requirement was met on some floors, but not all floors, as discussed previously.

2.5.6 Comparison of Current Code Requirements

Differences in Stairwell Occupant Capacity

The IBC allows a reduction in egress capacity for fully-sprinklered buildings, to 0.005 m (0.2 in.) per person. Thus, while IBC would require two 44 in. stairwells for 429 occupants, NFPA Life Safety Code would require two 65 in. stairwells from tenant floors in of dimension similar to WTC 1 or WTC 2. While NYC Building Code also uses 0. 3 in. per person of required exit width, the calculation is net square feet, rather than gross square feet, effectively reducing the requirements. However, minimum half-units of exit width (12 in.) used in the NYC Building Code often force the designer to 'round up' the calculated egress capacity (from 365 to 390, e.g.). Two stairwells, each 78 in. in width, would be a minimum allowed by the NYC Building Code, as an alternative to the three stairwells (two 44 in., one 56 in.). Table 2–3 summarizes the results of the calculation of the minimum number of stairwells for an office occupancy with a service area of 42,850 ft^2 gross (36,500 net) using each of the three building codes described above.

Table 2–3. Minimum stairwell design for 42,850 ft^2 office plan.

Building Code	International Building Code (2003)	NFPA Life Safety Code (2003)	New York City Building Code (2003)
Number and Width of Stairwells for a 42,850 ft^2 Office Plan	Two Stairwells 44 in. each	Two Stairwells 65 in. each	Two Stairwells 78 in. each

Net vs. Gross Occupant Load Calculations

The IBC and NFPA model codes both calculate the number of occupants per floor (business occupancy) based on the gross square footage of the floor divided by 100. NYC Building Code, on the other hand, calculates the maximum occupant load by subtracting from the gross square footage, shafts, storage rooms, and stairs. Thus, the WTC had a design occupant load of 390 persons per floor, whereas IBC and NFPA 101 would have required egress capacity for 428 persons per floor. On the other hand, the egress system would have to reflect the higher occupant load, as well. WTC 1 and WTC 2 would have required 7.5 (rather than 6.5) units of exit width if the occupant load calculation was on a gross basis rather than a net basis. Thus, three stairwells would need to have been 1.4 m (56 in.), rather than only Stairwell B, to accommodate the higher occupant load.

Areas of Refuge and Egress Capacity

When two stairwells are each located in separated areas of refuge, the capacity of each stairwell may be doubled. NYC Building Code, IBC, and NFPA 101 each permit doubling of a stairwell's capacity using this method. As discussed in Section 2.2.1, however, NYC Building Code also allows the capacity to be tripled when three stairwells are each separated from the other two by fire-rated partitions complying with requirements for areas of refuge. IBC and NFPA 101 do not allow tripling of stairwell capacity.

Stairwell Remoteness

NYC Building Code calculates the minimum separation distance for stairwells based upon a fraction of the longest travel distance on a particular floor (one-third, if fully sprinklered and one-half if not fully sprinklered). IBC and NFPA 101 calculate the minimum separation distance for stairwells based upon a fraction of the maximum diagonal of the floor or area served (one-third, if fully sprinklered and one-half if not fully sprinklered).

Chapter 3
First-Person Data Collection and Analysis Methods

3.1 Purpose and Scope of Collection of First-Person Data

The purpose of first-person data collection was to capture the full range of occupant experiences from World Trade Center (WTC) 1, 2, and 7 from 8:46:30 a.m., when WTC 1 was attacked, until all survivors had successfully evacuated. The goal was to capture both common (frequent) evacuation experiences and unique observations or actions that may have contributed to a greater understanding of the events of September 11, 2001. Potential respondents included all occupants inside WTC 1 or WTC 2 between 8:46:30 a.m. and 10:28:22 a.m. (when WTC 1 collapsed), building personnel, emergency responders, and family members who spoke to occupants inside WTC 1 or WTC 2 during the attack.

3.2 Methods

To best capture both the generic evacuation experience and the unique observations and experiences, multiple interview methods were selected: face-to-face interviews, telephone interviews of a statistically representative sample of people, and focus group interviews. Each method contributed a unique strength to the overall objectives, complemented and contributed to understanding the data collected through the other methods, and established multiple measures of a variety of phenomena. In addition to interviews, published media accounts, video, and photographs were collected and analyzed. Each method is discussed below.

3.2.1 Published First-Person Accounts

National Institute of Standards and Technology (NIST) contracted with the National Fire Protection Association (NFPA) to collect first-person accounts from newspapers, radio and television programs, e-mail exchanges, and a variety of websites and to distill them into a searchable database (Fahy and Proulx 2003). Over a period of 18 months, a total of 745 first-person accounts were collected. These accounts had been published up to 14 months after the event. Although media accounts do not provide the rigor of a proper scientific study, they do present important insights into events. The objective of the analysis of the first-person accounts was to gain insight into the variability of human behavior and response time displayed during the evacuation, and to use the findings as a guide for additional investigation. For the NIST investigation, the accounts provided background for development of the telephone survey instrument and aided in identification of individuals with particularly compelling stories that were of interest for face-to-face interviews conducted as part of the investigation.

A coding tool was developed for content analysis of the first-person accounts. Data were then entered into the database. The coding tool had 33 questions such as: "On what floor was the person?," "What was the first cue of the event?," "Was the person injured?," and "What were the conditions in the stairs?" Not every account provided answers for all 33 questions, since some accounts lacked certain details, but this is not unlike the situation of a respondent who did not answer some questions in a survey. Once the 745 first-person accounts were summarized, multiple accounts from the same person were merged into

one, which provided accounts for 465 distinct individuals. (Some survivors provided multiple accounts through different sources.) Before any analysis began, the database was further limited to the 435 building occupants who were actually in WTC 1 or WTC 2 on September 11, 2001. The accounts analyzed were from 435 individuals - 251 occupants of WTC 1 and 184 occupants of WTC 2 - representing occupants from low, middle, and high regions of both WTC 1 and WTC 2.

The content analysis of first-person accounts has significant limitations. First, the actual questions asked by the journalists reporting the accounts are not usually contained in the accounts. Second, some details may have been left unreported; and third, more dramatic stories may have been over-represented. Consequently, while the *results of the published accounts analysis cannot be generalized to the overall population of the towers of the World Trade Center,* they provided valuable input to the NIST Investigation.

3.2.2 Telephone Surveys

The survey objective of the telephone interview phase of this study called for collecting 800 computer assisted telephone interviews (CATI) of persons occupying either of the WTC towers (WTC 1 and WTC 2) at the time of the terrorist attacks on September 11, 2001. The sample size of 800 and allocation of n=400 to each tower were chosen to maximize the statistical precision of estimates and projections within each tower.[32] Primary statistical analyses were in the form of tabulations and linear statistics (e.g., reporting of percentages and average/means). Estimates of percentages from tower-specific survey data (at n=400) exhibit sampling errors no greater than 2.5 percentage points, and 95 percent confidence intervals of percentages are no greater than ± 5 percentage points. This level of precision was more than adequate for examining issues of interest in this investigation. Within WTC 1 and WTC 2, independent proportionate stratified samples of survivors were drawn. In other words, each occupant of a particular tower had an equal probability of being selected.

Population and Sampling Frame

The total population of people eligible to participate in a telephone interview consisted of individuals who were inside WTC 1 or WTC 2 between 8:46:30 a.m. and 10:28:22 a.m. on September 11, 2001, with the exception of emergency responders (FDNY, NYPD, OEM, FBI. Secret Service, ATF, and others). The sampling frame (i.e., the list from which the sample was drawn) consisted of the names of occupants from badge lists for persons authorized to be present in WTC 1 and WTC 2 and was assumed to represent the entire population of individuals eligible to participate in telephone interviews. All occupants who worked or regularly visited the World Trade Center were required to provide personal data to PANYNJ in order to be issued a badge to clear through the security station at the entrance of each tower. The badge lists were provided to NIST by the Port Authority of New York and New Jersey. The lists provide name, floor

[32] Multivariate modeling such as correlation analyses, multiple linear regressions, and path analyses, are also a prominent part of the survey analyses. Like the tabulations, these analyses were conducted independently by tower. A sample size of n=400 per tower provides more than ample statistical power for the F tests used to determine the significance of the regression models (i.e., testing the null hypothesis that the ratio of explained variance to error/residual variance is equal to zero). For instance, in a multiple regression analysis featuring 20 independent variables, the sample size of 400, and 0.05 level of significance (Type I error), the power of the F test to detect an r^2 statistic (i.e., proportion of explained variance) of 0.06 is just over 81%. See also Chapter 9 of Cohen, J., 1988, Statistical Power Analysis for the Behavioral Science, Lawrence Erlbaum Associates, Inc., Hillsdale, N.J.

of occupancy, employer, and social security number (the only available means of uniquely identifying individuals).

Representativeness of Badge List

Confidence in the assumption that the badge list accurately represented the WTC population was increased by comparing independent 'lists' of occupants to the badge list: survivors who were interviewed by the media and lists of decedents. The three sources of data that were compared were (1) the list of decedents from CNN web site, (2) a media list of survivors, and (3) the badge list of occupants.

One limitation is that the independent list of media interviewees may not have sufficient information to indicate whether the listed person should have had a badge (and thus been listed on the badge list).

After comparing the media list with the badge list, it was determined that 134 (93 percent) individuals of 144 selected from the media list were authorized to be at WTC 1 or WTC 2 the day of the tragedy. Approximately 2 percent of all individuals were definitely not supposed to be at WTC 1 or WTC 2 the day of the tragedy and insufficient information existed to determine positively if the remaining 5% were supposed to be at WTC 1 or WTC 2 on September 11, 2001.

Based on Table 3–1, a conservative estimate of coverage was obtained by taking the number of persons from the media list who were definitely authorized to be at WTC (134), and comparing them to the total *possible* number of authorized individuals from that list – (134 + 7) = 141. The resulting conservative coverage rate of the badge list, estimated based upon media interviews with survivors, was (134/141), or 95 percent.

Table 3–1. Comparison of media interviewees and badge list.

Status	Frequency	Percent
Definitely authorized to be at WTC 1 or WTC 2	134	93%
Definitely not authorized to be at WTC 1 or WTC 2	3	2%
Not enough information to determine	7	5%
Total	144	100%

A similar analysis was conducted using the victim list published on the web site of CNN. As Table 3–2 shows, a conservative estimate of coverage was obtained by taking the number of persons from the decedent list who were definitely authorized to be at WTC (2,141), and comparing that number to the total *possible* number of authorized individuals from that list (2,141 + 79 = 2,220). The resulting conservative coverage rate of the badge list was, as estimated from the CNN victim list, was (2,141/2,220), or 96.4 percent.

Thus, the assumption that the badge list was a complete universe of possible WTC survivors from which to select a representative sample was determined to be valid.

Table 3–2. Comparison of CNN victim list and badge list.

WTC Status	Badge List Status		
	Appears in Badge List	Does Not Appear in the List	Total
Person authorized to be at WTC	2,141	0	2,141
Not authorized to be at WTC	N/A	408	408
Insufficient information to determine WTC authorization	N/A	79	79
Total	2,141	487	2,628

Telephone Interview Sample Selection

The badge list contained September 11, 2001, occupants, occupants who were absent on the day of the attacks, decedents, former occupants, and non-person listings (false names used in sample testing input by PANYNJ prior to delivery to NIST but not removed). This meant that a screening effort was needed to identify "eligible" badge list members – namely, those who were inside WTC 1 or WTC 2 during the attacks and survived. Moreover, the absence of telephone numbers for the badge holders on the list necessitated a tracking/locating effort. The primary tracking mechanism was to search public databases using commercially available batch matching and web-based search utilities. Consequently, a large sample was needed to generate the 800 completed interviews.

The number of occupant selections drawn into the sample was contingent on four key design parameters:

- The percentage of individuals from badge listings for whom a working telephone number could be found (initial estimate: 80 percent tracking success)
- The percentage of badge listings that corresponded to a surviving WTC 1 or WTC 2 occupant on September 11, 2001 (initial estimate: 14 percent)
- The cooperation rate for screening the occupants (initial estimate: 65 percent)
- The interview response rate among September 11, 2001 survivors (initial estimate: 50 percent).

In planning the CATI survey, a number of design parameters needed to be quantified in order to determine the number of persons to draw from the badge list. The expected disposition of the sample was developed using the parameters defined in the preceding paragraph. A total sample of 22,735 persons from the badge list was needed to generate the desired 800 completed interviews. The expected disposition by tracking efforts, screening and interviewing are discussed later.

A reserve sample of about 14 percent (or about N=3,265) was added in the event additional respondents were needed due to unanticipated circumstance (if the eligibility rate was actually lower than anticipated). This brought the total sample size to 26,000. The reserve was initially held "in reserve" while the main sample was worked. Working the main sample allowed preliminary estimates of all design parameters to be monitored so that an informed decision could be made on the necessity of releasing none, some, or all of the reserve.

The badge list contained different counts of persons from each tower (slightly over 50,000 names for each tower), yet the sample design called for equal samples to be drawn from the collections of badge holders in WTC 1 and WTC 2. Thus, a disproportionate design (across tower strata) was employed. Within each tower, independent proportionate samples were drawn using stratification by floor (within tower), employer (within floor) and last name (within employer). This served to increase the statistical precision of the tower-specific samples.

Thus, equal-sized samples of 13,000 selections were drawn from each of WTC 1 and WTC 2 badge lists. Each tower-specific sample was partitioned into 20 random replicates (comprising 5 percent of the total), and the reserve sample was determined by the last several random replicates for each tower. It is important to note that all badge holders from WTC 1 floors 92 and above were omitted from sampling because there were no survivors from those floors.

Table 3–3 summarizes the final disposition of the CATI sample and the total (locating) sample. The table is comprised of two sets of rows. The top set pertains to the CATI sample and represents those sample persons for whom an initial telephone number was identified prior to commencing the CATI survey operations. The bottom set of rows with the heading "Total Sample Disposition" represents the results of the locating/tracking effort used to identify usable telephone numbers associated with the sample subjects. (Recall that only name, SSN, and employer were available; no other contact information was readily available.)

The bottom set of rows shows that telephone numbers were identified for just over three quarters (76.7 percent) of the sampled subjects. Moreover, this rate was fairly uniform across towers. The 19,923 individuals with an initial telephone number were then loaded into the CATI sample management system for calling. Ultimately, all reserve respondents were used in the telephone survey. In the initial design parameters, it was assumed that 82 percent of the subjects would be locatable. While 76.7 percent is close, many of the numbers were obsolete (e.g., disconnect, wrong number) and necessitated additional tracking during CATI operations. Ultimately, by the end of data collection, only half the sample (49.5 percent) represented confirmed contacts with respondents.

The top set of rows in Table 3–3 presents the final disposition of the sample by tower as well as for the overall sample. Several statistics in the percentage distribution (rightmost) column are notable. First, NuStats (under contract to NIST) was unable to contact subjects for half the sample (50.5 percent), due to failures to answer the phone, answering machines, unusable numbers (e.g., wrong number, disconnected, business), etc. Most of these unusable telephone numbers represent "unlocatable" subjects – subjects for whom the initial telephone number was incorrect. It bears reiterating that substantial additional attempts to locate individuals during CATI operations were conducted using powerful subscription-based web-based search engines. Unfortunately, little information was available for these individuals.

Table 3–3. Disposition of the CATI sample and the total sample by tower.

CATI Disposition:	WTC 1[a]	WTC 2[a]	Total	% Distn
Interview	427	376	803	4.0 %
Partial Interview	47	37	84	0.4 %
9/11 decedent	20	40	60	0.3 %
Other decedent	49	39	88	0.4 %
Not Eligible	3,712	3,752	7,464	37.5 %
Language Barrier	135	129	264	1.3 %
Eligible Refused to Interview	138	139	277	1.4 %
Other Refusal	224	181	405	2.0 %
Respondent not Interviewed	247	168	415	2.1 %
Can't contact/locate Respondent	4,987	5,076	10,063	50.5 %
CATI TOTAL	**9,986**	**9,937**	**19,923**	**100.0 %**
Total Sample Disposition:	**WTC 1**	**WTC 2**	**Total**	**% Distn**
Found initial telephone #	9,986	9,937	19,923	76.6 %
Unable to find a telephone #	3,014	3,063	6,077	23.4 %
SAMPLE TOTAL	**13,000**	**13,000**	**26,000**	**100 %**

a. Table data are unweighted. Tower location as indicated in the badge list and may differ from reported tower location.

Second, the badge list contained a number of ineligible subjects (37.5 percent) – individuals on the badge list but not in the building on the morning of September 11, 2001. An assessment of eligibility rates appears later. Third, the badge list included decedent names (0.4 percent) – some from the September 11, 2001, attack (0.3 percent) and others from causes not necessarily related to September 11, 2001 (e.g., cause unknown, natural causes, 0.1 percent). Most of the September 11, 2001, decedent names were encountered due to a difference between the full (formal) name of the subject and the name that appeared on the badge list (e.g., the badge list sometimes contained maiden names, middle names, nicknames, misspelled first or last names, out of sequence names, titles, and so on). This impeded the ability to remove known decedent names prior to calling.

The final outcome rates of the CATI operations are presented by tower in Table 3–4. The table shows screening rates, interview rates, and rates of eligible occupants (among those who responded to the screening questions). The first row shows that screening response rates were relatively uniform across the towers, at about 46 percent. In other words, approximately 46 percent of successful telephone contacts resulted in determining whether the potential respondent was present at WTC 1 or WTC 2 on September 11, 2001. Similarly, interview response rates (among screened eligible subjects) were relatively stable across towers, at about 49 percent.

The eligibility rates were higher than expected – about 18 percent overall compared to the 14 percent expected. The eligibility rate among WTC 1 subjects was slightly higher than those of WTC 2. However, the overall response rates are essentially uniform across towers, at 22.6 percent.

Table 3–4. Summary disposition rates by tower.

Disposition Rate[a]	WTC 1	WTC 2	Total
Screen	46.5 %	45.8 %	46.1 %
Interview	48.6 %	49.5 %	49.0 %
Eligibility	18.9 %	16.7 %	17.8 %
Overall	22.6 %	22.7 %	22.6 %

a. Definitions for "Rates" consistent with American Association of Public Opinion Research (AAPOR) Standards, which may be found at http://www.aapor.org/pdfs/standarddefs_3.1.pdf .

The telephone interview protocol resulted in 803 interviews with individuals who evacuated WTC 1 or WTC 2 on September 11, 2001, after 8:46:30 a.m. These 803 individuals were interviewed in roughly equal proportion (N = 440 for WTC 1 and N = 363 for WTC 2) between the two buildings. The interview results can be generalized to the entire population of survivors in both buildings with a high degree of statistical confidence.

Telephone Questionnaire

The telephone interview was conducted by trained interviewers using a computer program that provides questions and answer categories for the interviewer. Prior to being contacted by telephone, subjects received a letter that outlined the scope and purpose of the investigation and the purpose of the interview, and indicated that a telephone call would come several days later. A full informed consent statement also appeared in the letter, as well as in the script for the calls.

When interviewers reached the subjects by telephone, they described the survey, the confidentiality of responses, the length of the interview, and the voluntary nature of participation. Subjects were then asked if they wished to participate, which served as the means of obtaining oral informed consent.

The telephone interview instrument (see Appendix A in this report for the complete instrument) included the questions, variable names, response options, and skip patterns taken directly from the computer program used by the interviewers. Variable names are used as shorthand for subsequent data analysis. Questions had a variety of response option categories: multiple choice, interval, Likert scale, or open-ended. Open-ended responses were minimized where possible due to the analysis burden and the fact that face-to-face interviews also were being conducted. Skip patterns reduced the burden on the respondent by skipping questions that would not apply to a particular respondent. For example, a respondent would not be further questioned about fire drills if he or she had not received fire drill training. Subsequent discussions of the questions will indicate whether a respondent was read a list of choices or was expected to give a free response.

The interview, which typically lasted approximately 20 minutes, was designed around five primary groups of questions, covering emergency training and preparedness, three stages of evacuation experience, and background information about each respondent.

Emergency Training and Preparedness

The first group of questions measured the extent to which an occupant had any special level of knowledge about the building, other than what would be obtained by performing his or her job. The most prevalent special knowledge would be formal evacuation training, or fire drills. If respondents indicated that they participated in evacuation training during the 12 months prior to September 11, 2001, further questions were asked about the content of the training. The occupant's understanding of the emergency procedures, or the way it was 'supposed to go,' was also measured. Next, a Likert scale[33] measured the perceived usefulness of the evacuation training in the context of egress experiences on September 11, 2001, ranging from very helpful to very unhelpful. Finally, the respondent was asked whether he or she knew that there was a floor warden for his or her floor.

Initial Experience on September 11, 2001

The second group of questions covered the first moments of the September 11, 2001 attack on the World Trade Center as experienced by the respondent, also known as the initial awareness period. The manner in which a person first became aware that something was not normal (whether in the building or the neighboring building) may have influenced subsequent decisions. Examples of awareness channels may include sensory perception (such as feeling, hearing, or seeing the building shake; seeing or smelling fire or smoke) or may include a conversation with a person inside or outside the WTC complex. Next, the respondent was asked to provide context to the initial moment of awareness. Context was first created by identifying what activity the respondent was performing. Activities included, but were not limited to, working, conversing with coworker(s), eating, or participating in a meeting. The respondent was then asked to recall the number of other people he or she was with at the first moment of awareness. People in groups often defer to group decisions rather than making their own evacuation decisions. Next, a list of observations was read aloud, and the respondent was asked to indicate whether he or she noticed that event during the period of initial awareness. These events included smoke, fire, fireballs, collapsed walls, jet fuel, severely or fatally injured people, sprinklers going on, fire alarm sounding, power outage or flickering lights, fallen ceiling tiles, and extreme heat. The event proximity was probed for every affirmative response to determine whether the observed event was in the immediate area or outside the building. If no affirmative responses were indicated, the respondents were asked whether they observed any disaster related events not previously mentioned. Finally, the extent of any injuries to the respondent or those in the immediate area was ascertained, as well as whether the respondent felt that his or her life or the lives of other people were in danger.

Interim Experience on September 11, 2001

The format of the interim experience group of questions mirrored the format of the initial awareness questions. The interim time period was defined as the time after initial awareness, but before the person entered a stairwell or elevator to leave the building. This time period may have ranged from moments to tens of minutes. The objective of the interim period questions was to determine what motivated/forced people to either immediately evacuate or delay their evacuation by some period of time.

[33] A Likert scale measures the degree to which the respondent agrees or disagrees with a statement. In this case, the scale measured helpfulness, including very helpful, helpful, unhelpful, and very unhelpful. A neutral response was not included.

Information about the nature of the event obtained during the initial period often forms the basis for decision-making during the interim period. For example, many people may have found the environmental cues from the initial awareness period sufficient to initiate an immediate evacuation. Others may have required additional information in order to feel comfortable leaving the workplace. Occupants could have obtained information in two ways: passively and actively. Passive information is information received without seeking it. In other words, the information is received regardless of whether the person feels it is needed. Active information is information which the respondent actively seeks and considers important with respect to his or her decision to evacuate. In the interview, respondents were first asked whether they received any additional information about the event during the interim period. If so, the source (who), the nature (what), and the channel (how) of the information was probed. Next, additional information sought by the respondent was probed, including the source, nature, channel, and whether the process was successful in gathering additional information.

The perception of risk to the respondent's life, as well as the lives of others, was asked in the same way as during the initial period, to determine whether the sense of risk was increasing or decreasing over time. The interviewer probed about the activities of other people in the proximity of the respondent, which may have influenced the respondent's subsequent choices. Whether other people began evacuating prior to the respondent was specifically asked. Next, respondents were asked about the activities undertaken during the interim period, as well as activities that they wanted to carry out but could not. These activities included work-related actions, such as saving files or shutting machines down; personal actions, such as gathering belongings or calling people; and emergency-related actions, such as fighting fires/smoke, and searching for or helping others. If a respondent was unable to accomplish an action, the action and the reason for being prevented from doing so was captured.

As with the initial period, any observations of building damage were collected. If the respondent received help in any way before initiating evacuation, the nature and source of the assistance was determined. The respondent was asked for the primary cue was that initiated his or her evacuation on September 11, 2001 and how many minutes passed before initiating evacuation. Finally, respondents were asked whether anything prevented them from evacuating sooner than they reported.

Evacuation Experience on September 11, 2001

The next group of questions which followed the evacuation sequence to its completion, focused on time spent in the stairwell and/or elevator(s). Respondents were first asked whether they began their evacuation alone or with other people. Which stairwell (or elevator) the respondent entered was collected as either the stair identification letter (A, B, or C) or the geographic location, if known. Knowing where the stairwell emptied at the bottom could also narrow down which stairwell was used, which was collected near the end of this group of questions (Stairs A/C [44 in. wide] emptied out to the upper, Mezzanine Level, while Stair B [56 in. wide] went to the lower, Concourse Level). Next, the respondent's rationale for using a particular stairwell was probed. The respondent was then asked whether he or she left the stairwell or turned back for any reason during the evacuation and, if so, why.

Some events and features of the stairwells aided the progress of the evacuation, while other features constrained the progress of the evacuation. The following features or events were identified to the respondents, who were asked to indicate whether it was an aid to their egress: instructions or assistance from their floor warden, a police officer, or firefighter; support/encouragement from others; exit signage;

and photoluminscent paint. The following items were identified to determine whether they constrained the evacuation: crowded stairwells, counterflow (people moving up the stairs, against the flow of occupants), disabled or injured people being taken down the stairwell, locked doors, poor lighting, confusing or missing signage, and lack of clear instructions.

As with the initial and interim time periods, environmental cues related to fire, smoke, jet fuel and other disaster-related observations were probed, as well as whether the observation was in the immediate area or outside the tower. The final question about the respondent's own evacuation estimated the elapsed time from entering the stairwell until they left the building. A concluding evacuation question determined whether they knew why someone on their floor did not survive the WTC attack, if applicable.

Respondent Background

The final group of questions explored the background of the respondent relevant to evacuation. The first question identified any pre-existing disabilities or injuries which made evacuation more difficult. The respondent's age, gender, and primary language were collected. If the respondent was working in the building prior to 1993, they were asked whether they were present during the February 26, 1993 bombing. If so, respondents were asked questions about their evacuation experience on that day.

The interview concluded with an open-ended opportunity for the respondent to say anything additional about their evacuation experience on September 11, 2001. Respondents who indicated that they had a disability, were near the floors of impact, observed fire, smoke, or fireballs in their immediate area, or had a role of building responsibility on September 11, 2001, were asked if they would be willing to participate in a follow-up face-to-face interview.

Telephone Interview Response Rate Analysis

The response rate analysis of the telephone interview sample indicated an inverse relationship between floor height and the rate of response in WTC 1, as shown in the last column of Table 3–5. In other words, an individual was somewhat less likely to complete a telephone interview if they were high in WTC 1 than if they were lower in WTC 1. The non-response weight adjustment is the inverse of the overall response rate. For example, the inverse of 25.3 percent is 3.95.[34] In general, the weight adjustment for WTC 1 indicates that representative results should reflect that a single interview with a respondent high in the building is representative of more occupants than a single interview with a person lower in the building.

[34] 1 / 0.253 = 3.95. A lower overall percentage would, therefore, yield a higher weight adjustment.

Table 3–5. Response rate analysis for WTC 1.

Floor Stratum	Number of Selections	Number of Interviews	Screen	Eligibility	Interview	Overall	Non-Response Weight Adjustment
1 to 42	4464	256	46.2 %	22.6 %	54.8 %	25.3 %	3.95
43 to 75	3714	137	48.6 %	16.6 %	45.8 %	22.3 %	4.49
76 to 91	1802	34	42.7 %	14.7 %	30.1 %	12.9 %	7.78
Floor missing	6	0	50.0 %	0.0 %	NA	NA	
Total	9986	427	46.5 %	18.9 %	48.6 %	22.6 %	

Key: NA, not applicable.

A similar analysis of telephone interview response rates for WTC 2 (shown below in Table 3–6) did not indicate a significant need to weight the results; however, to be consistent with WTC 1 analysis, the results were weighted.

Table 3–6. Response rate analysis for WTC 2.

Floor Stratum	Number of Selections	Number of Interviews	Screen	Eligibility	Interview	Overall	Non-Response Weight Adjustment
1 to 42	4339	143	44.8 %	14.8 %	49.7 %	22.3 %	4.49
43 to 75	3187	134	45.0 %	17.7 %	52.8 %	23.8 %	4.21
76 to 110	2203	94	48.3 %	19.5 %	45.2 %	21.8 %	4.58
Floor missing	208	5	50.5 %	9.5 %	50.0 %	25.2 %	3.96
Total	9937	376	45.8 %	16.7 %	49.5 %	22.7 %	

All subsequent telephone interview data analysis in this report reflects weighting of the results in order to more accurately generalize the results. By convention, when a sample number is indicated (n=), the sample number will be the actual number of responses. Where percentages are indicated, however, the percentages were weighted to allow for generalization, unless otherwise indicated.

The source of differential non-response for floors 76 to 91 in WTC 1 when compared to floors 1 to 75 was not specifically identified.

3.2.3 Face-to-Face Interviews

The objective of the face-to-face interview segment was to gather first-hand accounts and observations of the activities and events inside the buildings on the morning of September 11, 2001. Using this approach, NIST identified previously unknown information, evaluated technical hypotheses, and explored conscious motivations for occupant behaviors, while allowing for comparisons to the telephone interview data. There was no recording of the face-to-face interviews, other than random selections for quality control purposes. It is estimated that the average face-to-face interview lasted approximately two hours.

The methodology for the face-to-face interviews is a synthesis of the Behavioral Sequence Interview Technique (BSIT), originally developed by Keating and Loftus (Keating and Loftus 1984), and the

Cognitive Interviewing Method (CIM), originally developed by Fisher (Fisher et al. 2000) and Geiselman (Geiselman 1986). These two interviewing methodologies were developed with the purpose of assisting persons in retrieving more comprehensive and accurate memories of incidents and sharing important details. Both approaches begin by allowing the informant to retell an unimpeded account without interruption by the interviewer, and both initially employ a chronological retelling of information. However, BSIT was designed to yield a database of qualitative information that could be subjected to systematic analysis and consolidation, while CIM was designed to facilitate investigative interviews. Since the Investigation is pursuing both goals (i.e., creation of a database of evacuation-related behaviors and an investigatory capture of information relevant to outcomes), the methodology combines these two approaches.

Cognitive interviewing has been the subject of many empirical investigations. Fisher et al. (Fisher, Brennan, and McCauley 2002) summarized these findings, demonstrating that the methodology significantly increases the amount of information recalled without affecting rate of errors. Interviewing a large number of informants will allow corroboration of information, thereby compensating for the likely increase in the absolute number of errors. Accordingly, it is likely that this approach will be productive in achieving a holistic view of the building evacuations.

The face-to-face interview methodology involved occupants who may have observed (knowingly or unknowingly) events important to completion of the objectives of the investigation.

Enumerating the population: The population included the entire occupant and building management population of World Trade Center WTC 1, 2, and 7.

Selecting the sample: The face-to-face interview sample was developed by identifying: (a) individuals who identified themselves as being willing to share information relevant to the objectives of the NIST investigation, (b) individuals identified from the telephone interview sample as having experiences or observation requiring further exploration, and (c) the snowball quota sample approach. A snowball quota sample approach asks individuals for the names of other people who may meet the selection criteria for the study. The people identified are subsequently contacted and asked the same question. The process continues until the quota has been reached.

Data Collection: The face-to-face interviews followed a four step technique, including unimpeded, open-ended narrative, a structured narrative, technical probes, and closed-ended questions. Each step is described more fully below.

Step 1: Unimpeded open-ended narrative account: Both BSIT and CIM begin the process by asking the participant to chronologically recount his or her "story." For the NIST investigation, the starting point was when it became apparent that something unusual had occurred on the morning of September 11, 2001. The ending point was when the participant felt that he or she reached a location where he or she felt safe (or, alternatively, when he or she successfully reached the exterior of the building). Researchers and practitioners involved with cognitive interviewing believe that starting the face-to-face interviews in this manner both improves recall and helps build rapport between the participant and the interviewer. Fisher et al. also noted that asking questions may interfere with recall because a participant must divide his or her mental resources between recall and listening to the interviewer's questions (Fisher, Falkner, Trevisan, and McCauley 2000). During the open-ended

narrative account, the interviewer often records notable information that was used for the probing phase conducted later.

Step 2: Structured narrative account: After participants completed their stories, interviewers prompted the respondents to go through the story again, but this time working cooperatively with the interviewer to record entries into a table. This approach was employed by BSIT for three primary reasons: (1) to yield a structured account that can be entered into a database without further processing; (2) to avoid the biasing effects of having interviewers ask specific questions; and, (3) to enhance the effort at recall put forward by participants by encouraging their active collaborative participation, an advantage to open-ended formats as noted by Fisher et al. (Fisher, Falkner, Trevisan, and McCauley 2000).

Each row of the table represented a single action. The approach was used based on the hypothesis that people encode narrative memory in a manner consistent with this format, thus facilitating both recall and data entry. Each column of the table represented three essential components of actions: a cue, an action, and the reason for taking that action. Cues can be either external (e.g., signs of a fire, someone saying something) or internal (e.g., remembering another means of escape). Actions are expressed using specific action verbs (i.e., "ran" instead of "went") and may include objects (e.g., a fire extinguisher) used by the informant. Reasons are the intentional, goal-directed base for the action. The interviewer used the participant's own words to the greatest extent possible. Participants were asked to review the data for accuracy.

Table 3–7 is an example of actions recorded in this manner.

Table 3–7. Example tabular face-to-face interview data entry.

Cue	Action	Reason
I heard but couldn't see someone yell "I've found a clear path"	So I stumbled in the dark towards where I thought the voice came	So that I could find a way to escape
My path was blocked by debris	So I called out to whoever yelled, "I'm near the reception area. Where are you?"	To try to get a better idea about where the person was

Experimental findings in psychological research on memory (Nillson 2000) suggest that when people perform actions, their abilities to verbally recall those actions are significantly improved. Script theory (Schank and Abelson 1977) suggests that people naturally organize their knowledge of actions using narrative sequences of actions structured around their pursuit of goals. However, in the case of WTC interviews, gaps in the narrative are anticipated, especially given the long period of time that has elapsed between the event and the interview. For the NIST investigation, however, interviewers encouraged participants to report only those memories about which they were confident really occurred to them.

Step 3: Probing for specific information: After completing the structured narrative account, interviewers asked specific open-ended questions (probes) intended to elicit specific information of particular value to the investigation. While some of this information was likely to have been part of the structured narrative account, participants could also recall other valuable information as well in response to probes.

Interviewers may use "context reinstatement" from CIM to improve recall of important information, because laboratory experiments have demonstrated that contextual cues enhance recall of related information. Fisher et al. explain that context reinstatement may enhance recall because people use multisensory coding of events. Using this mnemonic method, interviewers ask participants to "mentally recreate the external environment, and their affective, physiological, cognitive, and emotional states that existed at the time of original event" (Fisher, Falkner, Trevisan, and McCauley 2000).

Depending on the population, probes were used to try to elicit information including, but not limited to:

- Location of the informant at the time of certain marker events (e.g., location in WTC 1 when WTC 2 collapsed);
- Fire conditions (e.g., fire and smoke);
- Other cues of interest (e.g., the smell of jet fuel);
- Presence and activities of persons with disabilities;
- Use of elevators by self or others; and
- Knowledge of any obstacles to their progress while using the stairs.

Because information about many of these areas of concern required precise responses, questions for open-ended probes were developed collaboratively between the contractor and NIST. Responses to probes were recorded using standardized formats where feasible. For example, all participants who observed smoke were asked to estimate the smoke density qualitatively.

Quality Control for Face-to-Face Interviews: With the respondent's consent, some of the face-to-face interviews were audiotaped. The audio tapes were used for quality control of both data collection and interview quality. The audiotapes were periodically reviewed to ensure that interviewers precisely followed the protocol and conformed to administrative requirements.

Interview Responses

Over 200 face-to-face interviews were conducted with survivors from WTC 1 and 2; 131 interviews were performed with survivors of WTC 1, and 73 interviews with survivors from WTC 2, with the remainder from WTC 7 or with building personnel who moved between both WTC 1 and WTC 2. An attempt was made to interview occupants from each zone: low, middle, and high (at least 20 occupants were interviewed from each zone) of WTC 1 and WTC 2), as well as to interview occupants with unique experiences: occupants who witnessed fireballs, occupants with mobility impairments, occupants trapped in elevators, and occupants near or above the floors of impact. Occupants with special roles in the building, such as floor wardens and PANYNJ employees or contractors, were interviewed. Finally, six family members who spoke with occupants inside WTC 1 or WTC 2 after 8:46:30 a.m. on September 11, 2001 were interviewed.

3.2.4 Focus Groups

Williams reported that in a group setting, people provide cues that evoke memories in others and that social pressures mediate against reporting misrepresentations of what they recall (Williams 1990). The overall goal of the WTC focus group interviews was to elicit accurate group representations of specific events or themes. The six focus groups and the corresponding objectives were:

- Occupants located near the floors of impact. The objective of conducting a focus group with people near the floors of impact was to obtain information on the extent of the building damage and how the damage influenced the evacuation process.

- Floor wardens. The objective of the floor warden focus group was to explore the implementation of the floor warden procedures and the effect those actions had on the evacuation of the occupants on a floor and the evacuation of the floor warden themselves.

- Mobility-impaired occupants. The objective of this focus group was to explore the effect of a disability on the evacuation of the occupant and any other individuals who may have assisted or otherwise been affected by the evacuee.

- Persons with Building Responsibilities: The objective of the focus group with persons with building responsibilities was to capture the unique perspective custodians, security, maintenance, or other building staff.

- Random evacuees in WTC 1. The objective of the focus group with random evacuees in WTC 1 was to further explore the variables used in the causal modeling (i.e., those obtained from the hone interviews) that best explained evacuation delay and normalized stairwell evacuation time, including environmental cues, floor, and activities.

- Random evacuees in WTC 2. The objective of the focus group with random evacuees in WTC 2 was to further explore the variables used in the causal modeling (i.e., those obtained from the hone interviews) that best explained evacuation delay, including environmental cues, floor, risk perception, and use of elevators.

Sample selection: The people selected for inclusion in this study were selected using non-probability sampling procedures, i.e. snowball quota sampling (Blalock 1972; Cochrane 1977). Respondents contacted for face-to-face interviews or for other reasons were asked to provide the names and contact information for people they knew in each of the categories described above. Every effort was made to include approximately five people in each of these categories in the focus group study.

Data collection: The data collected in the focus group study produced qualitative and detailed narrative accounts of the experiences of several groups of people, including those near the floors of impact and those having mobility impairments. The focus group discussion was moderated by a trained and experienced facilitator. Two notetakers recorded the discussion and later compiled into a single summary of the focus group.

3.2.5 Audio, Video, Photographic, and Records Collection

Numerous emergency communications were recorded between 8:46:30 a.m. and 10:28:22 a.m., a period during which building occupants, WTC personnel, emergency responders, and people outside the WTC complex used radios and telephones to cope with the unfolding disaster. Emergency 9-1-1 call records, made available by the City of New York, were analyzed in both audio and transcript format. Communications at the WTC complex, transcripts of which were made publicly available by PANYNJ, were analyzed in both audio and transcript format. These communications included radio channels internal to the WTC complex, such as maintenance, vertical transportation, security, and PAPD. They also included communications external to the WTC complex, such as NYPD, EMS, PATH, and Newark airport.

In stark contrast to the number of photographs and video taken of the outside of WTC 1, WTC 2, and WTC 7, very few video or photographic records from inside WTC 1, WTC 2, or WTC 7 survived. A significant number of records related to the design and maintenance of the egress and communications systems, however, were collected and analyzed. In particular, records regarding the identities of the occupants authorized to enter the WTC complex (referred to as the badge list), architectural drawings, tenant alteration applications, building upgrades, emergency plans and procedures, and training materials contributed to a better understanding of the egress system performance on September 11.

Finally, complaints filed with the Occupational Safety and Health Administration (OSHA) were reviewed. The issues raised by complainants, a combination of surviving occupants and families of victims, guided the development of interview instruments and identified additional avenues of investigatory pursuit for emergency preparedness and evacuation system performance.

3.3 ANALYSIS OF FIRST-PERSON DATA

A systematic, comprehensive approach was required in order to consolidate the enormous volume of data collected or made available. Two primary techniques were utilized in order to capture the full range of the data collection: quantitative and qualitative analysis. Neither technique would have sufficed by itself, as the two techniques were highly complementary. In general, the quantitative data analysis was used with the telephone interview data, while the qualitative data analysis was used with face-to-face interviews, focus groups, and emergency communications. A number of analysis techniques were considered, however, the approaches described below were selected to provide the highest quality results across the three interview methods.

Quantitative Data Analysis

The quantitative data analysis, based on to a telephone interview data set collected according to rigorous statistical standards, provided the ability to generalize findings and conclusions to the entire population of WTC 1 and WTC 2 survivors. The results of the 803 telephone interviews were archived and analyzed using SPSS 12.0.1,[35] a statistical analysis software package. This package provided the ability to apply weights to the data, compute mean, median, mode, skewness, and other relevant statistical measures, recode data using expert judgment, and automatically produce reports of subsets.

[35] See Federal Government product disclaimer contained at the beginning of this report.

Qualitative Data Analysis

The purpose of the face-to-face interviews and focus groups was to explore the events of September 11, 2001 at WTC 1, WTC 2, and WTC 7 in an investigatory manner, allowing the individuals to communicate their experiences, observations, and thoughts outside the constraints of a closed-ended interview format. While a framework of data collection format and a time frame (the morning of September 11, 2001) was imposed, respondents had complete freedom to express their experiences in their own words. The primary value of the qualitative data analysis was two-fold: first, to collect information on the entire range of observations and experiences, and second, to enhance and provide a deeper understanding of topics explored and generalized in the telephone interviews. ATLAS.ti 4.1[35] was used to conduct qualitative data analysis. Each face-to-face interview and focus group was coded for over 130 different types of information, resulting in several thousand individual codings. The codings, along with a brief explanation of each coding, are included in Appendix B at the end of this report. The resulting dataset was queried for targeted exploration of various factors of interest.

Protection of Human Subjects

To ensure the protection of the respondents and to comply with the Common Rule for the Protection of Human Subjects, the protocols and informed consent forms for the conduct of the telephone interviews, face-to-face interviews, and focus groups were reviewed and approved by an institutional review board and by NIST. NIST NCSTAR 1-7B summarizes the procedures used in first-person interviews.

Confidentiality of Respondents

NIST noted the importance of maintaining the confidentiality of the respondents. Contractors and retained experts were bound by contractual obligation to protect the confidentiality of all interview respondents, whether interviewed by telephone, face-to-face, or focus groups. No identifying information (name, gender, floor number, job title, etc.) has been included in this report. Individuals may have previously spoken to the media or other individuals about their experiences and observations, however, which could diminish NIST's ability to protect an identity. Interviews conducted as part of Project 7 were distinct from interviews with emergency responders (NIST NCSTAR 1-8 2005), which were conducted in accordance with a separate agreement between the City of New York and NIST and between the PANYNJ and NIST.

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Chapter 4
SEPTEMBER 11, 2001, BEFORE THE ATTACKS

4.1 BUILDING POPULATION ON SEPTEMBER 11, 2001

The total number of people inside WTC 1 and WTC 2 on September 11, 2001, is not known precisely, but it is necessary to make a good estimate of that number in order to provide context for understanding the evacuation of the buildings. On a typical Tuesday at 8:46:30 a.m., some businesses within the WTC complex would be largely staffed and operational, with others mostly empty, owing to a later corporate start time. In addition, September 11, 2001, was both the first day of the new school year for many children, as well as the date of primary election in New York City. Finally, tourists were not yet traveling to the observation deck in WTC 2 as it had not yet opened. These factors, among others, may have acted to limit the number of people who were at the WTC complex on that morning.

The total number of building occupants is equal to the sum of survivors and decedents. Section 9.2 contains an analysis of likely decedent locations at the time or aircraft impact. The response rate analysis for interviews presented in Section 3.2.2 leads directly to a projection of the number of people present in WTC 1 (8,900 ± 750) and WTC 2 (8,540 ± 920) on September 11, 2001, at the time of the first airplane impact. Table 4–1 indicates that the populations of WTC 1 and WTC 2 were similar (within statistical uncertainty intervals) and that 17,580 ± 1,180 individuals were inside the towers at 8:46:30 a.m. These numbers do not include any airplane passengers or crew, emergency responders, or bystanders. The total population was rounded to reflect uncertainty in the projection and decedent analysis.

Table 4–1. Occupancy estimates on September 11, 2001, by tower.

Estimate	WTC 1	WTC 2	Total
Estimated Total Population of Survivors	7,470	7,940	15,410
Estimated Number of Occupant Decedents[a]	1,462 – 1,533	630 – 701	2,146 – 2,163
Estimated Total Building Population	8,960	8,600	17,560

a. See Section 9.2 of this report for analysis of occupant decedent locations in WTC 1 and WTC 2.

While Table 4–1 shows the estimated total population for WTC 1 and WTC 2, Table 4–2 shows the uncertainty calculations at different levels of statistical confidence.[36] The uncertainty is directly related to the number of interviews: more interviews completed results in less uncertainty in a projection (i.e., the number of occupants). Thus, the projection for WTC 1 has less uncertainty than the projection for WTC 2 (427 interviews and 376 interviews, respectively).

[36] The standard error expressed in Table 4–2 assumes that the probability distribution is approximately normal (Gaussian). The standard error then defines the interval over which the actual population of each tower (as opposed to the estimated population) existed with an approximate level of confidence of 68 percent. The range of population expands as the uncertainty decreases, as shown by the 95 percent confidence (confidence limit at 5 percent) row in Table 4–2.

Table 4–2. Occupancy estimate uncertainty.

	WTC 1	WTC 2	Total
Number of Telephone Interviews	427	376	803
Standard Error (p)	1.90 %	1.92 %	1.36 %
Standard Error (Total)	750	920	1,180
Confidence Limits at 5 %	±1,470	±1,790	±2,320

4.2 OCCUPANT CHARACTERISTICS

The survey data indicate that occupants of the WTC towers were twice as likely to be male as female (65 percent male (n=284) for WTC 1 and 69 percent (n=250) for WTC 2). As shown in Table 4–3 below, the average age of the occupants was mid-forties, with ages ranging from early twenties to mid-seventies, although one interviewee indicated that she attended the 90th birthday celebration for a fellow WTC evacuee (not included in the NIST sample) in 2003. The vast majority of respondents (92 percent (n=739)) spoke English as their primary language. It should be noted that some telephone contacts ended with a language barrier and that no interviews were conducted in any language other than English.

Table 4–3. Age for telephone survey respondents in WTC 1 and WTC 2.[a]

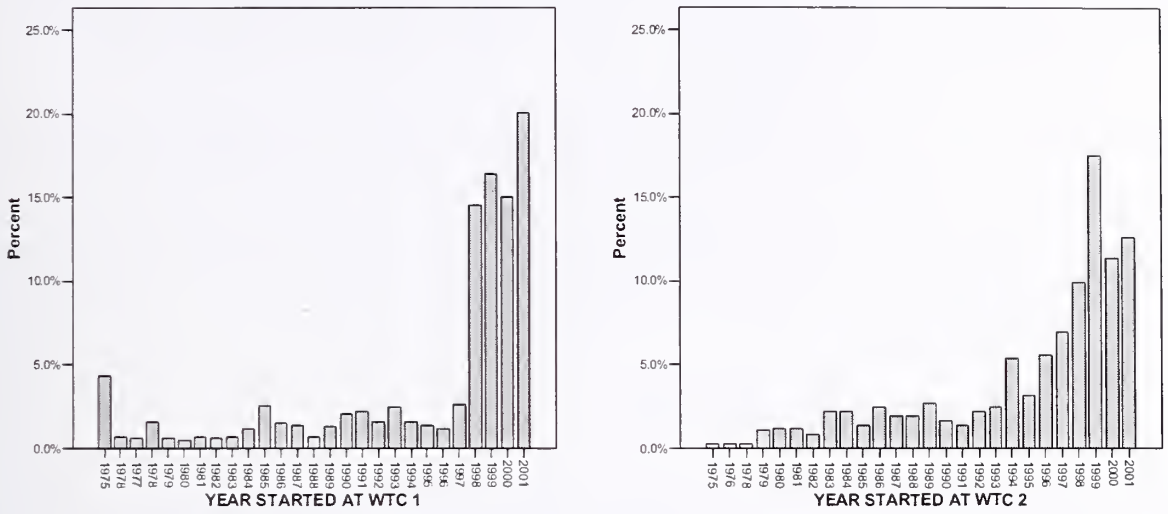
		WTC 1	WTC 2
N[b]	Valid	439	361
	Refuse	1	2
Mean		45	45
Median		46	44
Minimum		22	21
Maximum		73	74

a. Mean and Median values are weighted. N, Minimum, and Maximum are unweighted.
b. The sampling frame (badge list) identified 427 persons in WTC 1. 440 persons responded that they were in WTC 1 at 8:46 a.m. on September 11, 2001 during the telephone interviews.

Building occupants become familiar over time with a building, including the location of the emergency egress components and emergency procedures and protocols. The median residence time of the overall occupant population could thus be a predictor of how likely it was that an individual received training if the training was conducted every six months.

Tenant and employee turnover at the WTC was not uncommon. Figure 4–1 shows the reported start dates for respondents in WTC 1 and WTC 2. In WTC 1, 4 percent (n=18) of the occupants had worked in the building since 1975. Further, 25 percent (n=110) had been working in the building prior to the 1993 bombing, although only 16 percent (n=64) of the WTC 1 respondents were present on February 26, 1993. For WTC 1, 67 percent (n=287) of the occupants had started working in the building in the last four years (1998 – 2001). The mean residence time in WTC 1 was over 5.6 years, while the median was 2 years (half the respondents had been there two years or less, while half the respondents had been there longer than two years).

Occupant tenure in WTC 2 showed a similar trend. While only one respondent had worked in the building since 1975, 25 percent (n=91) of the respondents had been working in the building prior to the 1993 bombing (with 16 percent (n=59) present on the day of the bombing). Another 51 percent (n=185) started working in the building at some point in the four years prior to the 2001 terrorist attack. The mean residence time in WTC 2 (n=360) was 5.9 years, while the median was 3 years.



Note: Percentages are weighted.

Figure 4–1. Employment start date at WTC.

Overall, 7 percent (n=56) had a formal responsibility or special knowledge about the building. These respondents included fire safety staff, floor wardens, searchers, building maintenance, and security staff. Approximately 13 percent (n=105) of the respondents were employed by the PANYNJ, which may not necessarily imply a special knowledge of the building, as some PANYNJ employees had job duties related to functions outside the WTC.

Some 6 percent (n=52) reported having a limitation that constrained their ability to evacuate. Both WTC 1 and WTC 2 had roughly the same fraction of the population who reported a mobility impairment (n=26 in each building). Six percent of the population of WTC 1 and WTC 2 corresponds to roughly 1,000 people. The reported limitations included chronic illness, recent surgery or injury, obesity, elderly, heart condition, pregnancy, asthma, and other. Of these conditions, the most prevalent (n=20 of 52) was recent injury (in particular, severe knee and ankle injuries), followed closely (n=16 of 52) by reports of a chronic illness (such as cancer, leukemia, arthritis), or use of medications which hindered full mobility or cognitive ability. Four telephone interview respondents (of 52) reported being pregnant or having asthma, while three (of 52) reported having asthma-like conditions or indicated that age played a role in their ability to navigate the egress system. One person reported having a heart condition, while no telephone interviewee reported being blind, deaf, or requiring the use of a wheelchair. While the last three mobility impairments were not captured in the 803 telephone interviews, face-to-face interviews and published media accounts did provide information on people with these disabilities. A small number of respondents reported more than one mobility impairment.

4.3 PREVIOUS EXPERIENCE

Of the WTC 1 occupants present on September 11, 2001, 16 percent (n=64) were also present during the 1993 bombing. In WTC 1, 60 percent (n=38) of evacuees who evacuated both in February 1993 and in September 2001 reported that they evacuated immediately in 1993, while 30 percent (n=20) reported that they waited to evacuate in 1993, and 9 percent (n=6) did not recall. Most (95 percent (n=53)) who were able to recall their 1993 evacuation decision felt that they made the right decision, while 5 percent (n=3) did not believe they made the right decision.

Similarly, 16 percent (n=59) of WTC 2 survivors on September 11, 2001, also evacuated in 1993. In WTC 2, however, only 75 percent (n=42) felt that they made the right decision in 1993 (compared to 95 percent in WTC 1), possibly due to the fact that many more waited to evacuate in 1993 in WTC 2 (69 percent (n=39)) than did so in WTC 1. Only 31 percent (n=17) of those who reported their decision evacuated immediately from WTC 2 in 1993. It should be noted that the bomb had a more significant impact upon WTC 1 in 1993.

4.4 OCCUPANT PREPAREDNESS

Consistent with the NYC Building Code (Local Law 5 §C19-162.2.a.4) and Occupational Safety and Health Administration (OSHA) regulations (29 CFR 1910.38, "Employee Emergency Plans and Fire Protection Plans"),[37] the tenants of the World Trade Center were required by the Port Authority to conduct regular fire drills. Further, they were required to appoint employee floor wardens and searchers. Overall, 66 percent (n=529) of WTC 1 and WTC 2 occupants reported participation in at least one fire drill in the twelve months immediately prior to September 11, 2001, and a significant proportion of occupants had taken part in two or more drills during that time. However, 17 percent (n=139) reported that they had not participated in any fire drills in the 12 months prior to September 11, 2001, and 17 percent (n=135) did not know. Fire drill participation rates were similar between the two towers, as shown in Table 4–4.

Table 4–4. WTC fire drills in 12 months prior to September 11, 2001.[a]

Number of Drills	WTC 1	WTC 2
None	18 % (n=78)	17 % (n=61)
1	13 % (n=57)	8 % (n=29)
2	21 % (n=90)	24 % (n=88)
3	11 % (n=47)	15 % (n=53)
4	10 % (n=44)	9 % (n=32)
5 – 11	7 % (n=31)	9 % (n=32)
12 or more	3 % (n=13)	4 % (n=13)
Don't know	18 % (n=80)	15 % (n=55)

a. Percentages are weighted, n values unweighted.

[37] While the NYC Building Code required fire drills every six months, OSHA regulations require fire drills at least annually. The PANYNJ required fire drills for all tenants every six months.

One of the goals of fire drill training was to make occupants aware of the location of the emergency exits. Of respondents who reported participation in a fire drill, 93 percent (n=490) indicated that they had been instructed about the location of the nearest stairwell. However, of the respondents who reported being shown a stairwell, 82 percent (n=432) did not enter or use the stairwell during the fire drill. Some 17 percent (n=92) reported that they did use the stairs during a drill, while approximately 1 percent (n=5) reported not knowing whether they had used the stairs. Overall, more than half (51 percent (n=415)) of the occupants had never used a stairwell in WTC 1 or WTC 2 prior to September 11, while 48 percent (n=386) had used a stairwell. Two persons reported not knowing whether they had used the stairs previously. It should be noted, however, that Local Law 5, adopted in 1973, prohibits occupants from being required by building management or employers to enter or use a stairwell during a fire drill (1973). This prohibition may reflect social concerns regarding liability of required stairwell use by occupants and the economic costs of decreased employee productivity. In contrast, the City of Chicago, Illinois, (reacting in 2002 to the collapse of WTC) now requires twice-yearly fire drills, which "may conclude when all participating occupants have fully entered and have begun using designated stairwells." The City of Los Angeles, CA (Sixth Edition, 2002) in §57.33.19.C, entitled "Emergency Planning and Evacuation Requirements for High-rise Buildings," requires that a "minimum of one fire drill annually on individual floors is mandatory. Total building evacuation is not required."

Another goal of the fire drills was to introduce the floor warden system and evacuation procedures. Most occupants (82 percent (n=528)) with fire drill training were aware that there was a floor warden for their floor. Approximately 70 percent (n=557) of all occupants reported that they were aware of the evacuation procedures. When asked what those evacuation procedures comprised, however, answers varied significantly, including: wait in hallway for further instructions; do not use elevators, use stairs; meet at a designated site outside the building for a head count; or proceed down (varied number of) flights of stairs and wait.

In general, most (66 percent (n=212) in WTC 1 and 60 percent (n=167) in WTC 2) survivors who received fire drill training, reported that they found the training to be somewhat or very helpful to their evacuation experience on the morning of September 11, 2001.

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Chapter 5
SEPTEMBER 11, 2001, 8:46:30 A.M.
FLIGHT 11 CRASHES INTO WTC 1

"I heard the roar of the plane, looked out of the window [and] saw the plane halfway in the building. I jumped up and ran out into the hallway and screamed 'Everybody get out!'" Interview 1000749 (NIST 2004)

5.1 INTRODUCTION

At 8:46:30 a.m. on Tuesday, September 11, 2001, American Airlines Flight 11, a hijacked Boeing 767, hit the north face of WTC 1, as shown in Figure 5–1. This impact resulted in a direct hit on seven floors, from 93 – 99, with additional damage extending several floors above and below the direct impact area. As Flight 11 crashed into the North Tower, all access to safety for those at or above the impact was destroyed, including both elevators and stairwells. The fate of over 1,300 occupants located above the 91st floor of WTC 1 was sealed at that instant. This chapter focuses on occupant reaction during the initial moments after aircraft impact.

As the aircraft struck the building, jet fuel on board ignited. Part of this fuel immediately burned off in large fireballs that erupted at the impact floors. Remaining fuel flowed across the floors and down elevator and utility shafts, igniting intense fires throughout portions of the buildings. A fireball killed or injured several occupants in the Concourse Level lobby. Despite the massive localized damage caused by the impact, as shown in the computer simulation in Figure 5–2 and Figure 5–3, the structure initially remained standing.

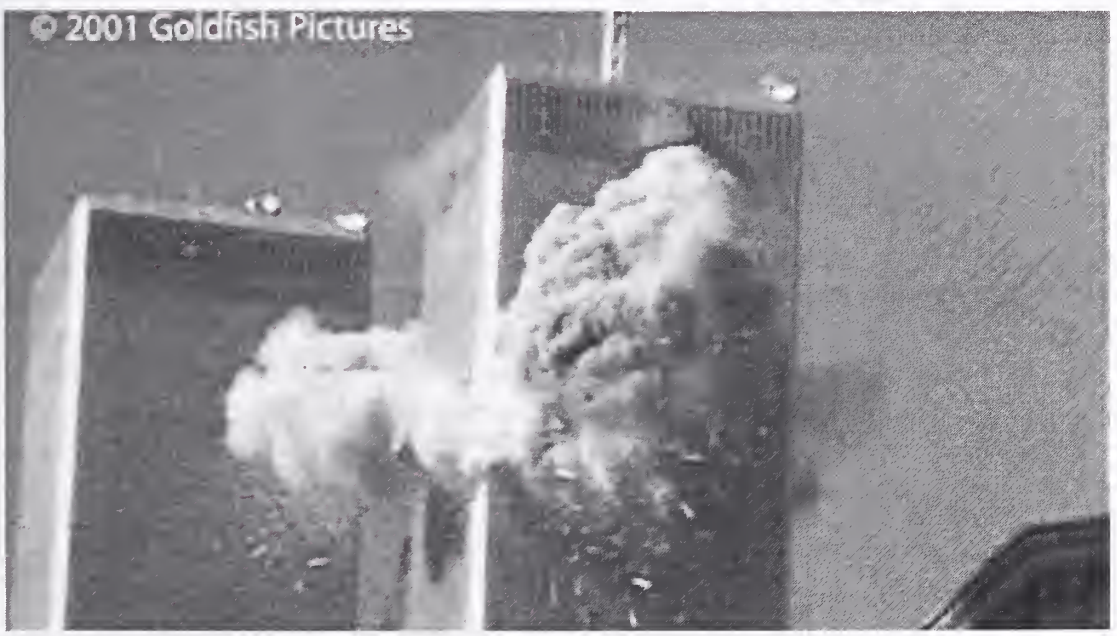

Figure 5–1. WTC 1 impact, 8:46 a.m.

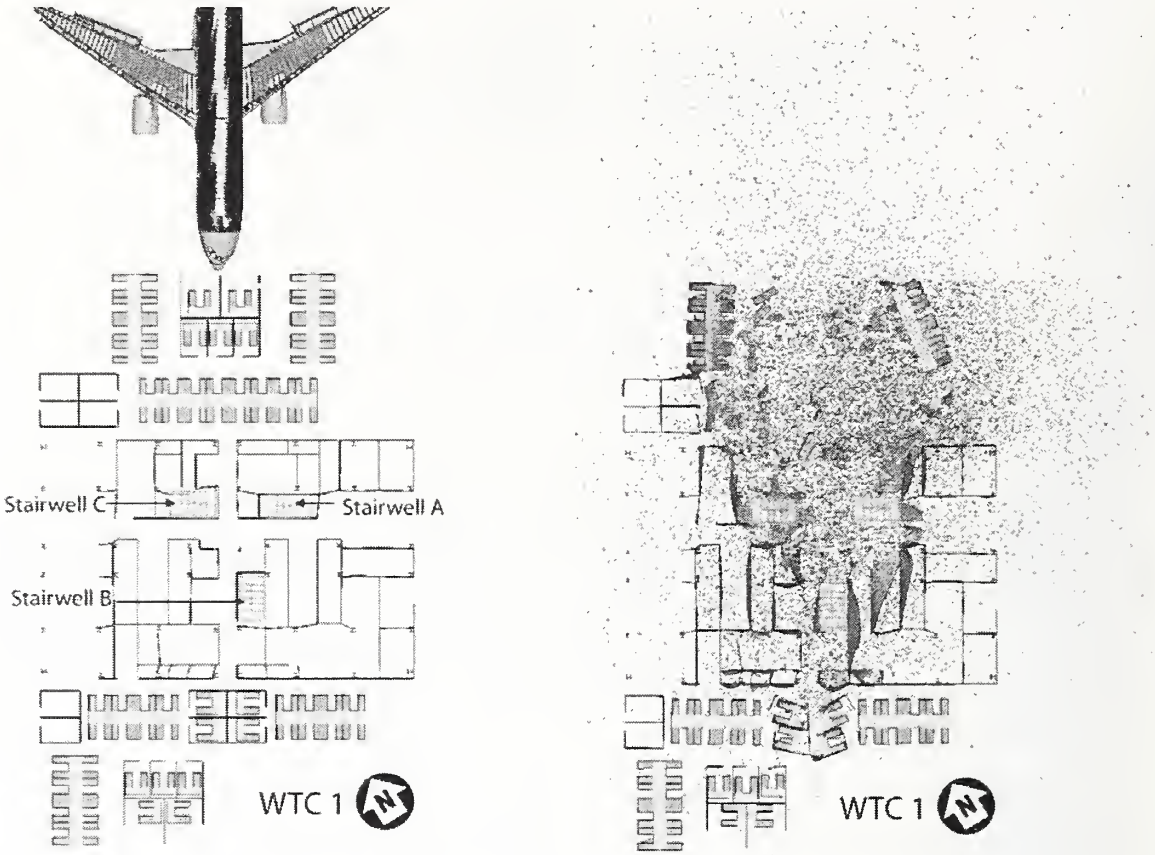

Figure 5–2. Computer simulated impact damage to WTC 1 on floor 95 at 0.7 s after impact with stairwells superimposed.

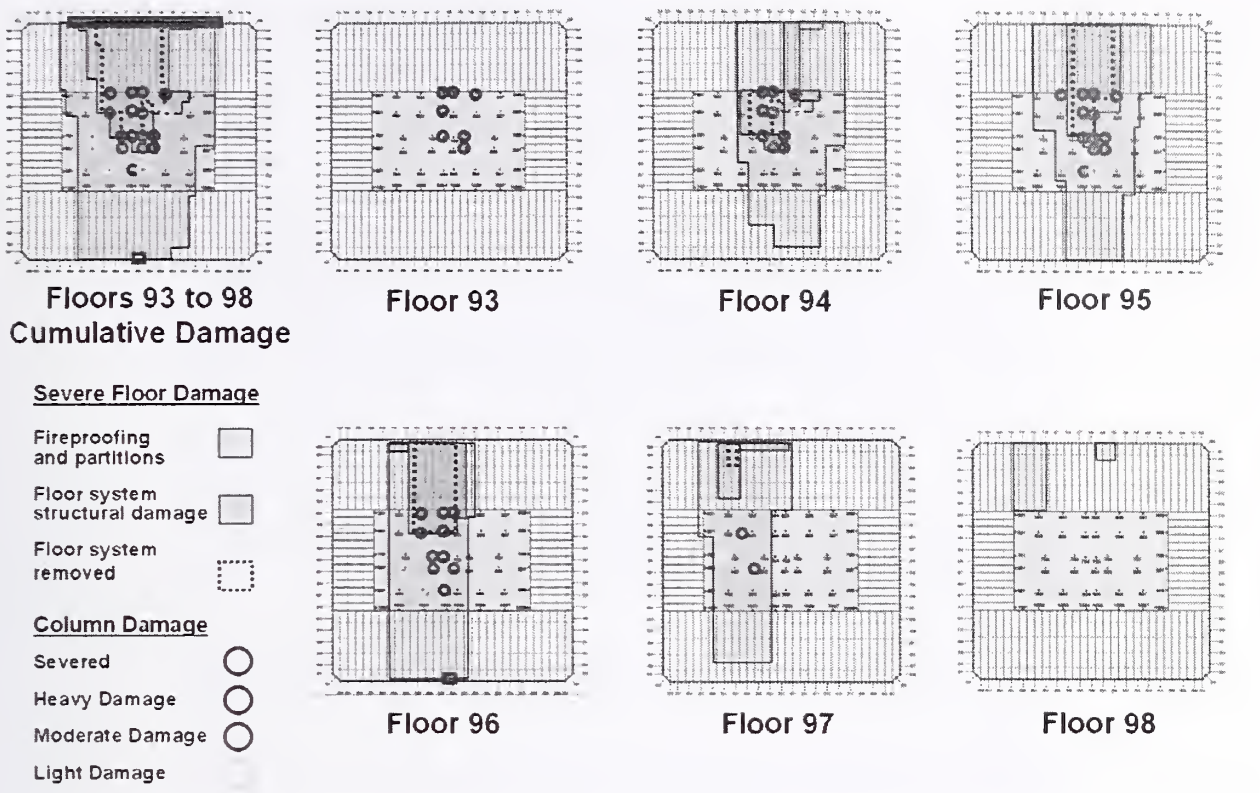

Figure 5–3. Calculated damage to floors 93 through 98 in WTC 1.

5.2 INITIAL OBSERVATIONS IN WTC 1

The New York City 9-1-1 call center was quickly besieged with calls, primarily from citizens outside WTC 1, reporting that the World Trade Center was on fire. Some callers reported observing a commercial airliner intentionally hitting the building, and a few quickly concluded it was an act of terrorism. Other callers reported missiles and bombs, while some called 9-1-1 seeking to find out what was going on, possibly preventing or delaying people in danger from accessing the 9-1-1 system. For example, occupants from an upper floor of WTC 1, finding they were unable to connect to 9-1-1, called a business colleague outside the building, who in turn, was able to contact 9-1-1 and report their plight.[38]

The plane strike was immediately obvious to occupants of WTC 1 throughout the building. Even below the floors of direct airplane impact, building occupants knew that a significant event had occurred, and many witnessed significant fire, smoke, or building damage. The majority of survivors in WTC 1 felt the building move from the airplane impact (63 percent, n=277). Table 5–1 shows a summary of how the survivors became aware that something was wrong. The reported percentages were roughly constant throughout the building. For example, 60 percent (n=157) in the upper third of the building (floors 78 and above) felt the building move, 62 percent (n=86) in the middle third (floors 44 to 77) felt the building move, while 64 percent (n=34) of the respondents in the lower third (up to floor 43) felt the building move. For some, this first cue was extreme; for others, less so. Still, it was clearly a significant event for all as the following quotes illustrate.

[38] New York City 9-1-1 Emergency Call Recordings, 2001.

A survivor from a floor in the 70s felt tremendous movement in the building: "There were large vibrations, the building shuddering, the floor shaking violently. The initial explosion was a large cracking sound, and then boom. The building swayed heavily to the South the first time, and then a couple other times with decreasing severity." Interview 1000103 (NIST 2004).

Forty floors below the impact, the effect was immediate and significant as a survivor from a floor in the 50s notes: "There were creaking noises in the closet. I walked out into the hall and stood there. There was no one else in the hallway. I heard whooshing noises in the closet. The door blew open from the closet door, causing my chair to hit the desk" Interview 1000054 (NIST 2004).

Thoughts of terrorism sprang quickly to the minds of many, particularly those who had survived the 1993 Bombing: "I felt the building sway. I knew it was really bad. My co-worker said, 'They did it again.'" Focus Group #4 (NIST 2004)

Even occupants low in the building knew something major had occurred. A survivor from a floor in the 20s reported: "We felt the impact. The building swayed about seven times. Debris was falling down on the street. We gathered our belongings, I shut off the computer and headed towards the stairwell" Interview 1000559 (NIST 2004).

Table 5–1. How survivors in WTC 1 became aware something was wrong on September 11, 2001.

Cue	Percent (n=440)
Felt something (building moving, impact, shaking, swaying)	63 %
Heard something (boom, crash, explosion, blast, roar, rumbling)	30 %
Other, including saw a plane, smelled jet fuel, fell down/fell off chair, warned by someone	7 %

Source: NIST WTC Telephone Survey Data.

Even at ground level, awareness of the incident was immediate. One survivor who was in the Concourse of the building recounts this experience:

"I was walking through the mall toward Tower One to get to the elevator. The lights flickered. I stopped in my tracks and looked around. I saw a brown cloud coming down the center corridor in the lobby, and I feared for my safety. The brown cloud had a heavy density and reached from floor to ceiling. It looked to me like it was both smoke and debris. It first came from the center corridor, but by the time it reached the revolving doors (a split second later) it seemed to come from every direction. At this point, the revolving doors exploded. They seemed to vaporize." Interview 1000046 (NIST 2004)

Like the Concourse Level, elevator lobbies throughout the building were particularly affected,[39] likely by excess jet fuel ignited by the crash pouring down the elevator shafts.[40] While only 3 percent (n=11) of the survivors reported seeing fireballs in their immediate area at the time of the airplane impact, the observations from the face-to-face interviews show the extreme nature of these events:

> A survivor from a floor in the 80s: "The entire corridor became an inferno outside our front door. Smoke began to enter our office. There was also debris falling. ... The fire on the corridor was at least 10 ft high, and it ran the … good length of the corridor. Then I saw a fireball come down the elevator shaft and blew the elevator doors. The fireball came right at me; it was a really bright color." Interview 1000055 (NIST 2004)

> A survivor from a floor in the 40s: "I saw the elevator in front me had flames coming out from it. The elevator was closed but the flames came from the front where the doors meet and on the sides. They reached about a foot and a half, with the flames standing from the floor to the ceiling. I saw a chandelier shaking; it was really moving. The corridor was dim. I also heard people screaming from the [nearby] floor. I felt the heat on my face and I thought that my eyebrows were going to get burned. Black smoke starting filling the corridor, it got really dense really fast." Interview 1000109 (NIST 2004)

> A survivor in the basement: "I saw a big bright orange color coming through the basement with the smoke ... A fire ball came shooting out of the basement door." Interview 100760 (NIST 2004)

The elevator lobbies were not the only areas of the building damaged at the time of the airplane impact. Survivors noticed a range of damage and conditions throughout the building, from lost power to fire and smoke, to missing walls and floors. Table 5–2 shows observations at the time of first awareness. While some of the observations involve less severe phenomena (fallen ceiling tiles or flickering lights), others are more extreme, including collapsed walls, fire, and smoke.

Observation of building damage during this initial awareness period were not as consistent over the height of the tower as the indications of the airplane impact. Table 5–2 presents a summary of observations reported during the telephone survey. While damage was more severe near the floors of impact, some damage was also evident at different locations lower in the building. Survivors provide a range of observations:

> A survivor from a floor in the 90s of WTC 1, just below the impact, recounts the severe damage on the floor: "In the hallway (from the bathroom to the elevator), there were no walls left (the wall board was blown off) and the bathroom seemed to be missing (the walls and the floor). There was a hole in the wall near the elevator (in the hall) and fire was coming up onto our floor through that hole." Interview 1000052 (NIST 2004)

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[39] The majority of face-to-face interview respondents who observed fire inside the building, observed flames at or near the elevator shafts (NIST Interviews 2004).

[40] See NCSTAR 1-5 for further information about the consumption of jet fuel in WTC 1 and WTC 2.

A survivor from a floor in the 70s in WTC 1: "To me everything seemed normal, all the ceilings were fine, the electricity was fine, and the air conditioning was also working." Interview 1000118 (NIST 2004)

A survivor from a floor in the 20s in WTC 1: "I was close to the windows. The windows were broken and I saw things from the office were going out the window." Interview 1000064 (NIST 2004)

Table 5–2. Observations of building damage in WTC 1 when occupants first became aware something was wrong on September 11, 2001.

Observation	Percent (n=440)
Fallen ceiling tiles	17 %
Power outage/flickering lights	17 %
Smoke	10 %
Jet fuel	8 %
Fire alarms	8 %
Collapsed walls	6 %
Other events, including fire, fireballs, injured people, fire sprinklers going off, extreme heat, debris	45 %

Note: Total does not add up to 100 percent because respondents may have observed more than one event indicative of damage.
Source: NIST WTC Telephone Survey Data.

While a significant event, not all occupants felt their lives were in danger initially. Of the survivors in WTC 1, 41 percent felt their life was at risk, and 48 percent felt others lives were at risk, at first awareness. Only 4 percent of the survivors reported being injured by the attack initially, while only 6 percent reported others being injured.

Most of the survivors were with other occupants when the event occurred. One of every eleven survivors reported being alone at the time. Sixty-one percent were in a group of 10 persons or less, although two respondents reported being in a group as large as 400. The average reported group size was 23 persons, while the median group size was 7 persons. This suggests that a few reports of very large groups (33 respondents [8 percent] reported being a group of greater than 100 people) skewed the average.

During the initial moments after WTC 1 was attacked, occupants above the 91st floor were trapped. A few occupants below floor 92 but near the impact region were alive, although trapped as well, some in their offices, others in elevators. Elevators were rendered inoperable. Occupants observed smoke, fireballs, damaged walls, fallen ceiling tiles, and injured colleagues on many floors throughout WTC 1.

Chapter 6
SEPTEMBER 11, 2001, 8:47 A.M. – 9:02 A.M.
OCCUPANTS REACT TO THE ATTACK ON WTC 1

"We gathered the group together to figure out what we should do. One exit was filled with smoke and it was dark; we tried to shut the door to keep out the smoke. The other exit was of no use, [so] we regrouped and went toward the main exit (towards the elevator). When the smoke was building up inside the office, I was more inclined to possibly break open the window and get some fresh air and wait for help; one or two of the other people insisted that we start evacuating [recognizing] that we were in very serious trouble." Interview 1000137 (NIST 2004)

Between 8:47 a.m. and 9:02 a.m., the time period after World Trade Center (WTC) 1 was attacked but before WTC 2 was attacked, one of the nation's largest building evacuations and emergency responses began to unfold. Occupants of WTC 1, aware that something significant was happening in their building, were assessing their situation, performing necessary duties, and actively seeking a way out of the building. With no operational elevators available to the occupants, the three stairwells began to fill, not only with occupants exiting the building, but also with emergency responders entering the building. Near and above the floors of aircraft impact, the fire and smoke continued to spread, threatening the lives of the trapped occupants. Some occupants fell or chose to jump from the building. Building fire safety staff coordinated the response with incoming personnel from the Fire Department of New York, New York Police Department, Port Authority Police Department (PAPD), emergency managers from the City of New York, and Federal agents. At 8:47 a.m., an evacuation order for WTC 1 was broadcast over the vertical transportation channel (Z). The first radio communication regarding evacuation of WTC 1 and WTC 2 was issued by a senior PAPD officer at 8:59 a.m. Two minutes later, at 9:01 a.m., an instruction was issued to evacuate all WTC complex building (PANYNJ 2001a). NIST NCSTAR 1-8 contains a detailed chronology of all radio communications with respect to evacuation.

Analysis of face-to-face interviews showed that many occupants of WTC 2, if afforded a view to the north or west, often chose to see for themselves what was happening to WTC 1. Once the significance of the event was verified, they were forced to decide, first, whether to evacuate or stay in place, and second, whether to evacuate using the stairs or the elevators. Building fire safety staff were deciding whether to order an evacuation of the occupants of WTC 2, taking into account the safety of WTC 2 occupants and what effect an evacuation of WTC 2 may have had on the evacuees from WTC 1 and on the incoming emergency responders (NIST 2004b).

6.1 CONDITIONS WORSEN IN WTC 1

Within minutes of the aircraft impact, occupants above the 91st floor began to assemble in groups of various sizes, often taking refuge in offices with access to windows. They also began to reach out for assistance, calling 9-1-1, family and friends, or colleagues. Electricity and phone service in the region

directly impacted by the airplane was apparently disrupted.[41] Electricity and phone service to floors above the impact floors was maintained, however, as evidenced by a number of 9-1-1 calls from the 100th to 106th floors during this time period.

Fire and smoke raced upward. As early as 8:50 a.m., occupants on the 106th floors reported worsening smoke conditions for about 100 people on that floor, some of whom took refuge in a back office.[42] Somewhat later, at 9:00 a.m., WTC Ch. 9 (PAPD Police Desk) received a call from a Windows on the World manager, who reported that floor 107 was "way too smoky" and most people had retreated to floor 106 (PANYNJ 2001a). 9-1-1 received reports of hazardous smoke conditions on 103, 104, 105, and 106 within ten minutes of aircraft impact. Each of those four floors reported having more than 100 people trapped on the floor. For some, the conditions remained at least partially tenable during this time period. Others jumped or fell out of the building within minutes of the aircraft impact. Along with falling building debris, this created a hazardous situation for emergency responders, evacuees, and bystanders.

Conditions for occupants below the 91st floor were deteriorating as well. More than one-third of the survivors reported seeing smoke after the initial airplane impact but before they left their initial floor to begin their evacuation, up from only 10 percent at first awareness. Eighteen percent of the survivors encountered the smell of jet fuel, up from 8 percent at first awareness. Table 6–1 shows a summary of these observations compared to those at first awareness. Observations of nearly all conditions increased as time progressed.

Table 6–1. Observations of conditions in WTC 1 before beginning evacuation.

Observation	At Awareness	During Interim Period
Smoke	10 %	35 %
Jet fuel	8 %	18 %
Fallen ceiling tiles	17 %	21 %
Power outage/flickering lights	17 %	17 %
Fire alarms	8 %	14 %
Collapsed walls	6 %	10 %
Fire	3 %	5 %
Other events	45 %	48 %

Note: Total does not add up to 100 percent because respondents may have observed more than one event indicative of damage.
Source: NIST WTC Telephone Survey Data.

In WTC 1, a number of people below the impact zone were trapped on their floors, unable to either leave their offices or reach the stairwells. Prior to 9:02:59 a.m., trapped occupants requested assistance by calling 9-1-1 from an elevator, from scattered floors in the 10s, 20s, 30s, 40s, 60s, and from most floors in the 80s.[43] Among those requesting assistance, heavy smoke, wall damage, and occupant injuries were

[41] New York City 911 Emergency Call Recordings, 2001.
[42] New York City 911 Emergency Call Recordings, 2001.
[43] 911 Emergency Call Records, City of New York, 2001.

common reports. Figure 6–1 shows graphically the distribution of observed conditions in WTC 1 after initial awareness, but before beginning evacuation. The information to develop Figure 6–1 was compiled from every source available to the NIST investigation, including interviews, published accounts, transcripts of emergency communication channels, and emergency 9-1-1 calls. Note that the "?" denotes a floor where there was no information found to record the absence or presence of observations. Further, the absence of an observation on any floor does not positively exclude the presence of that condition as it may simply not have been reported.

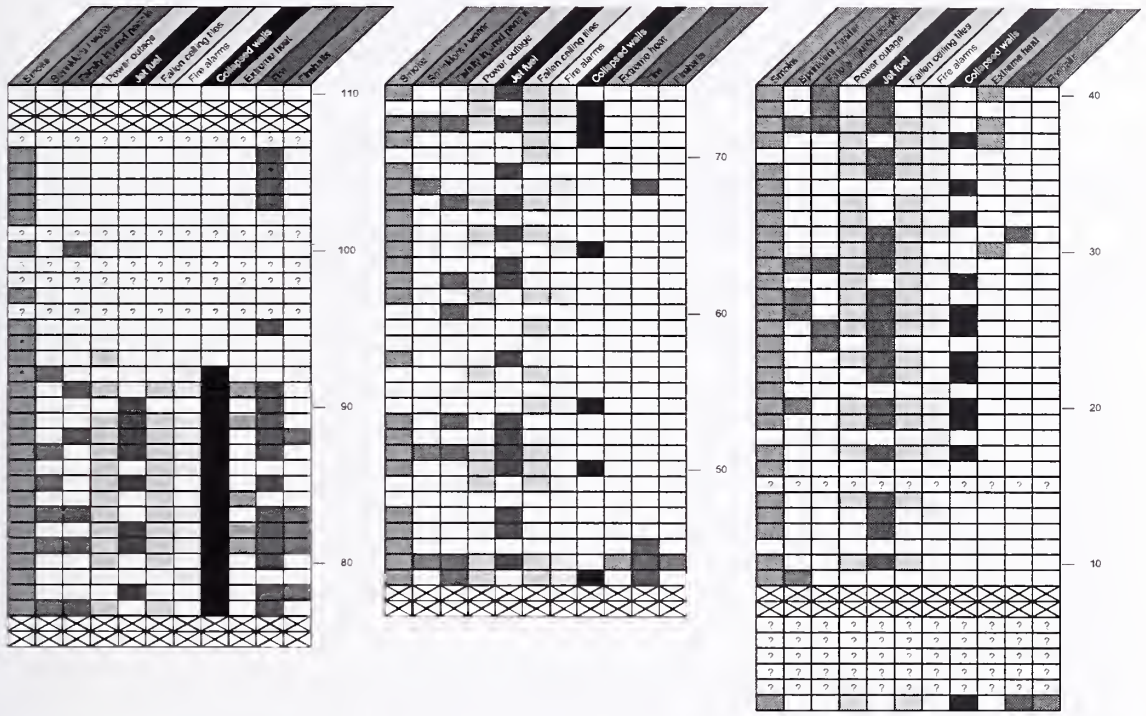

Figure 6–1. Observations of building damage after initial awareness but before beginning evacuation in WTC 1.

6.1.1 Activities and Information

Occupants of WTC 1 engaged in a variety of activities prior to leaving their floor and beginning their evacuation, including exchange of information, gathering personal items, helping or searching for others, and fire fighting. Table 6–2 summarizes activities reported in the telephone survey.

Many respondents used the time prior to beginning their evacuation to gather information about the event or to call family members. Others helped injured coworkers:

> A survivor from a floor in the 90s: "I heard a sound that sounded like a giant aluminum can being crushed and I felt the building tilt. I tried calling my company's home office but the line for long distance calls was not in service. I called home to test the phones and to let my family know that I was okay. I checked to see if our server was still up. I saw a man bleeding. I got a first aid kit and succeeded in halting the man's bleeding. We saw debris and smoke and decided it was time to get out. I

got my briefcase, a fire extinguisher, and four diet sodas, exited into the hallway and went towards stairwell C." Interview 1000052 (NIST 2004)

A survivor from a floor in the 30s: "I used a telephone in the trading room to call my wife. I wanted to see if she had seen anything on the news and could tell me what was wrong. I called my wife within 4 minutes of the impact of our building--and I got through okay. She wasn't there and I left a message. Because we saw the place of impact and fire coming out of the windows above us in our building, a co worker and I got our personal belongings and headed calmly to the stairwell." Interview 1000042 (NIST 2004)

Table 6–2. Activities prior to evacuation reported in telephone survey by survivors from WTC 1.

Activities Before Evacuation	Percent Reporting the Activity (n=440)
Talked to others	70 %
Gathered personal items	46 %
Helped others	30 %
Searched for others	23 %
Talked on telephone	16 %
Moved between floors	8 %
Fought fire or smoke	6 %
Shut down computers	6 %
Continued working	3 %
Other activities	25 %

Note: Total does not add up to 100 percent because respondents may have taken multiple actions.
Source: NIST WTC Telephone Survey Data.

Some occupants, on the other hand, started their evacuation almost immediately:

An occupant from a floor in the 60s in WTC 1: "It felt like the building was going to fall over. I grabbed my bag to leave the office floor. I was not waiting for anyone to tell me what to do." Interview 1000122 (NIST 2004)

An occupant from a floor in the 20s in WTC 1: "I waited for building to stop shifting. I began to run straight out the nearest exit out of my office towards Stairway B. It was the nearest exit from my office and co-workers were just saying let's go this way." Interview 1000064 (NIST 2004)

While only 11 percent of the telephone survey respondents reported being given additional information about the event during this interim period without consciously seeking the information, 28 percent reported seeking such information. Table 6–3 shows the types of information received and sought by occupants. The majority of occupants received or sought information about the event, with a smaller

number looking for information on whether to evacuate or remain in the office. For those who sought additional information, 43 percent were unable to find the information they were seeking.

Table 6–3. Information received and sought prior to beginning evacuation in WTC 1.

Information Type	Information Given (n=50)	Information Sought (n=122)
Information about what had happened	57 %	81 %
Instructions to leave	28 %	17 %
Instructions to stay	17 %	12 %
Other, including information about what to do and to receive assistance in evacuation, don't know	13 %	13 %

Note: Total does not add up to 100 percent because respondents may have observed more than one event indicative of damage.
Source: NIST WTC telephone survey data.

Occupants tried to obtain information through a variety of means –face-to-face conversation; telephone, television, or radio; e-mail or handheld devices; and from building announcements:

> A survivor from a floor in the 70s: "I walked to my desk and spoke on the phone to find out what happened. I went on the Internet and I was informed of what happened; also through telephone conversations. I thought it was necessary to look around. I walked around the floor with the fire warden; I also stopped, looked, and took some pictures. I was there in 93, and I wanted to wait for some directions from someone, through the speaker system, fire alarms, etc." Interview 1000576 (NIST 2004)

> A survivor from a floor in the 60s: "During the time in which I was circulating in the northeast side of the floor, I heard a secretary say, 'Aren't we supposed to wait for an announcement?' I saw other workers who were standing there talking and trying to assess what to do next. I went into the hall located between the stairwells A & C. People within the group helped each other make the correct decisions for evacuation." Interview 1000639 (NIST 2004)

Twenty-seven percent of survivors felt they began their evacuation before the people around them. Not surprisingly, survivors' perceptions of risk of death to themselves and to others increased as conditions in the buildings worsened. Table 6–4 shows a comparison of survivors' perception of risk at the point of airplane impact and in the interim period before they left their floor to begin their evacuation.

Table 6–4. Survivors perception of risk to self and others after airplane impact and prior to entering stairwell in WTC 1.

Perception of Risk	Others	Self
At awareness	48 %	41 %
Interim	63 %	52 %

Source: NIST WTC Telephone Survey Data.

Although occupants felt at a heightened risk during this time, many occupants helped others before beginning their own evacuation; 20 percent of the survivors reported being helped by someone; while 30 percent reported helping others. Table 6–5 summarizes the responses of the survivors who received assistance.

Table 6–5. Sources of help used by occupants prior to beginning their evacuation in WTC 1.

Source of Help	Percent (n=87)
Co-worker	48 %
Police officer/firefighter	16 %
Floor warden	12 %
Manager/supervisor	13 %
Other/don't know	13 %
Stranger	8 %

Note: Total does not add up to 100 percent because respondents may have received help from more than one person.
Source: NIST WTC Telephone Survey Data.

Requests for guidance or assistance were not uncommon. At 8:48 a.m., a mere two minutes after the plane hit WTC 1, an occupant from the 78th floor called the Port Authority Police desk requesting guidance:

> PAPD: Port Authority Police...
> Male: Yes, uh, we're on the 78th floor, at Hyundai Securities. Do we need to evacuate or not?
> PAPD: Right away.
> Male: Right now?
> PAPD: Right away.
> Male: Okay, which stairs do we take?
> PAPD: Uh, whichever is the easiest one nearest without too much smoke and everything. Try to get the best way down.
> Male: Well, there's...the hallways are full...full of smoke.
> PAPD: Okay. If you could find your way down one...
> Male: Okay, get out right now, right?
> PAPD: Right. Right, exactly.
> Male: Okay, bye. (PANYNJ 2001a)

The telephone interviews revealed a variety of reasons which caused occupants decide to evacuate their floor. Table 6–6 summarizes the single predominant reason given by occupants for beginning evacuation in WTC 1.

Some left due to observations of building damage or movement, others felt in danger, and still others left because co-workers left or told them to leave. Less than 1 percent said they left because they heard a fire alarm:

> A survivor from a floor in the 80s: "My boss told me that a plane came into the building. I was at a cubicle with no window view. I was

screaming and crying, my boss came over to my location. We only had one door to enter or exit the office. The door was blocked with debris. We saw the ceiling caving in, but I don't recall any smoke or fire at this point. We began to dig out pieces of ceiling debris to open the door to exit." Interview 1000722 (NIST 2004)

A survivor from a floor in the 60s: "The big boss, the treasurer, he stated "Get out now". I grabbed my pocketbook and started walking towards the stairwell." Interview 1000834 (NIST 2004)

A survivor from a floor in the 20s: "I saw the floors in the hallway were twisted. The burning stuff outside the window was getting heavier and I decided that maybe I should look for a stairwell." Interview 1001667 (NIST 2004)

Table 6–6. Single reason given by survivors to begin their evacuation in WTC 1.

Reason	Percent (n=440)
Building movement	20 %
Afraid/felt in danger	20 %
Was told to evacuate	14 %
Friends/co-workers evacuated	9 %
Saw debris	6 %
Saw smoke	5 %
Other, including saw fire, 1993 experience, saw/heard plane, people panicking, fire alarm going off	26 %

Source: NIST WTC Telephone Survey Data.

6.1.2 Emergency Response at the Fire Command Station, Lobby, WTC 1

Within minutes of the initial impact, personnel from the Port Authority, building security, FDNY, NYPD, FBI, Secret Service, and representatives of Silverstein Properties (principal leaseholder) were assembling at the Fire Command Station in the lobby of WTC 1, as shown in Figure 6–2. The deputy fire safety director (a contractor from O'Conner Security) after assisting a woman injured by glass in the lobby, quickly began to receive and log calls from floor wardens on floors above the mid-rise area, including floors above the impact area. As the first calls came in, announcements were made to the affected floors, indicating, in general terms, 'We have received an alarm downstairs and the alarm is being investigated. Please stand by.' Any information from the floor wardens about the condition of the floor or injuries was passed to the Fire Department personnel nearby. As multiple floors were reporting incidents, the deputy FSD took down the floor numbers on a pad and paper and awaited the arrival of a supervisor. Within ten minutes, it was determined that the attack was a multiple-floor event. Therefore, consistent with emergency procedures, building-wide public address system announcements were made informing occupants to evacuate the building using the stairs and not the elevators. Initially, the evacuation script

Figure 6–2. Fire Command Station in WTC 1 on September 11, 2001.

was used, but later the deputy FSD simply told people over the public address system not to use the elevators because they were crashing and to use the stairs to leave the building (Other Interview 03 [NIST 2004b]). Unfortunately, the individual was unaware of the condition of the 22nd floor, where critical communications hardware in the hidden security command center lay in ruins, likely preventing any building-wide public address announcements from reaching the occupants (PANYNJ 2001a; NIST 2004b). After the fact, a person familiar with the operation of the building suggested that the fire alarm closet on floor 22 destroyed the riser. NIST NCSTAR 1-4 has a more complete analysis of the fire alarm and public address system in WTC 1 and WTC 2.

The damage on floor 22 was also reported by several emergency responders (NIST 2004) and was noted several times in the NIST analysis of the published accounts (Fahy and Proulx, 2003). NIST NCSTAR 1-8 (Chapter 4.4) contains additional information regarding the status of the 22nd floor command desk, as well as information flow between occupants, 9-1-1, and emergency responders.

6.1.3 Survivors Begin Their Evacuation

Most, but not all building occupants began their evacuation of the WTC 1 before the WTC 2 was hit. Ninety-one percent of the survivors in WTC 1 reported beginning their evacuation before Flight 175 struck WTC 2. At this point, nearly all observations of types of building damage had become more widespread than those at first awareness. Survivors recalled a variety of conditions on the floors as they left for the stairwells, ranging from significant damage to damage insufficient to deter the occupant from completing a routine task:

> From a floor in the 70s in WTC 1: "As I was leaving it didn't seem as bad as I thought in the office and I decided that I would just walk all the way down and reassess the situation and go back to the office if things were ok." Interview 1000129 (NIST 2004)

> From a floor in the 60s in WTC 1: "There was smoke and smell of jet fuel coming from the stairwell. I covered my nose/mouth with tissue. This smoke wasn't a lot; not to the extent that [you] could choke. The smoke was coming from the vents/corners of the stairwell." Interview 1000036 (NIST 2004)

> From a floor in the 60s in WTC 1: "The first time I faxed my documents, they did not go through. I felt safe because I watched previous documentaries and I was informed that I was safe in my building. I went back to the fax machine." Interview 1000733 (NIST 2004)
>
> From a floor in the 50s in WTC 1: "I heard a chunk of ceiling fall and a woman screamed. We all stood and looked at each other and we tried to figure out what happened. We heard the cable snap in the freight elevator while we were talking, and the woman yelled "follow my voice". I followed the woman's voice to find where the stairwell was at to get out." Interview 1000054 (NIST 2004)
>
> From a floor in the 30s in WTC 1: "It [the stairwell] was the closest one to our office. I opened the doorway to the staircase... There was a lot of smoke and there was no one in it. I quickly closed the door." The occupant went to another stairwell down the hall to leave the floor. 1000009 (NIST 2004)

For consistency in evacuation measurement, time to begin evacuation was defined as the interval from first awareness to the time the respondent left his or her floor to begin evacuation.[44] On average, survivors in WTC 1 began their evacuation within 6 min. However, it is important to note that the statistical distribution of time to initiate evacuation was skewed in the direction of longer delays. In other words, while the most frequent response for survivors in all three zones in WTC 1 was one minute or less (referred to as the mode in statistics), and 50 percent of occupants had left their floor within 3 – 5 minutes (depending on zone), a few individuals took significantly longer (sometimes longer than 30 minutes) to start evacuating, thus disproportionately affecting the mean time to start evacuation.

Table 6–7 summarizes the quartile, mode, and average times to start evacuation for survivors in WTC 1. Note that Table 6–7 separates the occupants into lower, middle, and upper floors based upon the location of the mechanical floors, which roughly divided the building into thirds. The reported times from the lower floors were not different than the reported times in the middle floors (tail probability from a log-transformed t-test comparing the two zones was 0.81). The upper floor evacuation initiation delay times, however, were statistically significant different when compared to both the middle and lower zones (significant at approximately the 99 percent confidence level). Thus, occupants nearer the impact area in WTC 1 delayed their evacuation for a longer period of time than occupants of the other two zones. This could have been due to the increased frequency of fire, smoke, building damage, and injured occupants on the upper floors, although that is only one explanation. A further discussion of evacuation initiation delay time and comparisons across regions of WTC 1 and WTC 2 is contained in Section 10.1.

[44] The time to begin evacuation was defined as the time while on the floor of origin due to the fact that, while many people decided to leave quickly, they often chose to perform several activities prior to actually entering the stairwell. Thus, time prior to entering a stairwell (or elevator) was a better measure of evacuation delay than a moment when the occupant 'decided' to evacuate, which may have been significantly prior to actually starting evacuation.

Table 6–7. Elapsed time (min) to initiate evacuation for survivors from WTC 1.

Time for Survivors to Initiate Evacuation[a]	25% Initiation	50% Initiation	75% Initiation	Mode of Responses	Average Time (min)
Lower floors (Basement – 42)	1	3	5	1	5.7
Middle floors (43-76)	1	3	5	1	4.8
Upper floors (77-91)	2	5	10	1	7.4

a. Time to begin evacuation is the time interval from first awareness to the time the respondent left their floor to begin evacuation.
Source: NIST WTC Telephone Survey Data.

As shown in Table 6–8, survivors below the 92nd floor typically reported choosing the stairwell closest to them at the time. All three stairwells below the impact region were in use throughout the evacuation. Some found an appropriate stairwell quickly:

> From a floor in the 80s in WTC 1: "The hallway was free of debris and well-lit. We (my boss, and co-workers, about ten to fifteen) went back to staircase C and proceeded to evacuate. The door on the staircase was not damaged. We entered staircase C. The staircase was well lit and fairly empty." Interview 1000108 (NIST 2004)

> From a floor in the 60s in WTC 1: "The building shook and I thought something tremendous had struck the building. I looked out the building to see what had happened. The fire alarm went off. I went to the stairwell (the exit) to evacuate the floor." Interview 1000025 (NIST 2004)

> From a floor in the 50s in WTC 1: "It [the stairwell] was closest, and we had been trained in emergencies to only use the stairwells, never the elevators. We (four of us from my immediate office) exited down stairwell B." Interview 1000106 (NIST 2004)

For others, finding an appropriate stairwell for evacuation was not always a straightforward process, as a survivor from a floor in the 30s recounts:

> "I opened the doorway to the staircase. There was a lot of smoke and there was no one in it. I quickly closed the door to not bring smoke into the floor. The group of people that was with me (about 10 people) started running back to the office. I began running after my coworkers and yelling at them to come back to find a different staircase. I was trying to do the right thing, and they were doing the wrong thing based on the fire drill training we had. The coworkers weren't listening so I let them go their own way and I went by myself back out to the hallway to find a different staircase. I walked down the north-south hallway back past the original stairwell (the one with the smoke in it) and made a right down the other hallway because I wanted to go with the crowd. There was a lot of traffic, so it took a little longer. After a couple of minutes, I went into the stairwell." Interview 1000009 (NIST 2004)

Table 6–8 shows the percentage of occupants that chose each stairwell for evacuation, as well as their primary reason for selecting a stairwell.

Table 6–8. Stairwell chosen for evacuation in WTC 1.

Stairwell Used for Evacuation	Percent
Stairwell A	17 %
Stairwell B	25 %
Stairwell C	19 %
Stairwell A or C	10 %
Don't know	17 %
Other, not applicable, used elevator	12 %
Reason for Choosing Stairwell	
Closest one	66 %
Followed others	17 %
Was told to use	12 %
Other exits blocked	6 %
Other, including don't know, used before, best conditions, not applicable	18 %

Note: Total does not add up to 100 percent because respondents may have given more than one reason for choosing their stairwell.
Source: NIST WTC Telephone Survey Data.

6.2 INITIAL OBSERVATIONS AND REACTIONS FROM WTC 2

Many of the occupants of WTC 2 quickly became aware that something significant had happened in WTC 1. Table 6–9 shows how survivors in WTC 2 became aware that something was wrong on September 11, 2001. Most occupants in WTC 2 heard, saw, or felt the event in WTC 1 (81 percent of the 363 respondents). Others were made aware after a short time by coworkers, telephone, or the news media coverage.

Table 6–9. How survivors in WTC 2 became aware that something was wrong on September 11, 2001.

Observation	Percent (n=363)
Heard something (boom, crash, explosion, blast, roar, rumbling)	51 %
Saw something (smoke or flames, plane, debris)	19 %
Warned by someone around me	13 %
Felt something (building moving, impact, shaking, swaying)	11 %
Other, including contacted via phone, lights flickered, news media	7 %

Source: NIST WTC Telephone Survey Data.

For occupants near windows which faced north and west throughout WTC 2, what they saw made it instantly clear that the damage to WTC 1 was severe:

> A survivor from a floor in the 90s in WTC 2: "I heard a large noise that sounded like muffled dynamite and looked out the window which faces the East - Brooklyn Bridge or into Queens to see if the noise was connected to anything outside. I saw glittering paper which made no sense and thought it was part of a promotional event, as if some one was throwing confetti out of a plane. I headed in the direction of the noise and saw a gigantic red fire ball at the cubicle diagonally from my desk and smelled gasoline, which I later learned was jet fuel. I went back to my office to call my [spouse] to inform [him/her] that I was OK, and that I was leaving the building." Interview 1000001 (NIST 2004)

> A survivor from a floor in the 90s in WTC 2: "I felt a wave of heat; very high temperature. I went to the window on my floor to find out what was happening. I saw the flames/fire outside through the window (in Building One, just about the same floor as mine) and I saw everybody going to the manager. The manager instructed that, 'people without special responsibilities should evacuate the building.'" Interview 1000632 (NIST 2004)

> A survivor from a floor in the teens of WTC 2: "I heard a loud roaring sound. I thought it was a window washer falling off its tracks. I walked into my office and looked out of the window. I saw people running in the plaza, away from building one. I saw paper and dust floating down from the sky. I saw the fireball coming from Building One. I thought it was an explosion of Windows on the World. However, I realized that there were still several floors above the explosion. Seeing the explosion and the panic in the plaza triggered my evacuation decision." Interview 1000922 (NIST 2004)

For some in WTC 2, however, the event was not as obvious.

> A survivor from the 100s in WTC 2: "A co-worker came to my office and said "There's a fire in the first building, we recommend that you leave." I grabbed my bag and packed up my belongings in order to leave the office. I grabbed my belongings for the reason in which I thought I was going to go to the gym & then would return to the office." Interview 1000767 (NIST 2004)

Although aware of the event, some occupants of WTC 2 were unsure of appropriate action to take since the event at this time was limited to WTC 1.

> A survivor from a floor in the 50s in WTC 2: "I heard a loud, horrendous explosion. I turned and faced the source of the noise. I saw debris flying through the air outside the window. I saw large objects flying by, then reams of paper - some that were burning - like confetti. I looked up at One World Trade Center and saw a gaping hole and smoke. I called my wife and parents to reassure them, to tell them I was okay. Co-workers and I discussed what our course of action should be. We stood kind of

> paralyzed, undecided as to what we should do. The Bloomberg headline said a plane had hit WTC 1. We didn't know if we should close the desk and leave; if we should assume the day was over. We were looking for guidance." Interview 1000557 (NIST 2004)

An occupant from WTC 2 at 8:49 a.m. also sought guidance from the Port Authority Police:

> PAPD: Port Authority Police...
> [Caller]: Yeah, this is [Caller], Securities Department from Morgan Stanley.
> PAPD: Uh-huh?
> [Caller]: Uh, what's the status right now as far as (overlap)
> PAPD: We're still checking. Everybody just get out of the building right now.
> [Caller]: All right. Have you guys announced an evacuation of Two?
> PAPD: We are trying to do that right now.
> [Caller]: All right, thank you.
> PAPD: All right? We are just advising everybody to get out of the building.
> [Caller]: All right, thank you, bye-bye. (PANYNJ 2001a)

At 8:53 a.m., an occupant from WTC 2 called the Port Authority Police Department seeking advice.

> Male: Hi, um, I'm on the 95th floor of Two World Trade Center.
> PAPD: Yeah, just come on down anyway, sir.
> Male: Does that mean walk down the stairs?
> PAPD: You'd, be advised, right now at this time.
> Male: Should we evacuate all of our people?
> PAPD: Yes. Yes. Yes. Everybody.
> Male: Okay, thank you. (PANYNJ 2001a)

6.2.1 Activities and Information – WTC 2

Occupants of WTC 2 engaged in a variety of activities prior to leaving their floors and beginning their evacuation, including exchange of information, gathering personal items, helping or searching for others, and continuing work activity. Table 6–10 summarizes activities reported in the telephone survey.

A survivor from a floor in the 60s of WTC 2 engaged in a variety of activities before beginning her evacuation.

> "I observed that the secretary was very upset. I went with [the secretary] and my manager to the lobby area to help care for [the secretary]. People were leaving the building and I didn't know when I'd be returning to the building, so I gathered my stuff and I went to the [rest] room. I saw flying things in the air and everyone was in a commotion to see what was going on, so I went back to the windows in the northern part of the building to find out what was going on. I heard the announcement . . . and I went back to my desk. [There] I made two phone calls to my mother and my [spouse] to reassure them that I was not affected and that I was safe. Two of my co-workers came into my office area and stated that they saw people jumping from Building 1 and that we should leave.

I gathered my stuff again and prepared to leave." Interview 1000877 (NIST 2004)

Table 6–10. Activities prior to evacuation reported in telephone surveys by survivors from WTC 2.

Activities before Evacuation	Percent Reporting the Activity (n=363)
Talked to others	75 %
Gathered personal items	57 %
Helped others	34 %
Searched for others	32 %
Talked on telephone	16 %
Moved between floors	8 %
Shut down computers	7 %
Continued working	6 %
Fought fire or smoke	1 %
Other activities	20 %

Note: Total does not add up to 100 percent because respondents may have observed more than one event indicative of damage.
Source: NIST WTC Telephone Survey Data.

Another occupant from a floor in the 100s in WTC 2, who had only worked in the WTC for a couple of months, took relatively few actions before beginning evacuation.

> "I heard a female co-worker who had a window cubicle shouting 'Get out!' I turned around from my inner office, grabbed my purse, and walked out my office door. I ran to another co-worker and asked her what was going on. [The co-worker] didn't know and continued walking. I decided to follow the co-worker to [figure out] where to go and to find out what was going on. I followed [the co-worker] to a stairwell and began to go down the stairs." Interview 1000897 (NIST 2004)

While 21 percent of the WTC 2 telephone survey respondents reported being given additional information about the event during this interim period without actively seeking the information, 18 percent reported actively seeking such information. Table 6–11 shows the types of information received and sought by WTC 2 occupants. The majority of occupants received or sought information about the event, with smaller number looking for information on whether to evacuate or remain in the office. For those who sought additional information, 39 percent were unable to find the information they were seeking.

Before WTC 2 was hit, information about the event affected occupants of WTC 2 in different ways. Even if an occupant heard that something happened to WTC 1, he or she may have still felt safe in the building. For instance, an occupant beginning evacuation from a floor in the 50s in WTC 2 took to the stairs early, only to return to his/her desk.

> "[After a few floors], I thought to myself, 'Why am I running?' I remembered that I was the fire warden for my floor." The occupant then took an elevator back to his/her original floor "to see if anyone else was there. I thought about the training and what I was supposed to do." After following the training procedure of calling security, the occupant "picked up the cell phone and called our [out-of-town] office to let them know that we were evacuating the building. I got ahold of them and they told me that a plane hit the building and to get out of there." Interview 1001666 (NIST 2004)

Table 6–11. Information received and sought prior to beginning evacuation in WTC 2.

Information	Information Given (n=77)	Information Sought (n=64)
Information about what had happened	65 %	92 %
Instructions to leave	26 %	17 %
Instructions to stay	35 %	13 %
Other, including information to remain calm or a choice to evacuate or stay.	10 %	5 %

Note: Total does not add up to 100 percent because respondents may have received or sought information from more than one source.
Source: NIST WTC Telephone Survey Data.

The occupant then proceeded to look around the floor for other occupants as well as make a phone call home to a family member. The occupant took an additional phone call when WTC 2 was hit, which prompted an immediate evacuation. Interview 1001666 (NIST 2004)

However, another fire warden from a floor in the 40s of WTC 2 used observations from and media information about WTC 1 to begin evacuation immediately.

> After seeing paper flying outside the window and smelling gas, "I ran across the hall and came across the boss and immediately informed [the boss] that we should leave. I saw the TV and saw what had happened on CNN and was informed that a plane hit the building, Tower 1. I went to the stairs." Interview 1000867 (NIST 2004)

Twenty-four percent of survivors felt they began their evacuation before the people around them. Not surprisingly, survivors perception of risk to themselves and to others increased as conditions in the buildings worsened. Table 6–12 shows a comparison of survivors' perception of risk at the point of airplane impact and in the interim period before they left their floor to begin their evacuation.

Table 6–12. Survivors' perception of risk upon airplane impact and prior to beginning their evacuation in WTC 2.

Perception of Risk	Others	Self
At awareness	52 %	29 %
Interim	67 %	42 %

Source: NIST WTC Telephone Survey Data.

Although occupants felt a heightened risk during this time, many occupants helped others before beginning their own evacuation. Seventeen percent of the WTC 2 survivors reported being helped by someone and 34 percent reported helping others. Table 6–13 summarizes the responses of the WTC 2 survivors.

Table 6–13. How survivors received help prior to beginning their evacuation from WTC 2.

Source of Help	Percent (n=60)
Co-worker	56 %
Manager/supervisor	15 %
Floor warden	12 %
Other/don't know	11 %
Police officer/firefighter	7 %
Stranger	5 %

Source: NIST WTC Telephone Survey Data.

Even though the environmental cues were more obvious in WTC 1 than they were in WTC 2, 86 percent of the survivors in WTC 2 began their evacuation before their building was hit. Occupants gave a variety of reasons for beginning their evacuation, which are summarized in Table 6–14.

Table 6–14. Single reason given by survivors to begin their evacuation from WTC 2.

Reason	Percent (n=363)
WTC 1 observations	26 %
Was told to evacuate	21 %
Afraid/felt in danger	17 %
Friends/co-workers evacuated	11 %
1993 experience (thought was a bomb)	6 %
WTC 2 building hit	6 %
Other, including jet fuel, information seek, evacuating the building just felt like the right thing to do	7 %

Source: NIST WTC Telephone Survey Data.

Eighty-six percent to 91 percent of the occupants in WTC 2 began their evacuation before WTC 2 was hit.[45] Approximately one in four WTC 2 occupants began evacuation because of their observations of WTC 1 from their office windows, while a similar percentage (21 percent) were told to evacuate.

[45] 86 percent was calculated by summing the number of people who reported starting their evacuation in less than 16 minutes, whereas 91 percent of people reported starting their evacuation prior to WTC 2 being attacked. These two questions were asked independently of one another during the telephone interviews. Note that while the discrepancy may be partially

An occupant from a floor in the 90s in WTC 2 left because of observations of WTC 1: "[I] saw a gigantic red fire ball at the cubicle diagonal from my desk and smelled gasoline which I later learned was jet fuel. I went back to my office to call my [spouse] to tell [the spouse] that I was OK and that I was leaving the building." Interview 1000001 (NIST 2004)

Another occupant from a floor in the 30s in WTC 2 was told by company management that the occupant "should begin a self-evacuation, instead of waiting for the building management to tell us to evacuate. I went back to my desk to prepare to leave. I decided to follow the group that was heading for the stairwell." Interview 1000049 (NIST 2004)

An occupant from a floor in the 90s in WTC 2 "heard a noise that prompted me to get up and look out the window. I saw people out of the corner of my eye, grabbing their bags and leaving. I turned and got my bag, with my pocketbook and things to leave my cubicle and follow the people [to the staircase]. I didn't have to investigate; I just left [because] I saw other people leaving." Interview 1000070 (NIST 2004)

6.2.2 Survivors Begin Their Evacuation

On average, survivors in WTC 2 began their evacuation within 6 min. However, as with WTC 1, the statistical distribution of time to initiate evacuation was skewed toward longer preparation periods. Overall, the most frequent response for survivors WTC 2 was one minute or less (although the middle floors had a mode of 5 min), and 50 percent of occupants had left their floor within 3 – 5 minutes (depending on zone), a few individuals took significantly longer (more than 30 minutes) to start evacuating, thus disproportionately affecting the average time to start evacuation. Table 6–15 summarizes the quartile, mode, and average times to start evacuation for survivors in WTC 2. Note that Table 6–15 separates the occupants into lower, middle, and upper floors, based upon the location of the mechanical floors which roughly divided the building into thirds. The evacuation delay results may be biased for the upper floors in WTC 2, however, as only occupants who acted quickly to move below the 78th floor before 9:02:59 a.m. could be interviewed. In other words, those who delayed for whatever reason, with few exceptions, did not survive. The impact of this potential bias was not quantified, but should be noted. A further discussion of evacuation initiation delay time and comparisons across regions of WTC 1 and WTC 2 is contained in Section 10.1.

Table 6–15. Elapsed time (min) to initiate evacuation for survivors from WTC 2.

Time for Survivors to Enter Stairwell[a]	25% Initiation	50% Initiation	75% Initiation	Mode of Responses	Average Time (min)
Lower floors (Basement – 42)	1	4	5	1	6.3
Middle floors (43-76)	2	5	10	5	7.1
Upper floors (77-110)	*1*[b]	*3*[b]	*5*[b]	*1*[b]	*4.2*[b]

a. Time to begin evacuation is the time interval from first awareness to the time the respondent left their floor to begin evacuation.
b. The evacuation delay results may contain significant bias for the upper floors in WTC 2, as discussed in the text.
Source: NIST WTC Telephone Survey Data.

attributable to the uncertainty in time recollection by the occupants, the uncertainty intervals for the two percentages overlap at the 95 percent confidence level (plus or minus 5 percentage points).

Occupants typically chose the stairwell closest to them at the time. Below the impact region, all three stairwells were in use throughout the evacuation. Table 6–16 shows the percentage of occupants each stairwell for evacuation and why that stairwell was chosen.

Table 6–16. Stairwell chosen for evacuation in WTC 2.

Stairwell Used for Evacuation	Percent
Stairwell A	18 %
Stairwell B	18 %
Stairwell C	14 %
Stairwell A or C	10 %
Don't know	14 %
Other, including closest to the office, not applicable, used elevator	27 %
Reason for Choosing Stairwell	
Closest one	63 %
Followed others	20 %
Was told to use	10 %
Other exits blocked	4 %
Other, including don't know, used before, best conditions, not applicable	13 %

Note: Total does not add up to 100 percent because respondents may have given more than one reason for choosing their stairwell.
Source: NIST WTC Telephone Survey Data.

An occupant in the 80s of WTC 2 notes that colleagues "ran down the stairs in the South part of the office to evacuate the building. The staircase that I chose was the only one that I was aware of." Interview 1000003 (NIST 2004)

Another occupant in the 60s moved to the stairwell that was already being used.

> "I saw a person opening the door to a stairwell to the left of the reception area, near the men's room. We walked really fast to enter the stairwell to make our way down." Interview 1000526 (NIST 2004)

An occupant in the 100s of WTC 2 was aware that he/she was assigned to use Stairwell B.

> "Due to the fire drill training, we were always told to use Stairwell B. I began going down Stairwell B in order to avoid elevators and to get out of the building safely." Interview 1000906 (NIST 2004)

6.2.3 Elevator Use in WTC 2

Elevator usage by occupants played a significant role in reducing the total loss of life in WTC 2 on September 11, 2001. Sixteen percent of the occupants of WTC 2 used elevators for at least part of their

egress from the building; another 2 percent used elevators in the basement levels. Occupants higher in the building were somewhat more likely to use elevators than occupants lower in the building: subdividing the 16 percent who used elevators, 4 percent were from floors below the 44th floor skylobby, 5 percent from floors 46 to 73, and 7 percent from floors above the upper skylobby on the 78th floor. Expressed another way, 12 percent of survivors in the lower floors reported that they used an elevator, while 15 percent of survivors from the middle floors reported using an elevator, and 33 percent of survivors from the upper floors reported that they used an elevator to evacuate WTC 2. Interpretation of the latter percentage may be biased, however, as occupants who used stairwells or delayed evacuation may have been disproportionately trapped above the impact region after 9:02:59 a.m. when compared to occupants who initially chose to evacuate using elevators over stairwells.

For some occupants, the physical challenge of navigating the stairwells was daunting enough to precipitate rapid use of the elevator system.

> An occupant from the 90s: "I think perhaps a survival instinct prompted my decision. I grabbed my briefcase and walked fast toward the elevator. I saw someone who needed to use crutches just as the elevator door was closing on the floor. We opened the door for him manually; the 'open door' button never functioned properly. I was taking a new medication and knew I should not walk down the stairs, so I took the elevator to the 78th floor and then took another elevator to the lobby." Interview 1000553 (NIST 2004)

For others, physical challenges presented themselves while in the stairwells. Even before WTC 2 was attacked, Port Authority communications (Channel 27) indicate that an occupant required assistance in the stairwells at 9:00 a.m. (PANYNJ 2001a) Others were able to switch egress modes from the stairwells to the elevators, although not without some difficulty, as one occupant from the 40s demonstrated:

> "My leg was hurting (it was a pre-existing condition) and I had bronchitis. The security guard wouldn't let me go down the express elevator, [so] this man agreed to come to my aid. [We] started our descent on the steps and continued to the 40th floor where he knew of another elevator bank. The man who was helping me announced to the people around us that he was helping somebody (me) and that we would stop at each landing and get out of their way so that they could pass us easily. We exited the staircase on the 40th floor and found and entered an elevator. Two women joined us because they thought we knew what we were doing. We rode the elevator from the 40th floor to the lobby. It made two stops before expressing to the lobby." Interview 1000048 (NIST 2004)

Some occupants were successful in using an elevator to get to the lobby, but were turned around by building security, presumably in an effort to minimize the impact WTC 2 occupants would have posed on the evacuation of WTC 1 occupants:

> "I was in an elevator going up to my floor when Building One was hit. When I got to my floor, we took an elevator back down to lobby, but the guard sent the elevator full of people back up to the floor." Focus Group #3 (NIST 2004)

6.2.4 Announcements in WTC 2

At 8:58 a.m., WTC Channel 15 (NYC EMS Direct Line) recorded a statement from an unknown source, stating, "I want to start a building evacuation, Building One and Building Two." (PANYNJ 2001a). The timing was proximate with announcements in WTC 2, made from the lobby fire command station, first contradicting the Channel 15 statement, then supporting it.

At 9:00 a.m., approximately three minutes before the second attack, the first building-wide public address system announcement was made to the occupants of WTC 2. Synthesizing the content of the announcement as reported by many interview respondents indicates that the general announcement went as follows:

> *There is a fire condition in WTC 1. WTC 2 is secure. Please return to your offices.*

While some occupants interpreted the announcement as less of an instruction and more of a suggestion that it was safe to return to their offices, others interpreted the announcement as an instruction to remain where they were or to return to their offices. No respondent reported that the announcement told them to evacuate.

Approximately two minutes later, at 9:02 a.m., one minute before WTC 2 was attacked, a follow-up announcement was made, contradicting the previous announcement. Recorded in the background of an answering machine recording an occupant calling home from a floor in the 90s and subsequently provided to the interviewer during the interview, the announcement indicated that it was now permissible to initiate an evacuation:

> "May I have your attention please. The situation is in Building 1. However, if conditions on your floor warrant, you may wish to start an orderly evacuation." Interview 3000001 (NIST 2004)

The 9:02 a.m. announcement was also noted by an occupant catalogued in the collection of published accounts (Fahy and Proulx 2003). A survivor in the 70s of WTC 2 was still on his or her floor when the 9:02 a.m. announcement was given over the public address system.

> "I stayed on the floor [to] wait until everyone was cleared out. Most of the people on my floor evacuated using the elevators, which they took to the skylobby. It seemed to me [that] I would be in more danger by going out. I heard the phone ringing off the hook and my boss and I were going from phone to phone answering them to reassure the families that everyone was ok." Interview 1000524 (NIST 2004).

It was then that United Airlines Flight 175 crashed into WTC 2.

Chapter 7
SEPTEMBER 11, 2001, 9:02:59 A.M.
FLIGHT 175 CRASHES INTO WTC 2

"On the phone, [the occupant from a floor in the 90s in WTC 2] kept describing the people jumping out of WTC 1. I could not hear any noise in the background; it was quiet with some slight conversations going on. When the second plane hit WTC 2, I then heard people screaming, "No, no. Oh my God, no!" Screaming and then silence. People's sounds disappeared. I could hear 'whopping noises.' The sounds were similar to wind blowing and I could hear the fire alarms going off. Then, nothing else. Just silence." Interview 300003 (NIST 2004)

At 9:02:59 a.m., a second hijacked Boeing 767-200ER, United Airlines Flight 175, struck WTC 2, damaging nine floors, from 78 to 84, as shown in Figure 7–1. By the time WTC 2 was hit, 21 percent of the eventual survivors had already exited WTC 1, and 41 percent of the survivors had already exited WTC 2. With the second attack, occupants in WTC 2, like those from WTC 1, began a full-scale building evacuation.

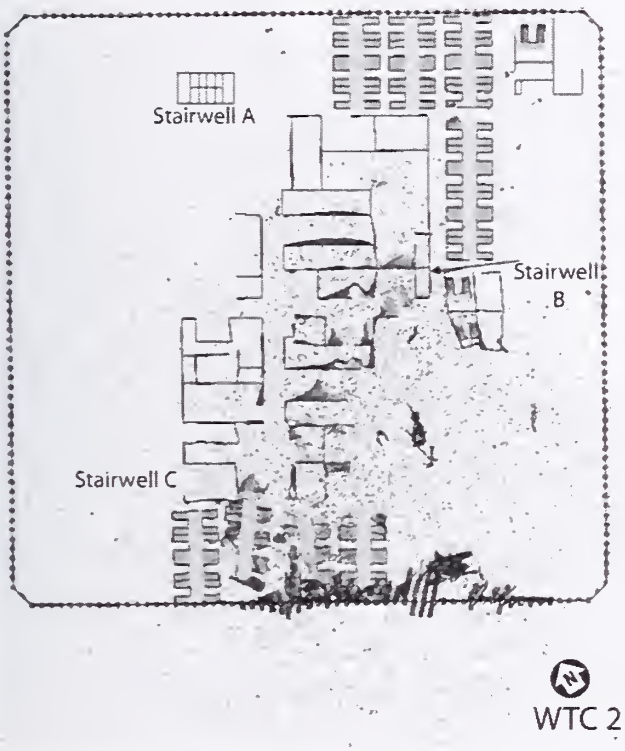

Figure 7–1. WTC 2 damage (computer simulated) at 0.62 s after impact with stairwells superimposed.

Alarm tones and public address announcements were overheard in 9-1-1 audio records from various floors from floors 82 to 105 after the impact, indicating that some power was available to most of the building.

As when WTC 1 was struck, a significant surge in 9-1-1 calls occurred when WTC 2 was struck, as bystanders and people watching television called to notify authorities that they witnessed the event. Many witnesses immediately reported that a deliberate terrorist attack was underway. Once again, the WTC 2 attack was described to operators in a variety of ways, from a large military aircraft to a bomb, to a commercial aircraft.[46]

[46] New York City 911 Emergency Call Recordings, 2001.

In WTC 1, many occupants only had passing knowledge of the second plane strike from cell phone or electronic communications received by other occupants within the stairwells during their egress:

> A survivor from the 50s in WTC 1: "Very soon after entering the stairwell, someone with a Blackberry communication device received word that a corporate jet had hit the building. Later the info was clarified as to what kind of plane it was. Later a report of the second plane hitting. We could feel the building shake a little, not that strong though." Interview 1000015 (NIST 2004)

Other occupants sensed that something happened, but had no idea what the source of the disturbance was.

> A survivor in the 60s in WTC 1: "I felt the air clear up due to a big gush of wind that cleared the smoke (this happened when Building 2 was hit by the plane)" Interview 1000100 (NIST 2004)

Occupants of WTC 1 with a view of the plaza observed large pieces of debris, some flaming, crashing down onto the central plaza. Evacuees from Stairwells A and C used escalators on the east side of the Mezzanine to proceed down to the lobby. The escalator access point, which often had a group of people waiting their turn to use the escalators, had a direct view of the debris, as shown in Figure 7–2.

Figure 7–2. East-looking view through WTC 1 lobby as debris from WTC 2 impact travels past lobby windows onto plaza.

As occupants exited the building onto the street or plaza level, many were unknowingly walking into danger, as debris rained down from the impact region in WTC 2. An occupant of WTC 2 from the 100s, having used an elevator to get to the lobby, exited WTC 2 at 9:03 a.m.:

> "I was guided by what I think were police officers who directed the crowd. I imagine they were guiding [us] away from where the debris was falling off Building 1. I walked out straight ahead towards the Liberty St. exit. Outside of Building 2, debris was falling down when the second plane hit. A piece of metal went into my arm. I went into shock due to severe blood loss [and] was assisted by NYPD, which [took] me to the hospital." Interview 1000563 (NIST 2004)

Due to the angle of the aircraft impact, large regions of survivability remained on some of the floors directly damaged by Flight 175. Figure 7–3 shows the individual and aggregated damage areas for floors 78 – 83 in WTC 2. See NIST NCSTAR 1-2 and NIST NCSTAR 1-6 for additional building damage information. From the time of impact and for the next 20 minutes, occupants called 9-1-1 from the impact region and above to request assistance.[47]

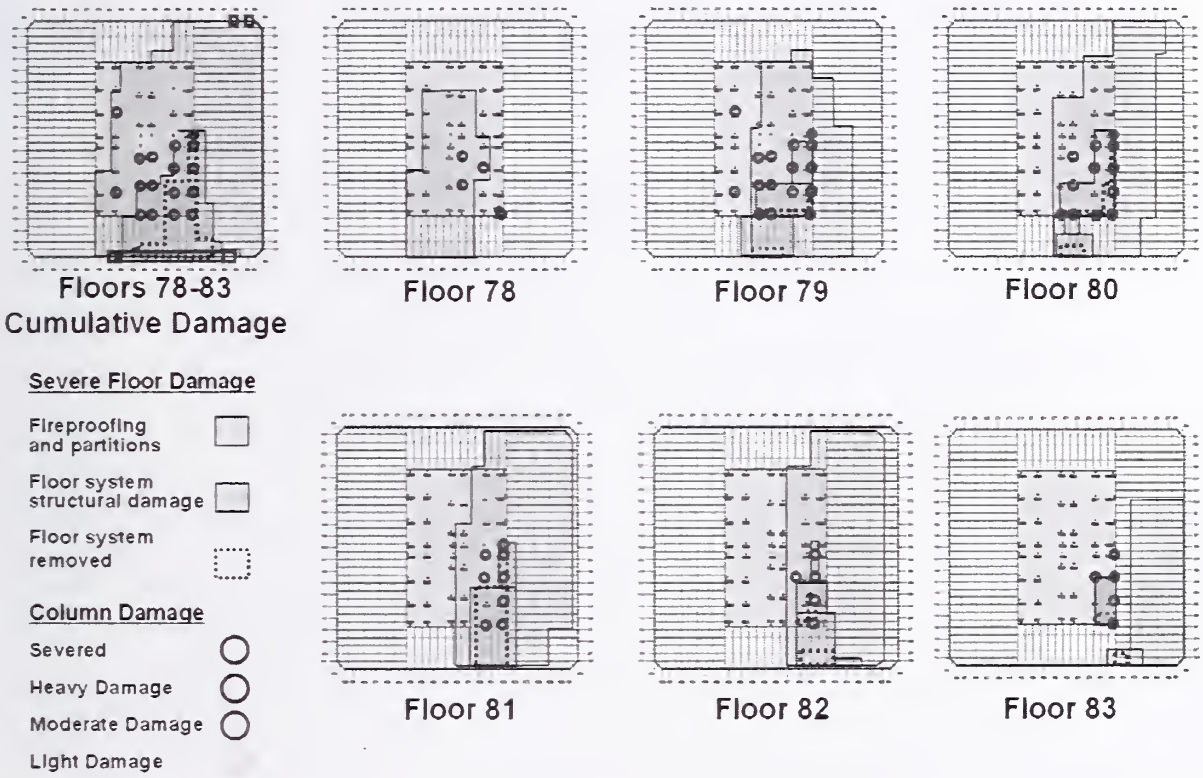

Figure 7–3. Calculated damage to floors 78 through 83 in WTC 2 (see NIST NCSTAR 1-6).

[47] New York City 911 Emergency Call Recordings. 2001.

Standing on a floor in the 70s in WTC 2, a survivor described the immediate aftermath of the aircraft impact:

> "I heard this deep thud and the ceilings and walls started to crumble. I grabbed my laptop, ran out of my office. I ran towards Stairwell A [because] this was the closest stairwell to my office. One of my colleagues opened the door to Stairwell A, but we didn't go in and turned around and went south. Stairwell A (the NW stairwell) was pitch black, filled with heavy black smoke. There was falling debris from the ceiling making the other two stairwells inaccessible [so we] ran back to Stairwell A [because] that was only stairwell we had access to. There was a lot of soot and dust in the air on the way back to Stairwell A. I had to cover my mouth and nose with my shirt to be able to breathe." Interview 1000625 (NIST 2004)

A survivor from a floor in the 100s in WTC 2 made it to the 78th floor skylobby just prior to the impact of flight 175:

> I was walking down the stairs, and got off at 78 (stairwell C). I encountered a lobby full of people (found some people from my group). The plane hit the building. I went flying and I landed on my right arm. When that happened my body turned over onto its left side and was sliding towards the elevators that were being repaired. I thought I would go down into the elevator shaft (since the door was slightly ajar and you could see fire coming up and I thought that it would be the end). I stopped and I called out to my friends and they called back with their location. I walked over to them climbing over dead bodies. We made an assessment of what had happened (my boss was dead, other man had broken legs and my coworker was missing). I got up and was walking in the direction of the plane. As I was walking there I came across people who were upset and I was climbing over bodies and I came to realize there was no communication desk." Interview 1000562 (NIST 2004)

The majority of WTC 2 occupants were not on their usual work floors when WTC 2 was attacked; most people had initiated or completed evacuation. Therefore, relatively few observations of damage to the floors in WTC 2 were reported. Figure 7–4 shows a summary of the reported damage to floors in WTC 2. The information to develop Figure 7–4 was compiled from every source available to the NIST investigation, including interviews, published accounts, transcripts of emergency communication channels, and emergency 9-1-1 calls. Note that the "?" denotes a floor where there was no information found to record the absence or presence of observations. Further, the absence of an observation on any floor does not positively exclude the presence of that condition as it may simply not have been reported.

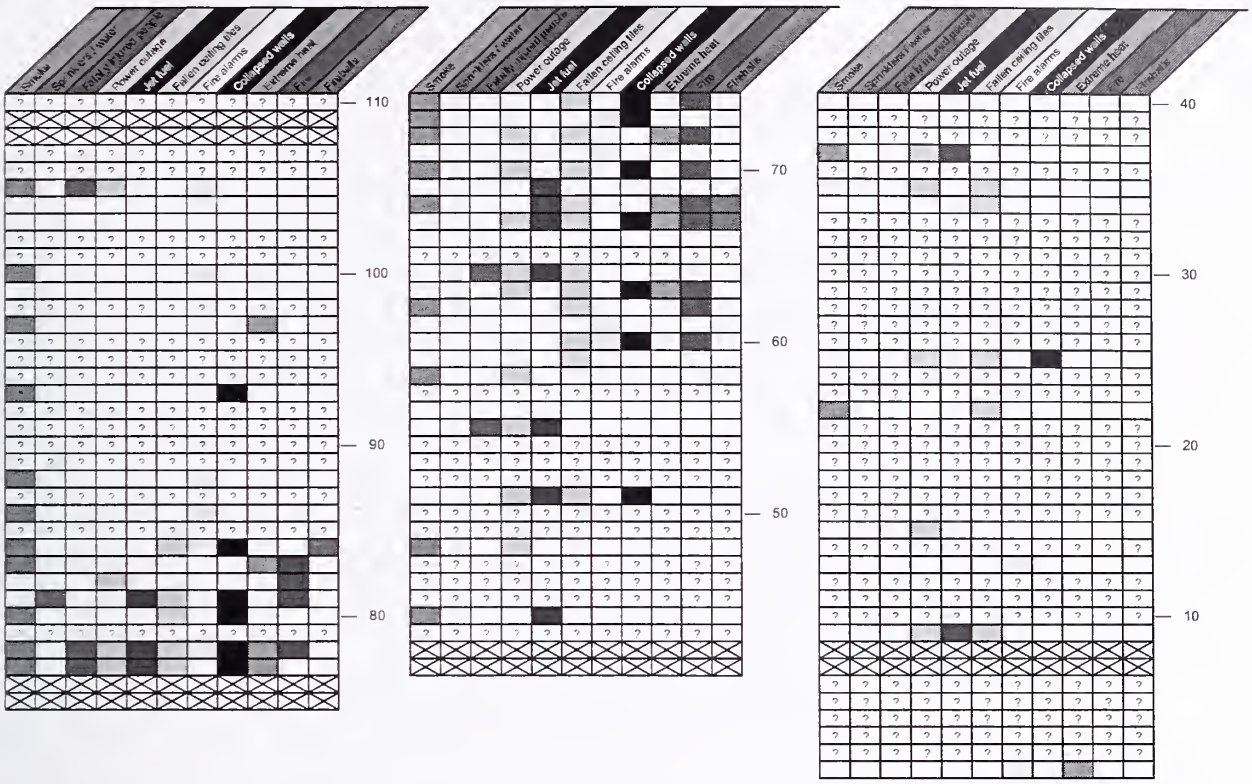

Figure 7–4. Observations of damage from tenant spaces in WTC 2.

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Chapter 8
SEPTEMBER 11, 2001, 9:02:59 A.M. – 9:58:59 A.M.
56 CRITICAL MINUTES

With the attack on World Trade Center (WTC) 2, the events in both WTC 1 and WTC 2 unfolded similarly, with survivors in both buildings trying to or continuing to evacuate the buildings. For those trapped above the plane strike in WTC 1, there was no way out. For those above the impact in WTC 2, a single intact stairwell provided a critical lifeline for at least 18 occupants fortunate enough to both find and use it.[48]

In both buildings, stairwells became not only a means of egress for occupants, but also the only significant route into the building for emergency responders. Interview analysis found that, prior to the collapse of WTC 2, the six stairwells in the two towers were relatively passable below the impact regions. While many occupants indicated that the conditions in the stairwells were better than the conditions experienced during the 1993 bombing, water, crowding, and the smell of jet fuel were cited as stairwell obstacles. All the while, building officials and emergency responders tried to cope with an incident of enormous scope and provide for as orderly an evacuation as possible.

By the time WTC 2 was hit, 91 percent of the survivors in WTC 1 and 87 percent in WTC 2 had begun their evacuation. Over 20 percent of the survivors in WTC 1 and more than 40 percent in WTC 2 had already left the buildings at the time of the second airplane strike. Table 8–1 summarizes when survivors began their evacuation and when they left their respective building.

Table 8–1. Estimated times for survivors leaving the building in WTC 1 and WTC 2.

	WTC 1 (n=440)		WTC 2 (n=363)	
	Begin Evacuation	Leave Building	Begin Evacuation	Leave Building
Before WTC 2 hit	91 %	21 %	87 %	41 %
After WTC 2 hit, but before WTC 2 collapse	7 %	67 %	13 %	58 %
After WTC 2 collapse	0 %	9 %	n.a.	n.a.

Key: n.a., not applicable; question not included in telephone survey.
Note: Numbers may not total to 100 percent. Some survivors were unsure when they began their evacuation and/or when they left the building.
Source: NIST WTC Telephone Survey Data.

[48] See Section 8.1 for further information.

8.1 SURVIVORS FROM AT OR ABOVE FLOOR 78 IN WTC 2, AFTER IMPACT

Above the floors directly damaged by Flight 175 in WTC 2, smoke traveled rapidly upwards. Within twelve minutes of WTC 2 impact, a smoke layer was descending on floor 105,[49] where multiple callers reported that between twelve and one hundred people were trapped.[50] Through face-to-face interviews and analysis of published accounts, however, NIST identified 18 individuals at or above the floors of impact in WTC 2 after 9:02:59 a.m. who escaped. The majority of these survivors were on the 78th floor, often referred to as the skylobby, waiting for an express elevator to the lobby or choosing a course of action just prior to the impact. Table 8–2 shows the location of the 18 individuals at 8:46:30 a.m., as well as 9:02:59 a.m. For the hundreds of occupants who remained above the skylobby when WTC 2 was hit, two of the buildings three stairwells had been destroyed by the impact. Only the staircase furthest away from the plane's impact was passable (Stairwell A) and even this stairwell was severely damaged in places. According to eyewitness accounts, there was drywall and other debris scattered over the stairs, water was running down the stairs, presumably from the sprinkler system (Murphy 2002), and smoke filled the stairwell (Adler 2002). In the region near the airplane impact, the stairwell walls had collapsed, and occupants had to crawl over or under the debris in order to descend below the 78th floor (Adler 2002). According to NIST interviews and several published accounts, the conditions in the stairwells then improved significantly below the 78th floor.

Table 8–2. Location of WTC 2 survivors at or above floors of impact at 9:03 a.m.

	Location at 8:46 a.m. (WTC 1 Impact)	Location at 9:03 a.m. (WTC 2 Impact)
1	Floor 103	Floor 78
2	Floor 103	Floor 78
3	Floor 102	Floor 78
4	Floor 101	Floor 78
5	Floor 100	Floor 82 (Stairs)
6	Floor 100	Floor 78 (Elevator)
7	Floor 100	Floor 78
8	Floor 97	Floor 78
9	Floor 97	Floor 78[a]
10	Floor 86	Floor 78
11	Floor 86	Floor 78
12	Floor 84	Floor 84
13	Floor 84	Floor 84[b]
14	Floor 84	Floor 84 (Elevator)
15	Floor 81	Floor 81
16	Floor 81	Floor 81
17	Floor 79	Floor 78
18	Floor 78	Floor 78

a. While this individual did evacuate the building, the occupant died several days later as a result of injuries sustained on September 11, 2001.

b. After impact, this occupant ascended to floor 91 for a period of time before finally making it below the impact zone.

Published accounts indicate at least two individuals were below the 78th floor in WTC 2 at the time of impact, but ascended in order to help injured or trapped colleagues (Fahy and Proulx 2003; Murphy 2002). Both individuals were building occupants, and one individual was reported to have had

[49] New York City 911 Emergency Call Recordings, 2001.

[50] New York City 911 Emergency Call Recordings, 2001.

an emergency response background. Neither individual successfully evacuated, although several survivors credited one of the individuals with saving their lives.

8.2 PROGRESS OF EVACUATION BELOW THE IMPACT REGION

For nearly all occupants below the floors of impact, the stairwells became the only means of egress from both towers. For some the egress went smoothly; for others it was far more difficult. Deteriorating conditions, coping with crowded stairwells, and the sheer physical effort required to descend dozens of flights of stairs presented a challenge for many occupants.

> A survivor who was on the 78th floor skylobby in WTC 2, then used the stairs down from there: "People were having general conversations, seemed calm, and walked at a steady pace, no sense of panic." Interview 1000825 (NIST 2004)

> A survivor who began on a floor in the 30s of WTC 1: "On about the 29th or 30th floor, as I was leaning against the wall letting an injured person pass, I felt the wall heave (which apparently was due to the second plane hitting the other tower). This was about 9:10. On the stairs, near the 28th floor, there was a pile of shoes that accumulated from people kicking them off. Some of the people around me were tripping on them and warning others to watch out for them. Our speed of descent was very slow. There were many firemen clogging the stairs and spilling out onto the 28th floor. They were resting and taking care of one who was sick--was having a heart attack. They were also carrying much equipment. All of this was happening at about 9:20 am." Interview 1000042 (NIST 2004)

Occupants also sought information from emergency responders by telephone. Advice from 9-1-1 operators was often to remain in place and await rescue.[51]

At 9:20 a.m., also in WTC 1, occupants frustrated by a lack of information reached out to authorities, including the Port Authority Police Desk.

> Male: Oh, hi. We're on the 39th floor here. We're not getting any messages. Can somebody tell us what's up?
> PAPD: Come on down. Just come on down, everybody just come on down. Get down the staircase. Don't take the elevator.
> Male: Is there smoke in the stair?
> PAPD: Check the stairway. We're not sure yet.
> Male: We've got…
> Male: We're in one, 39. We've got, uh…
> PAPD: You should be low enough to get down, because it happened up high.
> Male: All right.
> Male: Thank you. (PANYNJ 2001a)

[51] New York City 911 Emergency Call Recordings, 2001.

As the two communication records exemplify, calls to PAPD from occupants, in general, resulted in clearer, more specific information, such as where the emergency was. Further, some PAPD operators quickly recommended to occupants that they should leave the building, including WTC 2 prior to 9:02:59 a.m., although that was not universally true. FDNY dispatch and 9-1-1 operators generally advised occupants to shelter in place and await rescue, consistent with existing protocols, but not the preferable course of action on September 11, 2001.

These quotes and communication records point out several issues that occupants had to deal with during their evacuation. The environment in both buildings continued to worsen with time. In addition to the physical exertion required to descend the stairways, occupants were also faced with the need to allow injured persons to pass and firefighters and other emergency responders to travel up the stairs to respond to the fires. In addition, information from co-workers and managers at times conflicted with local and building-wide announcements about the event. These issues are discussed in more detail in Chapter 10.

Occupants of both buildings faced a number of challenges in their attempts to evacuate once the planes hit both buildings. As building authorities and emergency responders worked to organize the evacuation under rapidly changing conditions, many occupants were directed out of the stairwells during their evacuation. Thirty-four percent of respondents to the telephone survey reported leaving a stairwell at least once during their evacuation. While this occurred from floors 3 through 78 in WTC 1, the largest percentages were found in the skylobbies on floor 78 (7 percent of telephone interview respondents) and floor 44 (9 percent), as well as on floor 13 (9 percent). Similarly, in WTC 2, the skylobbies on 78 (13 percent of respondents) and 44 (25 percent) were mentioned most often. Some occupants left stairwells at the skylobbies or other locations to seek additional information or to find a better route out of the building. A survivor from a floor in the 90s in WTC 1 used multiple stairs during egress:

> "The staircase became crowded at about the 68th floor and I hoped to find a less crowded stairwell. I descended the stairs from 78 to about the 50s, before exiting the stairs again. The stairs at 68 became more crowded because they were evacuating some injured or handicapped people. The speed slowed to a halt--so we exited to find another staircase. I entered staircase B (in the 50s), and descended to the 40s before exiting the stairs again to find better conditions as I exited the building." Interview 1000052 (NIST 2004)

Occupants were also directed to leave the stairwells.

> A survivor who began on a floor in the 80s of WTC 1: "At the skylobby, we were re-directed by Port Authority personnel. We went to the stairwell on the far west side of the building. I saw many people trying to get into the little door of the stairwell. I went back to a different stairwell that was empty. The center stairwell was the one we ended up in that took us to the ground floor lobby." Interview 1000535 (NIST 2004)

In WTC 1, occupants with mobility impairments presented a particular challenge. A specific floor was designated by emergency responders to hold mobility-impaired occupants. The idea was to allow fully ambulatory occupants to egress, and then move the mobility-impaired occupants out once the stairwells had cleared somewhat. Numerous interview respondents indicated that a relatively small number of slow-moving occupants hindered the flow of faster moving occupants behind them in the stairwells. Reports of

the specific floor number in WTC 1 varied (12, 18, or 20), but several survivors recalled the existence of a holding floor.

> A wheelchair-user from a floor in the 60s was being assisted by four previously unknown occupants down the stairwells in WTC 1: "We saw a Port Authority person. He told us to go to the 18th floor [because] there was an evacuation station for people who needed special assistance. I was carried mostly by the two [occupants] who wandered onto my floor off the stairs [in the 60s], but then there were two more that also helped. They switched off. At about the 30th floor, we encountered firemen for the first time. We moved to the right." Focus Group #3 (NIST 2004)

NIST found no evidence that a similar holding floor for mobility-impaired occupants existed in WTC 2.

8.3 EVACUATION ROUTE THROUGH CONCOURSE

The first firefighter killed at the WTC was reportedly killed by a falling person (FDNY CD 12/15 2001); many evacuees and bystanders were injured by debris. Figure 8–1 shows the WTC plaza from the WTC 1 Mezzanine Level, perhaps viewed by thousands of occupants as they prepared to walk down the escalators to the Concourse Level. Throughout the evacuation, the lobbies and particularly the Concourse area served as the primary route to safety for survivors of the WTC attacks. Within approximately 10 minutes of the attack on WTC 1, building officials and police in WTC 1 and WTC 2 had established a procedure to route evacuees from both buildings through the Concourse (mall) rather than the plaza in order to prevent occupants from being injured by falling debris or people or being upset by shocking sights. As presented in Section 2.2.2, Stairwells A and C in both WTC 1 and WTC 2 discharged to the Mezzanine Level, while Stairwell B discharged to the Concourse Level, without the choice of exiting at the Mezzanine Level. Occupants who used Stairwell A or Stairwell C were directed to use an escalator (see Figure 8–2) in order to descend to

Figure 8–1. View from mezzanine level in WTC 1 looking east across WTC plaza, covered with debris. 'Sphere,' artwork by Fritz Koening, can be seen on the plaza.

the Concourse Level. Many face-to-face interviewees who used Stairwell A or C reported that the escalators were turned off in order to allow occupants to descend easily using both escalators.[52]

Once through the underground shopping mall, an occupant originating from a floor in the 30s in WTC 2, recalled being directed out of the Concourse at approximately 9:03: "The security guards were like a human chain telling us which direction to go. We followed the security guards direction, half walking, half running towards Borders [retail book store] to now go up from the Concourse to get out." Interview 1000842 (NIST 2004) Ascending the escalator from the shopping complex was captured in Figure 8–3.

Source: John Labriola 2001, edited by NIST.

Figure 8–2. Escalator from mezzanine to concourse level in WTC 1 on September 11, 2001.

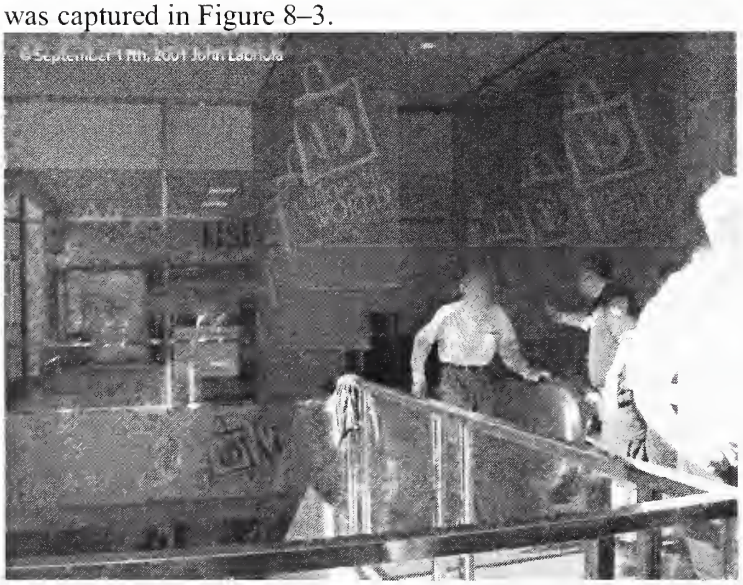

Figure 8–3. Evacuees leaving complex near WTC 5.

8.4 MORE ANNOUNCEMENTS IN WTC 2

At 9:12 a.m., the fire command station in WTC 2 (310-B) used WTC Ch. 22 to broadcast that the fire (floor) warden phones in WTC 2 were not working.[53] Further, WTC personnel indicated that they were making announcements that wardens should not wait for further instructions over the floor warden phones, as per protocol.

> 310-B to any units: Be advised that Building Two (inaudible) only (inaudible) warden phones. We can't pick up warden phones. We are just making straight announcements telling the people not to stay at the warden phones, because we can't pick them up. (PANYNJ 2001a)

NIST found no other evidence to confirm or refute that the fire command station issued such an announcement or that any occupant heard an announcement around that time.

[52] Analysis of Face-to-face Interviews (NIST 2004).

[53] For an explanation of the emergency communication channel assignments, see NIST NCSTAR 1-8.

At 9:20:10 a.m., approximately 17 minutes after the second tower was hit, the fire command station made another announcement over the public address system updating the occupants. The announcement was recorded in the background of multiple 9-1-1 calls.[54] To the best of NIST's ability to understand, the announcement went as follows:

> "This is the fire command station in building number two. We are in the lobby. We are holding down here. The condition seems to have subsided somewhat. There are people in the building. There are some people have left. If you wish to leave, you can now use the Concourse. You may walk to the Concourse on this side, avoiding building number one. The condition seems to have subsided in the lobby of building two. Some people have left the building. We are here monitoring the situation. The fire department are concentrating their efforts on building number one. People are leaving the building... (unintelligible)...Number 2...(unintelligible)..."

The announcement lasted between 60 and 70 seconds, with the unintelligible portion comprising approximately the final 10 seconds. The content of the 9:20 a.m. WTC 2 public address system announcement varied significantly from the pre-planned building evacuation announcement covered in Section 2.2.4. However, no survivors from whom NIST collected first-person accounts reported hearing the 9:20 a.m. announcement in WTC 2. This may be attributable to the fact that approximately 75 percent of all WTC 2 survivors had left WTC 2 by 9:20. Two occupants, trapped above the floors of impact, however, did respond to the 9:20 a.m. announcement, according to 9-1-1 records.[55]

8.5 CONDITIONS CONTINUE TO DETERIORATE IN BOTH TOWERS

As the events unfolded, conditions within both towers continued to worsen. At or above the floors where the airplanes hit the buildings, occupants had to cope with fire, smoke, and severe building damage. In the time period after 9:15 a.m., only four calls to 9-1-1 came directly from inside WTC 1. As Figure 8–4 shows however, many occupants above the impact region in WTC 1 remained alive at 9:58:59 a.m., shortly before WTC 2 collapsed.

Below the impact floors, occupants worked to evacuate the building while emergency responders made efforts to organize the evacuation and gain access to damaged floors to rescue injured or trapped occupants. At 9:35 a.m., a WTC Official in the security command center (SCC) reported to S2 trouble unlocking the remotely-controlled doors:

> Male B: S2 to SCC.
> Female A: Go, S2.
> Male B: How are you doing up there?
> Female A: We've got a lot of smoke.
> Male B: We're on 16 now.
> Female A: That's a copy. We can't use software right now to try to release the doors.
> (PANYNJ 2001a)

[54] New York City 911 Emergency Call Recordings, 2001.
[55] New York City 911 Emergency Call Recordings, 2001.

Figure 8–4. Occupants seeking fresh air on floors 103 – 105 on north face of WTC 1 at 9:58:12 a.m.

The reported difficulty unlocking doors did not appear to directly prevent any occupants from successfully evacuating, however, as every fourth door was always open and the doors were only locked

from the stairwell side. Further, only the mechanical rooms and roof were controlled electronically. The communication does reflect the condition of the SCC and the difficulty the conditions posed for operations originating from that office. Numerous other reports of fire, smoke, and damage were noted in transcripts of PANYNJ radio calls regarding the 22nd floor command center (PANYNJ 2001a).

In WTC 1, more than half of the survivors noticed smoke in their immediate area during their evacuation compared to only 10 percent who reported noticing smoke at first awareness. At least 25 percent reported collapsed walls during their evacuation compared to only 6 percent who noticed collapsed walls at first awareness.

Table 8–3 shows a summary of observations by the survivors during their evacuation from WTC 1 and WTC 2. All percentages increased from earlier observations on their floors prior to beginning evacuation.

Table 8–3. Observations of conditions during evacuation of WTC 1 and WTC 2.

Observation	WTC 1 (n=440)	WTC 2 (n=363)
Smoke	57 %	21 %
Sprinklers/water	55 %	3 %
Fatally injured people	41 %	8 %
Power outage/flickering lights	37 %	29 %
Jet fuel	31 %	21 %
Fallen ceiling tiles	29 %	12 %
Fire alarms	26 %	19 %
Collapsed walls	25 %	11 %
Extreme heat	10 %	7 %
Fire	9 %	4 %
Fireballs	3 %	2 %

Conditions in the stairwell were challenging, as well.

> A survivor from a floor in the 20s in WTC 1: "The stairwell was lit the entire way down. There was a grayish color smoke which smelled like fuel. The more we reached the lower floors the stronger the smell became. On the 6th floor, the sprinklers were on, which slowed us down because we wanted to be cautious and not slip or fall." Interview 1000044 (NIST 2004)

> An occupant who survived the horror of aircraft impact on the 78th floor in WTC 2:"... not much debris, but there was a pipe that we had to go under, hanging wire, and water in the stairs; no counter flow after we were hit, stairs were well lit, but 78 had no lighting. On 40-well lit, a lot of doors were locked, stranger smell that I can't identify. As we were walking down, we saw fireman coming up and told us to get to 40 and that someone would take us in an elevator down to the lobby." Interview 1000562 (NIST 2004) Firefighters and security personnel would escort

the occupant down in the elevator, out through the Concourse area to a waiting ambulance.

At 9:36 a.m., an occupant's telephone call to a New York City 9-1-1 telephone operator indicated that a floor in the 90s of WTC 2 had collapsed. According to NYPD records, information from this call concerning the floor collapse appears to have been conveyed inaccurately by the 9-1-1 call taker and the NYPD radio dispatcher.[56] The NYPD dispatcher transmitted the message at 9:41 a.m. and 9:51 a.m. Independent of the exact floor number, the call content demonstrated deteriorating conditions above the impact region in WTC 2.

Table 8–4 shows the total evacuation time for survivors in WTC 2. Total evacuation time was measured from first awareness to exiting the building and included time spent on the starting floor. While the total evacuation time increased from the lower floors to the middle floors, as would be expected when the proportion of occupants who used elevators was roughly constant, the total evacuation time for survivors from the upper floors decreased due to the increased proportion (approximately twice as many, see Section 6.2.3) of survivors who used elevators to evacuate.

Table 8–4. Total evacuation time (min) for survivors from WTC 2.

Total Evacuation Time[a] (min)	25% Evacuated	50% Evacuated	75% Evacuated	Average Time (min)
Lower floors (Basement – 42)	10	15	21	17.6
Middle floors (43-76)	23	35	45	34.9
Upper floors (77-110)	*11*	*23*	*36*	*25.5*
All survivors in WTC 2	13	21	35	25.0

a. Total evacuation time was measured from first awareness to exiting the building.
Note: Italics indicate the presence of a bias in the underlying data. Interpretation and comparison of data should consider this bias.
Source: NIST WTC telephone survey data.

Minutes prior to the collapse of WTC 2, an NYPD Emergency Services Unit (ESU) officer radioed from a floor in the 20s to the outside that he was having trouble ascending the stairwell due to the large number of occupants descending (Interview 24 NYPD [NIST 2004]). While the origin of the occupants remains unknown, only 11 occupants who started evacuating below the impact region were known not to have survived.

WTC 2 collapsed at 9:58:59 a.m., leaving over 600 occupants and over 100 emergency responders dead.

[56] NYPD, McKinsey and Company, NYPD call-routing and message dispatch, "106th floor is collapsing." Draft summary report July 23, 2002.

Chapter 9
SEPTEMBER 11, 2001, 9:58:59 A.M. – 10:28:22 A.M.
COLLAPSE

> *"The lights were off and it was dark. You could barely see your hand in front of your face and there was a lot of dust. We just stood there and waited for the dust to settle. The emergency lights went on and we tried resuming going back down those stairs for half a flight. People [were coming back] up the stairs and said, 'the egress is gone.'" Interview 1000594 (NIST 2004)*

At 9:58:59 a.m., many of the 624 to 680 occupants and building personnel who had fought for survival in WTC 2 for the 56 minutes after the building was attacked were killed by the building collapse. Over 100 emergency responders, unaware of impending collapse, were killed as well (NIST NCSTAR 1-8 2005). The effect of the collapse of WTC 2 was felt not only at the remaining WTC buildings, but all over Lower Manhattan, as shown in Figure 9–1.

9.1 EVACUATING WTC 1

Although occupants in WTC 1 may or may not have comprehended the magnitude of the collapse at the time, it still had a significant impact on the evacuation of remaining survivors in WTC 1. As described below, survivors related to NIST, during face-to-face interviews, the nature of the cloud of debris and smoke which filled the Concourse and lower portions of the stairwells in WTC 1, making evacuation that much more difficult for those still left in the building.

> A survivor in the shopping Concourse who began on a floor in the 50s of WTC 1: "We heard (what we later learned) the South Tower/WTC 2 collapsing. We stopped near the joining of the Gap store and the PATH escalators. The sound, at first, was muted and rumbling. It was a scraping sound that grew louder over the course of 15-30 seconds. It seemed like it was going to envelop us. The sound became very loud (like steel on steel). Very quickly after WTC 2 collapsed, the lights went out in the Concourse. Immediately, people screamed and panicked, and started to run in the dark. This was the one time I thought I really was going to die. I saw what I thought then was a wall of water, like a tsunami, coming at me (I thought I was going to drown). What it turned out to be was the cloud of debris and smoke. It irritated my eyes and filled my mouth, and made me cough and spit. I called to the others (my staff/ co-workers) who were with me. I felt the need to be in touch with them, since we had come all this way together." Interview 1000106 (NIST 2004)

Figure 9–1. Collapse of WTC 2, viewed from north.

A survivor still in a stairwell who began on a floor in the 30s of WTC 1: "We descended on this stair until we got to the landing between floors 7 and 8. The lights now went out in the stairwell. I entered the 8th floor and went down a corridor to a different staircase (I'm not sure which stair, but I believe it was the original one I started out on). People on the stairs below me (who apparently got a big rush of air) said the floors below us were collapsing. They turned around and started running back up and they were covered with a gray, powdery substance, such as ash or smoke -- so we believed them. Then when the fireman opened the door on the 8th floor and said to come onto the 8th floor, I readily followed

> his instructions. Some didn't follow those instructions and continued back upstairs. I descended the stairs from the 8th floor to what I believe was the 5th floor. It was still dark in the stairwell. I changed stairwells for the last time and descended to the Mezzanine Level. I exited the stairs onto the Mezzanine, headed toward the west wall, then the north wall, and finally exited through the emergency exit door." Interview 1000042 (NIST 2004)
>
> A survivor from a floor in the 50s in WTC 1: "We thought it was a bomb at this point, however, it was Building Two collapsing. Vibrations stopped; the noise was incredible; the lights went out and the sprinklers came on. We walked a lot more quickly. We were getting out of the building. It was hard to walk down the stairs because of the water coming from above from the sprinkler system. There was a large amount of smoke and I couldn't see the person in front of me. I guess we smelled jet fuel. I could barely see the emergency strips on the stairs, but you could see them [because] the lights had gone out." Interview 1000054 (NIST 2004)
>
> A survivor in the stairwell who began in the teens of WTC 1: "We heard a gigantic explosion. We reached the second floor landing and we stopped. It was pitch black; black and tremendous suffocating smoke and dust. We stopped there and choked and froze. The lights went back on after it seemed like forever. We were told by the firemen and rescue workers that we had to go up to the fourth floor, that the exit was blocked." Interview 1000093 (NIST 2004)

Whereas occupants were primarily using the cover of the underground Concourse Level to escape the WTC site prior to the collapse of WTC 2, the debris created by the collapse forced the remaining occupants to proceed outdoors after they left the stairwells. For occupants leaving Stairwells A and C on the Mezzanine Level, the exit on the North wall, West corner provided access to the Tobin Plaza, from which many proceeded North between WTC 5 and WTC 6; others used the bridge to cross West St to the World Financial Center. Occupants leaving Stairwell B on the Concourse Level moved West to the West Street VIP entrance, where many continued to the World Financial Center, while others traveled North along West St.

The evacuation rate slowed dramatically in WTC 1 after WTC 2 collapsed. Clearly, the obstacles presented by the dust, debris, and loss of power from the WTC 2 collapse contributed to slowing the occupants travel speed. By 9:58:59 a.m., 88 percent of survivors (over 6,500 people) in WTC 1 had exited the building. Approximately 900 additional occupants and many emergency responders would exit WTC 1 over the remaining 29 minutes before the building collapsed.

Many mobility-impaired occupants remained in a holding pattern on a lower floor in WTC 1 during this time. An FDNY Battalion Chief wrote "Last Man Down," in which he described walking onto the 12th floor of WTC 1:

> "The office was filled with people. Forty, fifty, sixty of them. I didn't stop to count, but there they were, in all shapes and sizes, of all ages. All of them were sitting quietly, patiently, apparently waiting for instruction

> or assistance...There had to have been a couple dozen nonambulatory office workers in that room, easy, and each one of them had one or two or sometimes three friends helping them. Friends, coworkers, people they'd just met in the stairs, for all I knew." (Picciotto 2002)

Some occupants, however, had resisted the idea of delaying their evacuation by stopping on the designated holding floor. A mobility-impaired occupant who started in the 60s had been instructed while in the stairwell by a Port Authority employee to report to the 18th floor, when the time came to choose between resting or continuing to evacuate:

> "At about the 22nd floor, Building Two collapsed. The building swayed. There was smoke and dust from the collapse of building two. I had my mask on, but it was hard to breathe and see. We picked up speed. Firemen started coming back down (from above us). We had to leave the staircase because we couldn't see or breathe. We went into a tenant's space for 5 or 10 minutes. Then, we couldn't find another staircase so we went back to the one we had just left. When we got to the 18th floor, we just kept going. The [helpers] asked me if I wanted to stay, I said "No." I had been with them this far. After that we were moving more quickly." [NIST Focus Group #3, 2004]

Battalion Chief Picciotto described ordering the evacuation of the holding floor in "Last Man Down," largely steering them down Stairwell B, at approximately 10:21 a.m. The fate of those mobility-impaired occupants remains unclear. The conditions inside the stairwells, after WTC 2 collapsed, became more difficult.

> A survivor who began on a floor in the 60s of WTC 1: "The staircase was a mess; it was filled with concrete, pieces of metal sticking out of the stairs. There were also holes on the walls. There was also lots of water on the floor." Interview 1000543 (NIST 2004)

While building personnel attempted to provide building-wide announcements in WTC 1, only two survivors remembered hearing announcements in WTC 1, both near the time of the collapse of WTC 2. Specific details of the announcements were not recalled beyond "some sort of an emergency" or "to evacuate the building" Interviews 1000594 and 1000068 (NIST 2004), respectively.

After WTC 2 collapsed, there was a sharp decrease in 9-1-1 call volume from inside WTC 1. Above the floors of impact in WTC 1, NIST found only one call to 9-1-1 from a person inside WTC 1.[57]

Table 9–1 shows the total evacuation time for survivors in WTC 1 overall, as well as by zone (low, middle, and high). Comparisons of upper zone data with data from lower and middle zones should be carefully considered, however, as the upper zone represents a smaller region (fewer number of floors and less vertical height represented) than the lower and middle zones. This was due to the fact that no individuals survived from above the 91st floor.

[57] Several calls were received from persons relaying information on behalf of occupants in WTC 1, but the time delay in relaying the information from the occupant to the 9-1-1 dispatcher was unknown.

The quartile and mean times for survivors to exit the building shown in Table 9–1 increased as the survivors were higher in the building. The first quartile of surviving evacuees from the middle zone were exiting WTC 1 at approximately the same time as the last quartile of surviving evacuees from the lower zone (approximately 40 minutes). Similarly, the first quartile of surviving evacuees from the upper zone were exiting WTC 1 at approximately the same time as the last quartile of surviving evacuees from the middle zone (approximately 60 minutes). Note, however, that the number of floors (and vertical range) of the upper zone was significantly less that the lower and middle zones. Therefore, comparisons of the upper zone times to the lower and middle zone times should factor the zone differential into the analysis.

Table 9–1. Total evacuation time (min) for survivors from WTC 1.

Total Evacuation Time[a] (min)	25% Evacuated	50% Evacuated	75% Evacuated	Average Time (min)
Lower floors (Basement – 42)	16	27	42	29.0
Middle floors (43-76)	41	51	65	54.7
Upper floors (77-91)	*60*	*71*	*77*	*70.3*
All survivors in WTC 1	25	41	58	41.9

a. Total evacuation time was measured from first awareness to exiting the building.
Note: Italics indicate the presence of a bias in the underlying data. Interpretation and comparison of data should consider this bias.
Source: NIST WTC Telephone Survey Data.

9.2 LOCATION OF VICTIMS AND SURVIVORS WITHIN THE BUILDING

Once the two towers collapsed, the fate of 2,749 building occupants and emergency responders was sealed. Table 9–2 shows the likely location at time of impact of all decedents identified by the City of New York as decedents. It also categorizes types of emergency responders who perished in the disaster. To identify locations, NIST relied on more than 300 face-to-face interviews and 800 telephone surveys, various Web sites maintained by survivors or victims' families and colleagues, several media outlets' reports, and a badge list maintained by The Port Authority of New York and New Jersey. Table 9–2 below shows the results of that analysis.

The following sources were used to identify the likely location of decedents at time of impact:

- September11Victims.com: This site is dedicated to the victims of September 11, 2001 tragedy.
- Portraits: 9/11/01: Published by the New York Times in 2003, this book includes short interviews with family members of many decedents.
- CNN.com In-Depth Special (http://www.cnn.com/SPECIALS/2001/memorial/index.html): Tribute site for people to write remembrances of decedents.
- Badge List maintained by Port Authority of New York and New Jersey: Includes name, employer, building, and floor for all occupants with badge-access to WTC 1 or WTC 2.
- Numerous memorial sites maintained by companies which lost employees: Includes names and remembrances of decedents. Examples include the Port Authority, Fire and Police Departments, Marsh & McLennan Companies, EuroBrokers, Fiduciary Trust, and others.

- Newsday.com: Includes short stories written about specific decedents.

Table 9–2. World Trade Center decedent location.

Likely Location at Time of Impact[a]	
World Trade Center 1 Occupants	**1,462**
At or Above Impact	1,355
Below Impact	107
World Trade Center 2 Occupants	**630**
At or Above Impact	619
Below Impact	11
Confirmed Below Impact in WTC 1 or WTC 2	**30**
Unknown Location Inside WTC 1 or WTC 2	**24**
Emergency responders (Total)	**421**
FDNY	343
NYPD	23
PAPD	37
Hospital/Paramedic	7
Federal	2
Volunteer Responders	9
Bystander / Nearby Building Occupant	**18**
American Flight 11	**87**
United Flight 175	**60**
No Information	**17**
Total	**2,749**

a. Where possible, NIST has used eyewitness accounts to place individuals. Where no specific accounts existed, NIST used employer and floor information to place individuals.

The analysis shown in Table 9–2 generally assumes that individuals were on their work floor when his or her building was hit. The employer and floor number from the badge list were generally used to designate location. An employee of Cantor Fitzgerald, for example, would be assumed to have died above the floors of impact in WTC 1, unless evidence to the contrary was discovered. Often, information about the activities or location of an individual was available from on of the sources described above, and that information was used to categorize individuals. Additional information was necessary to place the 18 individuals documented as bystanders or occupants of nearby buildings. There were 30 individuals who were known to have been below the floors of impact, but whose locations could not be determined. Typically, these individuals were security guards and fire safety staff who were observed performing activities below the floors of impact after the airplanes struck. There were 24 individuals who were likely in the building, but for whom no clarifying information could be uncovered indicating whether they were above or below floors of impact. Their occupations largely included maintenance, janitor, delivery, safety, or security functions.

Emergency responders were defined to be people who arrived at the site from another location; thus, security staff and Port Authority staff (different from PA Police Officers) were not defined as emergency responders.

No information could be determined for 17 individuals.

Estimated Number of Decedents below the Impact Regions

The total number of people who perished below the floors of impact was:

- 421 emergency responders;
- 107 individuals in WTC 1;
- 11 individuals in WTC 2;
- 30 individuals below the impact region in either WTC 1 or WTC 2;
- Up to 24 individuals were somewhere in the building, but may have been above or below impact regions in either building;
- Up to 17 individuals for whom no information could be located;

Thus, there were between 569 – 610 individuals who were below the impact floors but did not successfully evacuate. Assuming that all of these individuals were alive at the time that his or her respective building collapsed, approximately 20 percent of those lost on September 11, may have been alive just prior to collapse of the WTC towers.

Estimated Number of Decedents at or above the Impact Region

The total number of individuals who perished who were at or above the floors of impact was:

- 1,355 individuals above the 91st floor in WTC 1 at 8:46:30 a.m.;
- 619 individuals above the 77th floor in WTC 2 at 9:02:59 a.m.;
- Up to 24 individuals were somewhere in the building, but may have been above or below impact regions in either building;
- Up to 17 individuals for whom no information could be located.

Therefore, between 1,974 and 2,005 individuals were at or above the area of impact in WTC 1 and WTC 2 who did not successfully evacuate.

Number of Aircraft Passengers and Crew

The total number of airplane passengers and crew was 147, not including the 10 hijackers.[58] American Flight 11 had 87 passengers and crew, while United Flight 175 had 60 passengers and crew.

Other Victims

Additionally there were 18 people (non-WTC occupants) killed outside the building by debris and jet fuel.

9.2.1 Fatalities in Elevators

USA Today (Cauchon 2001) reported that as many as 200 occupants died in elevators in WTC 1 and WTC 2. While the NIST Investigation did not produce an estimate of the number of occupants who died in elevators, NIST did collect information related to elevators and elevator use that may be of benefit in identifying ways of reducing building occupant risk in general.

The elevators were the normal means of vertical travel in WTC 1 and WTC 2, and it was likely that many, if not most, of the elevators were in use at the time of aircraft impact. There were two ways in which lives of building occupants may have been lost on September 11, 2001 while using the elevators. First, if the cables above the elevator car were severed, the car would have dropped to the bottom of the shaft (which may not be the basement, depending upon the specific elevator shaft). The safety brakes on the elevator car would have been activated by the governor cable when the governor wheel exceeded the design speed. Since the governor was mounted at the top of the hoistway, should the governor cable have been cut along with the hoist cables, the safety brake would not have been activated, and the car would have fallen. If the car dropped far enough, occupants of the car may not have survived the impact. For shorter falls, the occupants may have survived but remained trapped in the elevator car at the bottom of the shaft.

Each of the towers had 99 elevators serving the above ground floors, but most were locals that ran to only a few floors within one of the three elevator zones. For an elevator's cables to be cut and result in dropping the car to the bottom of the shaft, the cables would need to have been in the aircraft impact debris path, floors 93 through 98 in WTC 1 or floors 78 through 83 in WTC 2. Inspection of the elevator riser diagram and architectural floor plans for WTC 1 shows that the following elevators met these criteria: cars 81 through 86 (Bank B) and 87 through 92 (Bank C), local cars in Zone III; car 50, the freight elevator, and car 6, the Zone III shuttle. Inspection of the elevator riser diagram and architectural floor plans for WTC 2 shows that the following elevators met these criteria: cars 75 through 80 (Bank A), local cars in Zone III; car 50, the freight elevator, and car 6, the Zone III shuttle. Bank A local cars could have fallen a maximum of 6 floors, Bank B cars 16 floors, and Bank C cars 23 floors. Cars 6 and 50 could have fallen all the way to the pit in the sub-basement level, and car 50 in WTC 1 was reported to have done so.[59] Elevator 81 (Bank B) in WTC 1 was apparently not destroyed, as WTC Radio Channel 25 (maintenance and electric) recorded a request for assistance in getting the elevator doors opened and noted smoke and water infiltration into the elevator cab (PANYNJ 2004).

[58] New York City has not issued death certificates for any hijackers.

[59] NIST Interview, 2004.

In WTC 1, several occupants seeking to use elevators reported that the elevators were not working immediately after impact, despite signage and a training program specifically prohibiting elevator usage in the event of an emergency (see Chapter 4). In WTC 2, analysis of telephone interviews determined that approximately 18 percent of the survivors evacuated primarily using an elevator on September 11, 2001. As with WTC 1, however, it remains unknown how many occupants were using the elevators at the time of impact. In addition to the occupants who may have been killed while using elevators, several occupants reported numerous fatalities in the 78th floor skylobby, where occupants were either waiting for elevators or deciding whether to return to their offices when the second aircraft struck WTC 2. Interview 1000562 (NIST 2004) and (NIST NCSTAR 1-7A).

Not all occupants in an elevator when their building was hit were killed. Some occupants were able to force doors open, a few 'chopped' their way through walls (one group famously used a window washing squeegee [Dimarco 2004]), while others were able to climb out of elevators which had fallen to the bottom of their respective shafts (Cauchon 2001). Figure 9–2 shows occupants leaving an elevator in the lobby of WTC 1 shortly prior to the collapse of WTC 2 on September 11, 2001. The reason the occupants were able to escape after an extended entrapment remains unclear, although Port Authority officials speculate that the elevator may have reverted to slow-speed (50 fpm [0.25 m/s]) run, designed to prevent entrapment.[60]

Figure 9–2. Occupants leaving a previously stuck elevator on September 11, 2001, in the lobby of WTC 1.

Second, a number of safety systems and sensors in the WTC 1 and WTC 2 elevator systems were arranged to stop the elevator in place if they detected an abnormal condition (PA Interview 5 [NIST 2004]). Stopping an elevator car generally represents the safest course of action. The intercom in

[60] Public Comments to Draft NCSTAR 1-7. PANYNJ. 2005.

every car would then be used to notify authorities of an entrapment. Given the size of WTC 1 and WTC 2 and the number of elevators, however, occupant extraction could have taken hours, as evidenced by the five or more hour waits for some occupants during the 1993 bombing (Isner and Klem 2003).

In fires and earthquakes, however, entrapment may result in additional risks to the occupants before they can be removed. In an earthquake, for example, one of the greatest safety risks comes from the possibility that the counterweight jumps its track and is struck by the car. Seismic switches on elevators in seismic zones are designed to detect the earthquake and cause the system to stop, move the car in the direction away from the counterweight to the next floor, stop and open the landing doors (ASME 17.1, Safety Code for Elevators and Escalators).

Another issue regarding entrapment was the presence of "door restrictors." A door restrictor is a safety device required on all new elevators (ASME 17.1, Safety Code for Elevators and Escalators) and retrofit on existing elevators (ASME 17.3, Safety Code for Existing Elevators) upon any elevator equipment upgrade. Door restrictors mechanically prevent the elevator car doors from being forced open unless the car floor is within 36 in. of a landing floor. They were installed in some, but not all, elevators in WTC 1 and WTC 2 (Interview PA 5 2005). Door restrictors address the significant safety hazard that occurs when occupants force the car doors open and fall through the gap down the shaft or get crushed between the car and shaft wall. Door restrictors have all but eliminated these accidents, but have made self-escape by entrapped occupants nearly impossible. Elimination of door restrictors alone would lead to increased deaths from accidents. A better solution would address both issues.

Occupants could have become entrapped at any level if the aircraft impact caused the elevators to stop. If the car floor were not within 36 in. (plus or minus 18 in.) of a landing floor, the door restrictor would have prevented the car doors from being forced open from the inside, and the roof hatch could only be opened from the top of the car, making for self-escape extremely difficult. If the car was within 36 in. of a landing, occupants could have forced the car doors open and then would have had to force open the landing doors or break through the elevator shaft wall, which was 3 in. to 3.5 in. of gypsum material.

Chapter 10
DISCUSSION AND ANALYSIS

The attacks on the World Trade Center (WTC) towers were unprecedented events, extending well beyond the typical engineering design scenarios of buildings on many levels. Occupants were forced to deal with a full evacuation of severely damaged buildings, although training and procedures called only for partial evacuation near affected floors. Emergency responders and building management were forced to deal with multiple extreme disasters in the buildings while facilitating the safe egress of some occupants and attempting the rescue of others.

This chapter provides a discussion of the factors that affected the overall safety of occupants on September 11, 2001. It is divided into several topics areas: a summary of total evacuation time for WTC 1 and WTC 2 from the telephone survey data, an analysis of the important factors that affected total evacuation time and its components of delay prior to evacuation, and evacuation time in stairwells or elevators. The face-to-face interview data also highlight additional factors that were not included in the telephone survey, but were prevalent in sufficient number in the face-to-face data to warrant discussion.

10.1 OVERVIEW OF TOTAL EVACUATION TIME

Figure 10–1 shows the percentage of survivors who reported evacuating over five minute intervals, measured from the moment that WTC 1 was attacked. There was a large peak in evacuation in WTC 2 during the time period immediately surrounding the WTC 2 impact. Recall that WTC 2 was attacked at 9:02:59 a.m., approximately 16 minutes after WTC 1 was attacked. Nearly one in six WTC 2 survivors reported having left the building in a single five minute period between 9:01 a.m. and 9:06 a.m. Over 40 percent of the surviving occupants left WTC 2 prior to 9:02:59 a.m. That so many evacuated was largely due to occupant use of the elevators in WTC 2 to evacuate prior to impact. Approximately one in six surviving occupants (18 percent) initially used an elevator to evacuate WTC 2. After WTC 2, was hit, only one elevator was operating, under the control of the Fire Department of New York.

Integrating the rates shown in Figure 10–1 yields Figure 10–2, which represents the fraction of survivors remaining in the building at different points in time. Within the bounds of statistical uncertainty, the same number of occupants successfully evacuated WTC 1 as WTC 2. Therefore, comparing the slopes of the curves is appropriate. For a period of approximately 30 minutes in WTC 2 (when only stairwells were available) the slope (or evacuation rate) roughly matches the slope of the first 70+ minutes of evacuation in WTC 1. This result would be expected given the similarity of the egress systems in the two buildings. The evacuation rate declines significantly for the final twenty minutes before each building collapses, due to the fact that over 90 percent of the occupants who were physically able to affect their own escape had done so by that time. Further, the collapse of WTC 2 slowed the evacuation rate in WTC 1 due to the significant quantity of dust and debris complicating the path from the bottom few stair landings out and away from WTC 1.

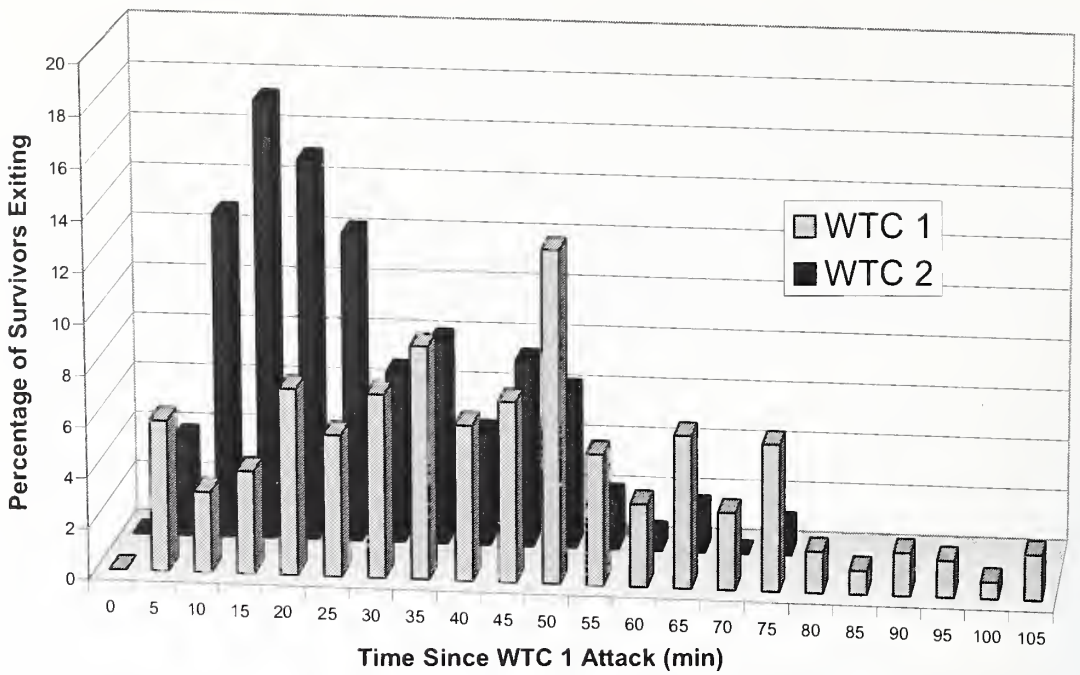

Figure 10–1. Reported evacuation time for survivors of WTC 1 and WTC 2.

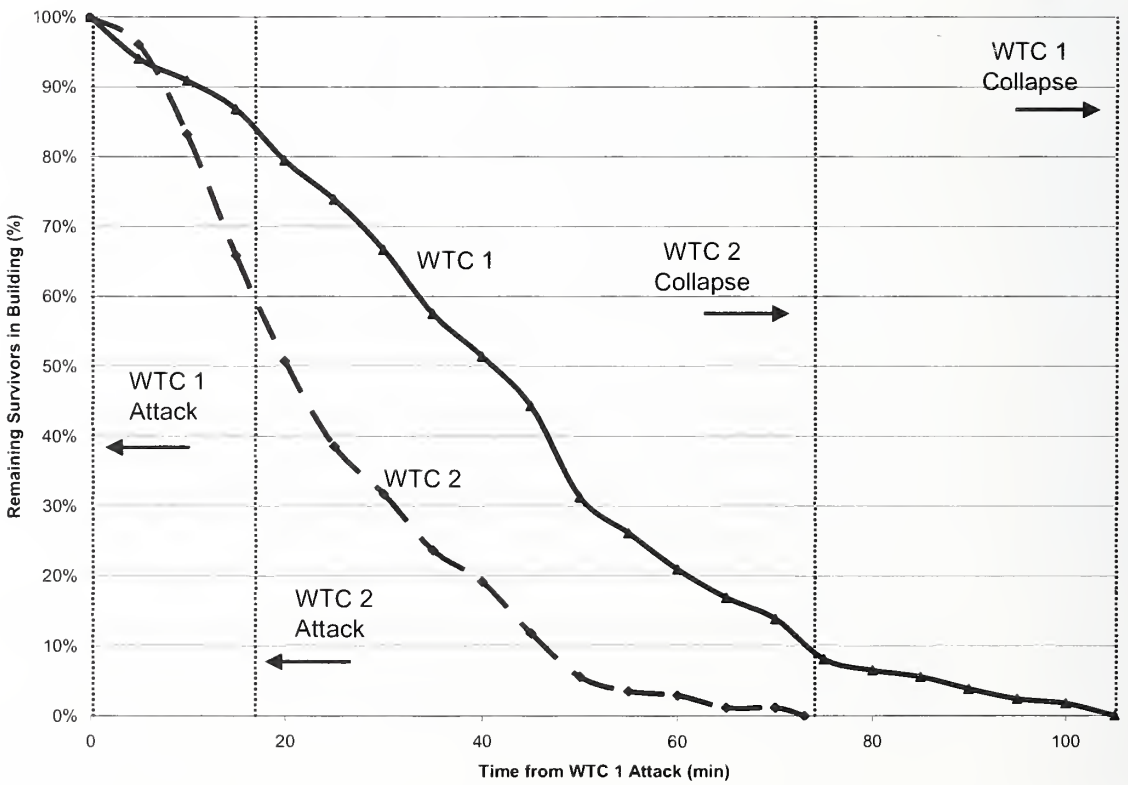

Figure 10–2. Percentage of survivors remaining in the building for WTC 1 and WTC 2.

While Figure 10–2 provides a comparison of overall rate of evacuation in WTC 1 and WTC 2, analyses should also take into account that many occupants did not survive the attacks. Recasting Figure 10–2 to include those who did not survive results in Figure 10–3, which shows the percentage of the total building population remaining in the building over time. Note that the slopes of the two curves in Figure 10–3 are not directly comparable since twice as many occupants perished in WTC 1 as did in WTC 2. When occupants who were unable to evacuate are included, more than 80 percent of the occupants of WTC 1 survived and more than 90 percent of the occupants in WTC 2 survived.

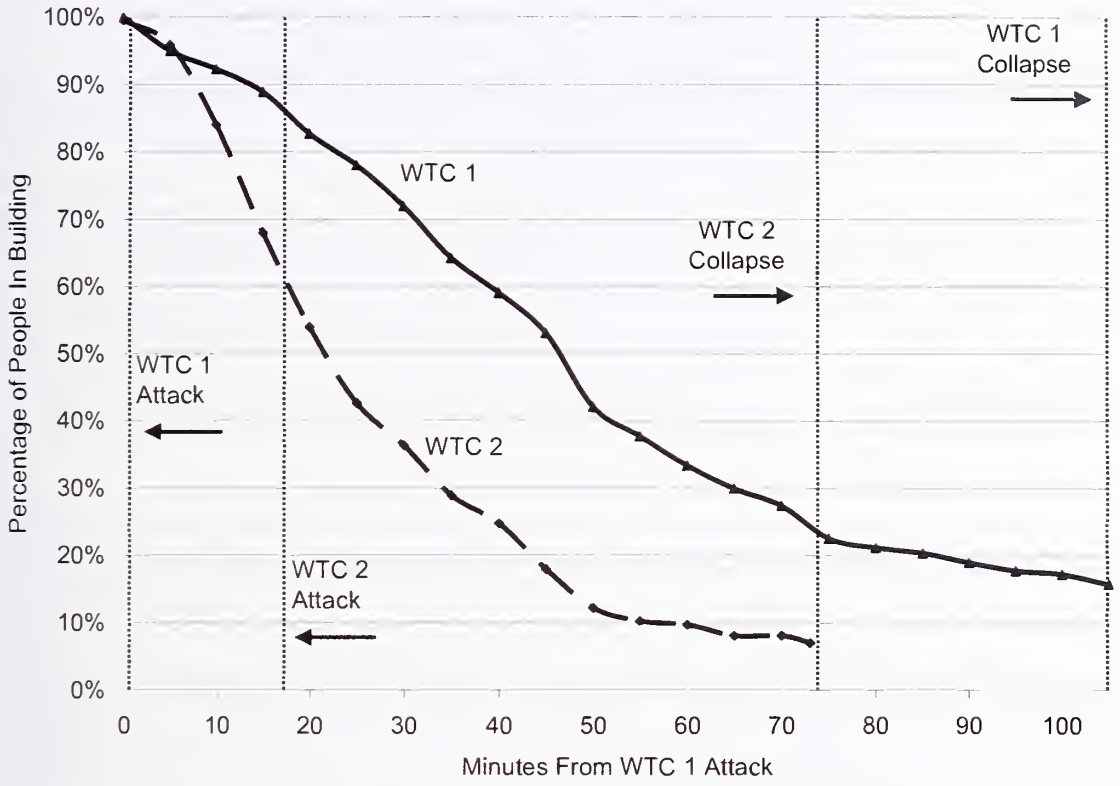

Figure 10–3. Percentage of occupants remaining in the building for WTC 1 and WTC 2.

Evacuation time, however, has two primary components which contribute to the total time: the delay time prior to initiating evacuation and the time spent evacuating. Each of these components is discussed in detail below, incorporating multiple regression analysis (causal modeling) of each.

10.1.1 Evacuation Initiation Delay Time in WTC 1 and WTC 2

Evacuation initiation delay time for occupants of WTC 1 and WTC 2 was discussed briefly in Chapter 6. The analysis presented here explores whether statistically significant differences existed in the overall evacuation initiation times for occupants in WTC 1 and WTC 2 and among occupants located in the high (floor 77 and higher), middle (floors 43 to 76), and lower (basement to floor 42) regions of each tower (for a total of six zones). Histograms of reported delay time based upon the telephone interview results showed that each zone had a peak evacuation initiation around minute one or minute two, generally decreasing over time (or skewed right). The general distribution for all six zones was a non-normal distribution, approximated by a gamma or log-normal distribution.

Note that due to the probable bias in the data from the high region in WTC 2 discussed previously (occupants who delayed a length of time sufficient to prevent them from descending below the 78th floor prior to 9:02:59 a.m. were disproportionately removed from the telephone interview sample), no further consideration was given to comparing the results from the high zone in WTC 2 for the variable of evacuation initiation delay time.

In order to calculate whether differences between the remaining five zones were statistically significant, the reported data were transformed to better approximate a normal distribution and, thus, satisfy statistical testing assumptions. A Box-Cox Power analysis revealed that all five zones had peak normal probability plot correlation coefficients (of approximately 0.95 or better) when the Box-Cox power was approximately zero, which indicated a log transformation. After the reported evacuation initiation delay times were log-transformed, an analysis of variance (ANOVA) F-statistic was calculated for WTC 1 and WTC 2.

Meaningful differences in the evacuation initiation delay time in WTC 1 among the three zones (high, middle, low) existed, significant at the 1 percent level. Exploring the interzonal differences in WTC 1, there was not a statistically significant difference in the reported evacuation initiation delay times between the low zone and the middle zone. The high zone, however, exhibited significantly longer reported delay times, when compared to both the low zone and the middle zone. The increased delay time in the high zone compared to the low zone was significant at the 2 percent level, while the increased delay time in the high zone compared to the middle zone was significant at the 1 percent level.

For WTC 2, evacuation initiation delay time was higher in the middle zone, compared to the lower zone; the difference was significant at the 5 percent level. Again, comparing the high zone to either the middle or lower zone in WTC 2 was not considered due to the bias in the upper zone delay time results.

In conclusion, the general trend in WTC 1 and WTC 2 was for evacuation initiation delay to increase with building height, although there may be other explanations for this phenomenon. In WTC 1, occupants reported being trapped by debris and building damage, observing fire and smoke, and assisting injured colleagues at a higher rate near the impact region (high) than was reported in the lower or middle zones. The causal modeling in Section 10.2.1 explores this further through the independent variables 'floor' and 'environmental cues.'

Additionally, comparison of evacuation initiation delay times across buildings should be made with considerable caution. In WTC 1, the cues which led occupants to decide to evacuate were substantively different from those that likely influenced the decision process in WTC 2. In WTC 1, the building had been attacked, stairwells were the only available route out of the building, and there were generally no instructions delivered over the public address system. WTC 2 had not yet been attacked for over 90 percent of the occupants by the time they initiated evacuation. Thus, for less than 10 percent of the WTC 2 survivors, their building had been attacked by the time they chose to initiate evacuation. In addition, in WTC 2 stairwells and elevators were available for most people to choose to use, and multiple (though conflicting) public address system announcements were made. Note, however, that many occupants in WTC 2 did not hear any announcements, because they had evacuated the building prior to the time the announcements were delivered.

10.1.2 Time and Average Travel Speed in the Stairwells, WTC 1

The reported time spent in the stairwells for occupants of floor 10 to floor 91 in WTC 1, based on the NIST telephone interviews (n=368), yielded a mean normalized travel speed of 1.3 floors per minute. Normalized travel speed is defined as the total time from entering the stairwell until leaving the building, divided by the number of floor that had to be descended. According to Figure 10–4, 25 percent of the occupants traveled faster than 1.5 floors per minute, while 25 percent of the occupants traveled more slowly than 0.9 floors per minute. The median normalized travel speed was 1.2 floors per minute. The data include all interruptions to the evacuation process, including crowding, transfer floors, smoke, water, switching stairwells, and resting. Assuming an average floor height of 3.7 m (12 ft), the distance along the stair slope (including landings) would have been approximately 10 m (33 ft), yielding a movement speed of approximately 0.2 m/s (0.65 ft/s) for the median occupant in WTC 1 while in the stairwells, which is on the slow end of published scientific literature values for stairwell travel speeds. This is understandable given the frequency of crowding and the significant number of obstacles to evacuation reported by many occupants.

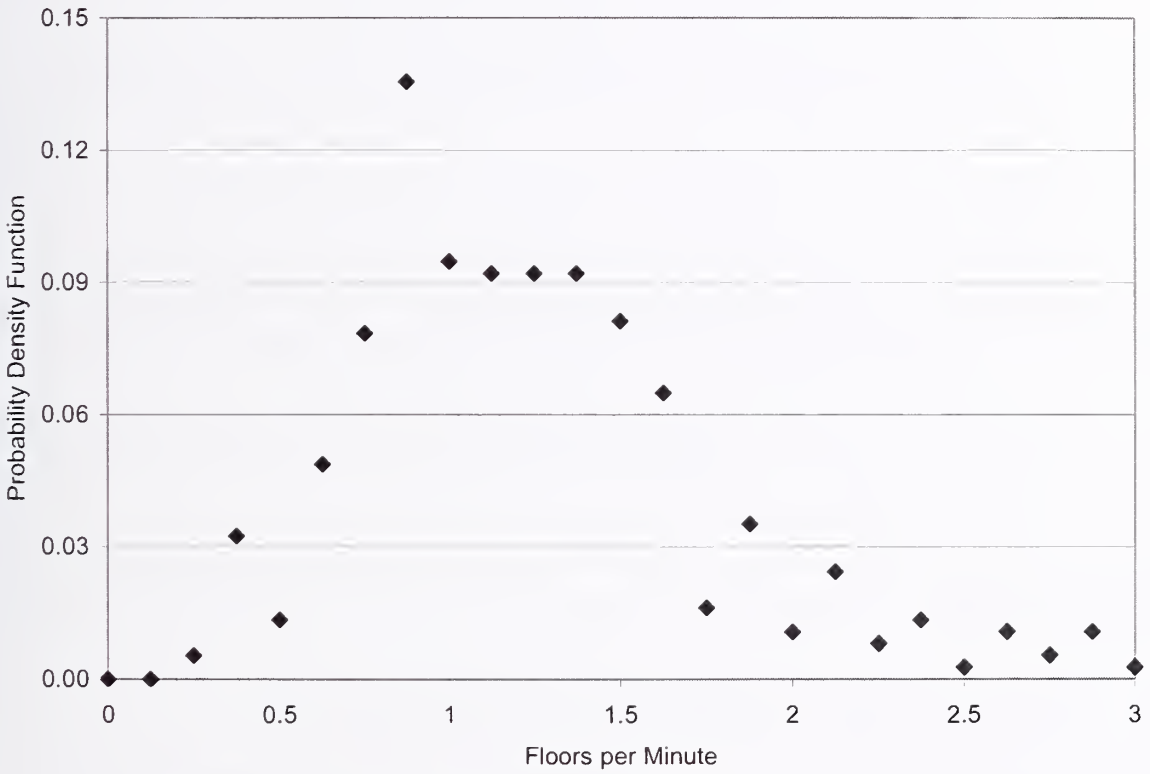

Figure 10–4. Stairwell travel speed in WTC 1 for all stairwells.

A "rule-of-thumb" for calculating evacuation flow rate is to assume that a standard size door at the bottom of the stairwell is capable of discharging approximately one person per second. (Fruin 1987)[61] By that logic, with three stairwells, the WTC system would have been capable of moving approximately

[61] Fruin reported values of 40 – 60 persons per minute for free-swinging doors. The "rule-of-thumb" captures the high end of the reported range.

three people per second from the occupied floors to the Mezzanine or Concourse. In WTC 1, where elevators were not operational for the duration of the evacuation, approximately 7,500 occupants used the stairwells over a 100 minute period, yielding a flow rate of 1.3 people per second from the occupied floors. Even discounting the final 27 minutes (after the collapse of WTC 2 when the flow rate dropped significantly), the flow rate was 1.5 people per second (or 0.5 people per second per door), or about one-half the "rule-of-thumb" flow rate. This is consistent with the previous observation that the stairwell movement speed was slower than the published literature values would have predicted and that the slower rate was to be expected given the number of obstacles to egress encountered by the evacuees and the total travel distance required.

Impact of Wider Stairwell on Stairwell Evacuation Times

An analysis of the hypothesis that wider stairwells correspond to faster overall evacuation times is most reliable when all other variables are held constant. In WTC 1 on September 11, 2001, however, many other variables were not constant, complicating the comparison: (a) Stairwell B (56 in. wide) exited into the Concourse, while Stairwells A and C (44 in.) exited to the Mezzanine where occupants typically traversed to the escalator in order to descend to the Concourse; (b) Stairwell B only required one (relatively short) horizontal transfer section, while Stairwells A and C required multiple, sometimes lengthy (over 100 ft) horizontal transfers; (c) emergency response personnel preferentially used Stairwell B to climb to higher floors; and (d) an occupant may have switched stairwells during egress, introducing a significant uncertainty. Therefore, these four factors confound any conclusions regarding stairwell width which may be drawn from the evacuation of the WTC towers. Respondents reported three pieces of information critical to this analysis: number of floors they had to climb down, the total time spent in the stairwells, and which stairwell they used. Each reported time was normalized (divided by) with the number of floors descended in order to compare results independently of starting location. The normalized times were then averaged over all occupants who reported using that stairwell.

In Stairwell B in WTC 1, the average occupant spent approximately 61 ± 38 s per floor, while in Stairwells A and C (the narrower stairwells), the average occupant spent 53 ± 34 s per floor. The uncertainty was calculated using a standard deviation. Unfortunately, the large uncertainty, relative to the average, in the data collected from WTC 1, combined with the confounding conditions referred to previously, do not allow differentiation of stairwell movement speeds for the wider stairwell compared to the narrower stairwells.

10.2 FACTORS INFLUENCING TOTAL EVACUATION TIME

The telephone interview results permit rigorous statistical analysis of factors that played a role in the evacuation process. In order to understand what factors influenced the overall evacuation time of the average occupant in WTC 1 or WTC 2, two primary dependent variables were predicted: how long an individual delayed initiating his or her evacuation, where initiation is defined as entering a stairwell or elevator with the intention of exiting the building; and how long an individual spent traversing the stairwells. Elevator travel time was not considered in this analysis. The sum of these two elements of the evacuation process is the total evacuation time. Multivariate regression modeling was utilized to establish factors which contributed to overall evacuation time. A more detailed discussion of both causal models, including methods, equations, and significance testing can be found in Appendix C: Causal Modeling. This chapter will only present the basic model structure and findings.

10.2.1 Predicting Evacuation Delay in World Trade Center

The analysis of evacuation behavior consisted of two stages. The first stage, which focused on how long it took for people to begin evacuating, determined the factors (variables) and social processes (the major paths of causal links between variables) that influenced people delaying the initiation of their evacuation out of WTC 1 and WTC 2 on September 11, 2001. Evacuation delay was defined as the number of minutes that passed from when a person first became aware that something was wrong until he or she began evacuating.

Model Description

The model used to predict important factors in evacuation delay in the towers used variables that preliminary analyses suggested were salient and closely followed general evacuation theory from the social and fire sciences The model is diagrammatically illustrated in Figure 10–5. It can be described as follows: (1) delay in evacuation initiation (X_7, the dependent variable in this analysis) was a direct consequence of environmental cues (X_1), the floor on which occupants were located (X_2), obtaining information without seeking it (X_3), perceived risk (X_4), seeking additional information (X_5), and taking pre-evacuation actions (X_6); (2) taking pre-evacuation actions was a direct consequence of environmental cues, floor, obtaining information without seeking it, perceived risk, and seeking additional information; (3) seeking additional information was a direct consequence of environmental cues, floor, obtaining information that was not sought, and perceived risk; and, finally, (4) perceived risk was a direct consequence of environmental cues, floor, and obtaining information without seeking it. This model was parsimonious (in other words, the model was constructed of no more or fewer components than were necessary), and consistent with theory that stems from research on existing evacuation and risk communication research, and the model accurately reflected findings from preliminary analyses on the many variables that could have impacted evacuation delay. With this conceptual model, a set of equations for evacuation delay, pre-evacuation actions, seeking additional information, and perceived risk that were assumed to depend linearly on the factors above were solved simultaneously to obtain the relative importance of each factor in predicting the four primary variables.

Results

The estimated parameters of the models for WTC 1 and WTC 2 revealed that the model had a very high degree of success in explaining evacuation initiation delay, pre-evacuation actions, seeking information, and perceived risk in both towers. The adjusted explained variance (R^2) for perceived risk was 55 and 60 percent in WTC 1 and WTC 2, respectively. The adjusted explained variance for sought information was 25 percent in both towers. Respectively, the adjusted R^2 for pre-evacuation actions was 68 and 69 percent for WTC 1 and WTC 2. Finally, the adjusted R^2 for delay in evacuation for WTC 1 and WTC 2 was, respectively, 49 and 56 percent. These were extraordinarily high levels of adjusted explained variance to observe in a study of human evacuation. The combined amount of variance in the dependent variable, evacuation thereby, established the strong predictive power of the models for both towers. All of the equations in the model for WTC 1 and WTC 2 were statistically significant at the 0.001 level or higher, indicating a high degree of confidence in the explanatory power of the model.

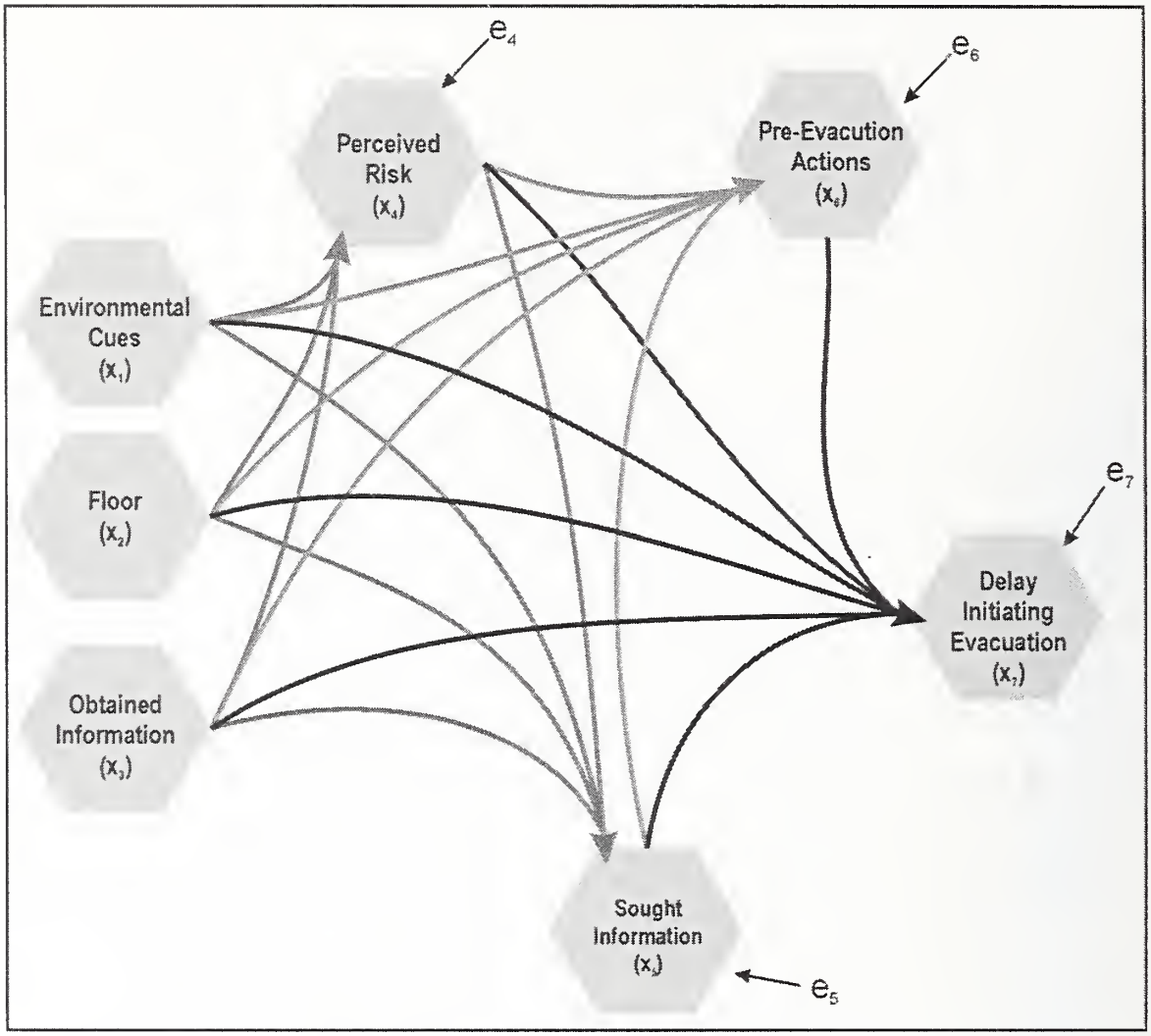

Figure 10–5. Model of evacuation delay.

Direct Effects

With a few exceptions, similar findings regarding evacuation delay emerged in both WTC 1 and WTC 2. Repeatability of findings lends validity to the conclusions that can be drawn from the analyses. The findings are presented below. First, each of the four equations in both models for both towers was considered; next, the models were interpreted as a whole so that the most significant paths of influence for each tower could be distinguished.

Predicting Perceived Risk

The findings that emerged regarding predicting the risk that people perceived were virtually identical across the two towers. 'Perceived' risk was considered more important than objective or actual risk because identical observations may be interpreted differently by individuals, and because people act on the basis of perceptions, or what they believe to be true. The R^2 for perceived risk was 55 percent in WTC 1 and 60 percent in WTC 2. In WTC 1, both environmental cues and floor had strong and similar impacts on predicting perceived risk, while obtained information had a weaker but statistically significant

impact. In WTC 2, once again, both environmental cues and floor had strong impacts on predicting perceived risk, and, once again, obtained information had a weaker but statistically significant impact.

These findings suggest that the risk that people perceived before they began their evacuation increased largely as a function of their starting floor (distance to safety) and being exposed to environmental cues. Clearly, information had a lesser impact on risk perception than did the two more salient variables of experiencing environmental cues and floor height. The only difference in findings between the towers was that, in WTC 2, floor height was by far the strongest predictor of perceived risk, while in WTC 1, both floor and environmental cues were equal predictors. In other words, those who were on higher floors felt more at risk and moved more rapidly to evacuate.[62]

Predicting Seeking Information

The variable 'sought information' may include verification of the nature of the attack, instructions or directions, or other information deemed relevant prior to evacuation initiation. Once again, the findings that emerged for predicting seeking information were almost identical across the towers. Explained variance (R^2) for seeking information was 25 percent in both WTC 1 and WTC 2. In WTC 1, environmental cues and floor both had the strongest and identical impacts on seeking information; obtained information had no statistically significant impact on seeking information; and perceived risk had a slight impact on seeking information. In WTC 2, environmental cues had the strongest impact on seeking information; the impacts of floor and obtained information were not significant; and perceived risk had a slight impact on seeking information.

Seeking information in times of rapid onset emergencies is a typical human response, since people need to interpret and make sense out of an event before they act on it. The finding that the variable of environmental cues was the strongest predictor of seeking additional information is consistent with this theoretical finding about "milling" from past research. Obtained information had no impact on seeking information in either tower. This was likely because information to make sense out of the event had already been obtained. Perceived risk had a similar effect on seeking information—albeit lesser of an effect than environmental cues—in both towers. Interestingly, floor height (or distance from the exit) had a significant effect on seeking information in WTC 1, but not in WTC 2. Evacuation theory would predict that this effect would be present; it was present in the tower that was struck first, and it was not present in the tower struck second.

Predicting Pre-Evacuation Actions

Pre-evacuation actions included activities such as making telephone calls, gathering belongings, or performing any other tasks deemed necessary prior to evacuation initiation. The explained variance (R^2) for taking pre-evacuation actions in WTC 1 was 68 percent, and it was 69 percent in WTC 2. In both towers, the strongest predictor of taking pre-evacuation actions was floor. Environmental cues was also predictive of pre-evacuation actions. Once again, observing cues indicating that one is at risk and being high in the building with a longer path to safety emerged as strong predictors. Obtaining information had virtually no impact on pre-evacuation actions in either tower. Seeking information impacted pre-evacuation action likely because the information obtained supported the need to evacuate and, hence,

[62] Recall, however, that individuals who were not motivated to initiate evacuation on higher floors in WTC 2 were more likely to be trapped above the aircraft impact region when WTC 2 was attacked.

related to getting ready to leave. Finally, the impact of perceived risk on taking pre-evacuation actions was higher in WTC 2 than in WTC 1.

Predicting Delay in Evacuation

Explained variance (R^2) in evacuation delay was 49 percent in WTC 1 and 56 percent in WTC 2. The greatest predictor of evacuation delay in both towers was taking pre-evacuation actions. Obviously, doing anything before initiating evacuation—including preparation to leave—delayed departure. Setting this factor aside, some clear differences emerged between the two towers in terms of the relative impacts of the remaining variables in the model. Perceived risk had no direct effect on evacuation initiation delay. This finding is consistent with general evacuation theory where perceived risk's impact on actual behavior is indirect through other factors. The three factors with the strongest direct effects on evacuation delay were the same in both towers. These were environmental cues, floor, and obtained information. In both towers, floor's effect was negative, that is, the more floors one was from the exit, the quicker people were to initiate their evacuation. Environmental cues and information that was received passively both increased delay in the initiation of evacuation. Finally, seeking additional information had a minimal impact on evacuation delay.

Paths of Greatest Influence and Conclusions

Although each of the aforementioned findings are interesting in and of themselves, perhaps the most important findings that we can offer are those that emerge when all of the individual findings offered above are brought together and viewed at the same time in the context of the entire model.

Bias

As discussed previously, any conclusions about evacuation initiation delay time in WTC 2 should consider the impact of disproportional decedent location, particularly as a source of the disproportionality may be highly correlated to the variable of interest, evacuation delay. In other words, those who exhibited long delay times in one region of the building were unable to be interviewed, thus artificially shortening the average delay time for one-third of the building. In the causal modeling, this would affect the relationship between 'floor' and 'delay initiating evacuation,' likely tending towards zero a slightly negative estimate (-0.19) of the beta value between the two variables. As floor was not a primary path which directly predicted evacuation initiation delay in WTC 2, the impact of this bias was considered secondary. The effect of this bias as it worked through other variables was not considered.

WTC 1

Although there were other factors that had some lesser impacts on influencing what people did, the paths of causal influence that defined the main process that led to delay in the evacuation of WTC 1 on September 11, 2001 follows.

Environmental cues (information from the physical environment that something was terribly wrong) and floor (increased distance to safety) caused people to set out to find additional information, most likely information about what was going on and what they should do. Next, the act of seeking additional information, that is, "milling" about to make sense out of the situation, led people to take actions to

prepare to evacuate. Finally, taking those actions to prepare to evacuate delayed the initiation of actually evacuating.

In addition to this four step causal process, environmental cues and floor also had indirect impacts on evacuation delay as follows. Both factors increased the odds of seeking information and both factors increased the chances that people would take pre-evacuation actions prior to evacuating. Both factors also had direct impacts on actual evacuation delay. Environmental cues increased delay while floor decreased delay.

WTC 2

Although there were other factors that had lesser influence on what people did, the paths of causal influence that defined the main process that led people to delay in the evacuation of WTC 2 on September 11, 2001, were identical to WTC 1 with one decided difference.

Environmental cues (information from the physical environment that something was terribly wrong) and floor (increased distance to safety) predicted perceived risk. Environmental cues, floor, and perceived risk caused people to set out to find additional information. Next, the act of seeking additional information, that is "milling" about to make sense out of the situation, and perceived risk both led people to take actions to prepare to evacuate. Finally, taking those actions to prepare to evacuate delayed the initiation of actually evacuating.

In addition to this five step causal process, environmental cues and floor also had indirect impacts on evacuation delay. Both factors increased the odds of seeking information and both factors increased the chances that people would take pre-evacuation actions prior to evacuating. Both factors also had direct impacts on actual evacuation delay. Environmental cues increased delay, while floor decreased delay.

10.2.2 Predicting Normalized Stairwell Evacuation Time in WTC 1 on September 11, 2001

The second component of total evacuation time was the time spent in the stairwells. This analysis determined the factors and social processes that influenced the normalized stairwell evacuation time per story of stairs for the people who evacuated out of WTC 1 on September 11, 2001. WTC 2 was excluded from this analysis because evacuees used stairs, elevators, and/or a combination of both for their evacuation and could not be separated for the analysis. Evacuation time was defined as the average number of seconds per story of stairs that it took people from the time they entered a stairwell until they completed their evacuation out of the building. The model used to predict important factors in stairwell evacuation time again used variables that preliminary analyses and general evacuation theory suggested as salient, and is illustrated in Figure 10–6. It can be described as (1) normalized stairwell evacuation time is a direct consequence of floor, evacuation decision delay, environmental cues, emergency responders, crowding, and evacuation interruption; (2) evacuation interruption is a direct consequence of floor, evacuation decision delay, environmental cues, emergency responders, and crowding; (3) crowding is a direct consequence of floor, evacuation decision delay, environmental cues, and emergency responders;

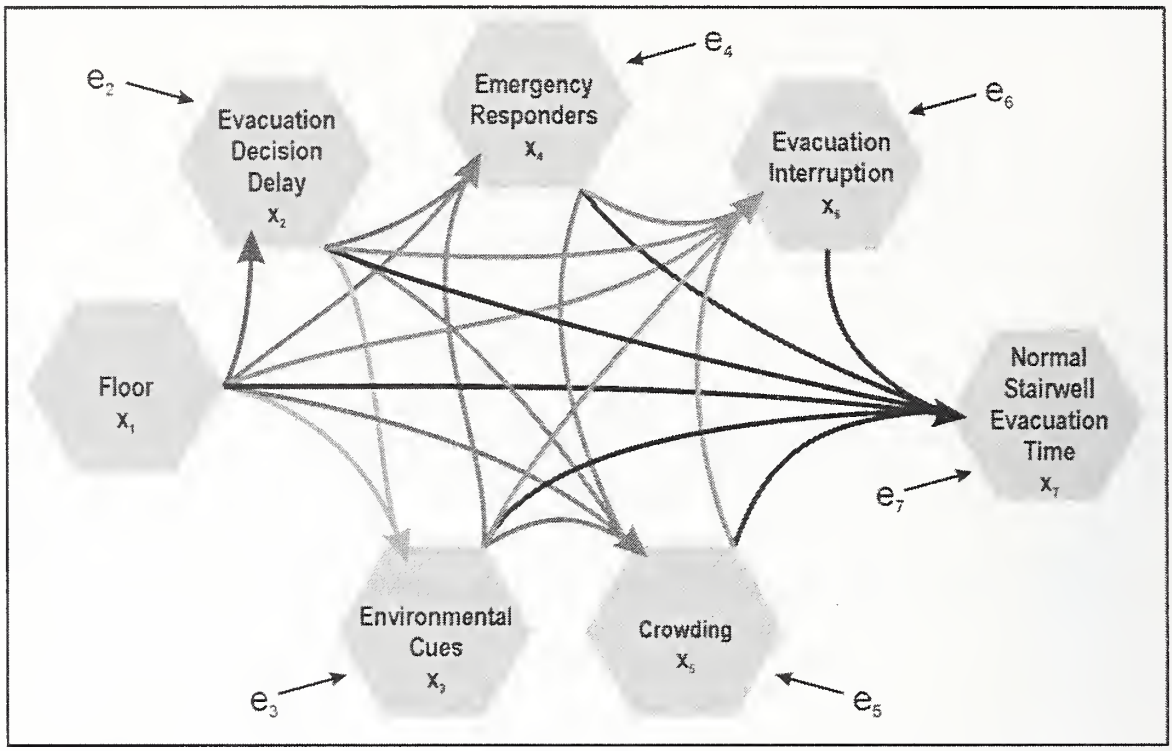

Figure 10–6. Causal model for predicting normalized stairwell evacuation time.

(4) emergency responders is a direct consequence of floor, evacuation decision delay, and environmental cues; (5) environmental cues is a direct consequence of floor and evacuation decision delay; and, finally, (6) evacuation decision delay is a direct consequence of floor. This model is parsimonious, consistent with the high rise fire evacuations theory, and it well-represented the positive findings of our preliminary analyses of the many variables that could have impacted normalized stairwell evacuation time.

Results

The estimated parameters of the model for WTC 1 revealed that the model had a very high degree of success in explaining normalized stairwell evacuation time. The adjusted explained variance (R^2) for normalized stairwell evacuation time was 44 percent, 11 percent for evacuation interruption, 72 percent for crowding, 57 percent for emergency responders, 79 percent for environmental cues, and 34 percent for evacuation initiation delay. With the exception of evacuation interruption, these are extraordinarily high levels of adjusted explained variance to observe in a study of human evacuation; and, these R^2's, thereby, establish the strong predictive power of the model. All of the equations in the model were statistically significant at the 0.001 level or better.

Direct Effects in the Model

We first consider each of the factors individually, and then the model is interpreted as a whole so that the most significant paths of influence can be distinguished.

Predicting Evacuation Initiation Delay

Evacuation initiation delay is the total time from first awareness that something was wrong on September 11, 2001, until entering a stairwell to evacuate. The findings that emerged regarding predicting delay in the initiation of evacuation from floor were that the R^2 was 34 percent. This relationship is already discussed in detail in the previous section.

Predicting Environmental Cues

Environmental cues were the visual, auditory, or other sensory perceptions that indicated danger on September 11, 2001. Explained variance (R^2) for observing environmental cues was 79 percent, and the equation was statistically significant at the 0.001 level. Floor had a very strong direct impact on observing environmental cues, and it was significant at the .001 level. The effect of delay in the initiation of evacuation was smaller, but still statistically significant at the 0.001 level. It would appear that the longer a person took to begin their evacuation, the more the physical impacts of the event grew and the more likely people were to experience them.

Predicting Emergency Responders

Emergency responder was denoted as either observed or not observed. The explained variance for predicting encountering emergency responders was 57 percent, and the equation was statistically significant at the .001 level. Experiencing environmental cues and floor both predicted encountering emergency responders. This makes sense when one considers that emergency responders would be most likely to go to areas experiencing the impacts that would also yield environmental cues, and the higher one was in the tower, the more stairwells one had to traverse, the longer the traversal time overall, and, thus, the greater the odds of encountering emergency responders.

Predicting Crowding

Stairwell crowding was denoted when a respondent indicated that the stairwell was crowded to the extent that it impacted progress down the stairs. The explained variance for perceived crowding on the evacuation stairwells was 72 percent. Perceived crowding largely increased as a result of environmental cues and encountering emergency responders.

Predicting Evacuation Interruption

Evacuation interruption was denoted by respondents who indicated that they left the stairwell or stopped in the stairwell by choice. The explained variance for interrupting evacuation was only 11 percent. Even though this equation was statically significant at the .001 level, none of the five predictor variables in the equation had a statistically significant impact on evacuation interruption. At best, these findings can be interpreted to mean that there was a slight but not statically significant tendency for people to interrupt their evacuation if they had more rather than fewer floors to traverse to safety, and if they encountered environmental cues (perhaps obstacles) in the process of evacuation.

Predicting Normalized Stairwell Evacuation Time

Explained variance in predicting normalized stairwell evacuation time was 44 percent, and the equation was statistically significant at the .001 level. Only two factors in the equation were statistically significant, both at the .001 level. These were environmental cues and evacuation interruption. Clearly, the single factor that had the biggest impact on increasing the amount of time people spent, on average, per stairwell was environmental cues. The only other factor that had a significant impact was interrupting evacuation, obviously, because stopping egress would increase the amount of time needed to complete evacuation.

Paths of Greatest Influence and Conclusions

Although each of the aforementioned findings are interesting in and of their own right, the most important findings that we can offer are those that emerge when all of the above findings are brought together and viewed at the same time in the context of the model as a whole. Thus, the main process that led to increased normalized stairwell evacuation time in the evacuation of WTC 1 on September 11th was straightforward and clear. Floor (increased distance to safety) substantially increased the odds that people would encounter environmental cues. Floor also increased delay in starting evacuation (this relationship is elaborated upon in much detail previously), which, in turn, also increased the chances that people would encounter environmental cues. But it was encountering environmental cues that had a large and direct effect on increasing the amount of time that people spent, on average, to traverse their evacuation stairwell. In addition to this multi-step process with environmental cues as the key predicting variable, interrupting the process of evacuation for any reason also increased the amount of time, on average, that people used to descend their evacuation stairwell.

10.3 ISSUES THAT IMPACTED OCCUPANT EVACUATION

While the multivariate regression analysis of the telephone data has extraordinary power to distill the telephone interview data to the salient features, the analysis was necessarily limited by the constraints of the number and type of questions contained in the telephone interviews. Face-to-face interviews and focus groups provided a more detailed understanding than can be achieved by exclusive use of the telephone interviews. This section provides a discussion of some of the issues identified from both the telephone survey and face-to-face interviews that impacted the ability of occupants to successfully evacuate the two towers on September 11, 2001, including both those issues that aided evacuation and those that made evacuation more difficult.

10.3.1 Environmental Cues and Information

In any emergency, occupants obtain information about the event by passively receiving it and actively by seeking it out through various means. Information may have led occupants to evacuate or to delay evacuation to gather additional information or to perform additional tasks prior to beginning evacuation. As soon as WTC 1 was struck, most occupants' first reaction was to look out the window for information. These first environmental cues from the building (hearing the explosion, feeling the building shake, etc), coupled with the reaction of looking out the window (and seeing the fireball and smoke in WTC 1, the debris falling outside of the window, or even the plane hitting the tower), was enough to signal that

something was wrong for many in the towers. This first set of information caused some to begin the evacuation process immediately.

> An occupant in WTC 1 from a floor in the 70s reported immediate evacuation initiation: "The building was swaying more than normal and I slammed into the cabinets. I got up and headed for the staircase." Interview 1000574 (NIST 2004)

> Also, an occupant in WTC 2 from a floor in the 80s also noted evacuating immediately. "Somebody in my area jumped up and said there is a bomb. At this stage, everybody else took the stairs. I went directly to the Stairwell C. I didn't think I was in danger at this point." Interview 1000568 (NIST 2004)

In both towers, many delayed evacuation to find out more information before entering a stairwell or elevator. This may have involved talking with coworkers, making and receiving phone calls, sending and receiving emails, searching the internet, and watching TV.

According to the telephone interviews, 11 percent of the occupants in WTC 1 and 21 percent of the occupants in WTC 2 received information related to the event through various means. Of the occupants who received information, 57 percent in WTC 1 and 65 percent in WTC 2 received information about what happened. A majority of the occupants in WTC 2 (54 percent) received information about what happened to WTC 1 through the public address announcement. Many of them, already in the process of evacuating, were faced with the decision of whether to return to their offices or continue their evacuation.

While on their floor, occupants were receiving information about what was going on in the buildings from each other and through a variety of technological means. Technology such as landline phones, cell phones, blackberries, email, internet, and TV was used inside the building to receive such information.

> An occupant from a floor in the 80s of WTC 1 received a phone call from a co-worker. "A co-worker was calling from home. She said that 'a plane hit the building and you better get out of there.'" Interview 8000005 (NIST 2004) This information caused the occupant to begin their evacuation process.

However, the situations in the towers were different before WTC 2 was hit. The information that was received by the occupants in both buildings was that only WTC 1 had been hit by an aircraft. This message produced a variety of responses from occupants in WTC 2.

> After hearing the public address system announcement, an occupant from a floor in the 50s in WTC 2 was calling an out-of-town office to let them know they were evacuating the building. "I got a hold of them and they told me that a plane hit the building [WTC 1] and to get out of there." The respondent hung up and continued to call loved ones and answer other phone calls until his or her own building was hit by an aircraft. Interview 1001666 (NIST 2004)

> An occupant in the 40s from WTC 2 was watching TV before WTC 2 was hit. "I saw what happened on CNN and was informed that a plane

> hit Tower 1. I entered the emergency stairwell A and proceeded down. Interview 1000867 (NIST 2004)

Even after entering the stairs, the evacuation flow continued through the use of technology and information sharing among the occupants inside the building. Although they had already entered the stairs, additional information (aside from the public address system announcement in WTC 2 telling occupants to return to their floor) sometimes increased the occupants' motivation to evacuate the building, as shown in the following quotes from WTC 1 occupants.

> An occupant from a floor in the 50s in WTC 1 was traveling in a stairwell when he or she heard another occupant say "that another plane hit the building. [The person] got this information from a cell phone and we speeded up our evacuation." This respondent went on to indicate that "cell phones were working and people were trying to figure out what was going on." Interview 1000071 (NIST 2004)

> While in Stairwell B, an occupant from a floor in the 70s in WTC 1 "heard a fire department radio say the words '. . . Structural Instability . . . '" This radio message was relayed at the time of the collapse of WTC 2. The respondent went on to say that they "stopped because there was no movement in the staircase, but then became frightened for the first time. [I] began to focus more on getting out." Interview 1000118 (NIST 2004)

> An occupant in WTC 2 also experienced the same knowledge about his building during evacuation. "The phone was ringing, [so] I answered the phone on the 3rd floor. I listened to my daughter tell me that both buildings were hit [by a] commercial airliner, and that it was a terrorist attack. I told my boss what I learned from my daughter, so we would both have more determination to get out." Interview 1000003 (NIST 2004)

When people were given new information about the event from outside of the building, they shared that information freely with those around them. People provided information about the phenomena that they witnessed themselves (at first awareness) or information that they had received from another source, such as from someone outside of the building. As evidenced in face-to-face interviews, the behavior of sharing information was frequent, regardless of whether the individuals involved were strangers.

> For example, there was an occupant in WTC 1, who originated on a floor in the 40s, whose phone rang while in the stairwell: "I answered the phone and my [spouse] was telling me that another plane had struck Tower 2. [The spouse] said to get out of the building as fast as you can and that it is a terrorist attack. [The spouse] also told me about the plane hitting the Pentagon. [The spouse] mentioned that there was another plane in the air but [the spouse] wasn't sure where it was. I told others around me what had happened, in order to spread the available information." Interview 1000572 (NIST 2004)

In addition to passively receiving information from inside the buildings, 28 percent of the survivors in WTC 1 and 29 percent of the survivors in WTC 2 actively sought out information related to the event

through various means. In the face-to-face data, this includes nearly everyone when the occupants who looked out the window for information are included. However, the telephone interview data shows that approximately 40 percent of these who sought out information about the event in both towers were not successful in finding the information they were searching for.

> For example, an occupant from a floor in the 60s of WTC 1 tried making several phone calls after the building was hit, but was unsuccessful. "The building started to sway and everything started shaking. I knew that there was something [wrong]. I ran to my desk and made a couple of phone calls. I dialed about five times trying to reach my [spouse]. I also called my sisters to find out more information." Interview 1000733 (NIST 2004)

Occupants also attempted to seek information about what was going on in the buildings through a variety of technological means. This technology included landline phones, cell phones, blackberries, email, internet, and television broadcasts inside the building.

> An occupant in the 70s performed a variety of information seeking activities before deciding to leave WTC 1. "I was curious and wanted to get information on what happened. I tried to find information on the internet, [because] that was the fastest way of getting information. [Also], I knew my mother had TV access. I called my mother to get information on what she had seen so far on TV." This occupant also phoned a brother-in-law for more information until the occupant witnessed the plane impact WTC 2. Then, the occupant began to evacuate. Interview 1000583 (NIST 2004)
>
> Also, an occupant from a floor in the 100s in WTC 2 noted that "there were a lot of people trying to find out what was going on by using cell phones." Interview 1000563 (NIST 2004)

Emergency responders also confirmed what happened to inquiring occupants inside the stairwell, but then reassured them that everything would be okay. Obtaining information from emergency officials inside the building was not frequently reported. In return, occupants would provide information to the firefighters about where certain people were waiting for rescue assistance.

Overall, the information flow and its impact on occupants' evacuation were dependent upon many factors, including the tower in which the occupant was located and the time the information was received during the emergency. Occupants in WTC 2 were sometimes affected differently to news that only WTC 1 had been hit by aircraft, when compared to occupants in WTC 1. Information was received and sought out at various times throughout an occupants' evacuation and from different sources. However, many occupants in both towers reacted to the first set of information provided by the plane crash into WTC 1, either by initiating evacuation or by beginning pre-evacuation activities.

10.3.2 Building Alarm Systems

Fire alarms have been a hallmark of fire protection for more than a century, with systems proposed in New York City as early as 1847 (Bukowski and Moore 2003). Typically, the systems serve dual purposes,

occupant notification and transmission of information about the fire to emergency responders. On September 11, 2001, with significant damage to the fire alarm system in the towers, only a small percentage of occupants in both towers (14 percent in WTC 1 and 10 percent in WTC 2) noted hearing a fire alarm during different stages of their evacuation. Many occupants in WTC 1 had already begun to evacuate their building due to a variety of building observations from the plane impact (less than 5 percent of occupants in WTC 1 said that their decision to evacuate was based on the fire alarm going off). The same is true for occupants in WTC 2 who heard alarms after their tower was hit, since a large majority had already begun evacuation before or when their tower was hit (less than 1 percent said their decision to evacuate was based on hearing a fire alarm).

Some occupants of WTC 2 believed that the emergency was limited to WTC 1 and were unclear if their evacuation was necessary. Also, occupants in WTC 2 were faced with a public address system announcement informing them to return to their offices. For example, a respondent in WTC 2 heard the announcement that the building was secure first, followed by the fire alarm.

> "At the 25th floor, I heard someone on the loudspeaker who said that 1 World Trade was hit but that 2 World Trade was OK and that we should all go back to our office. After I heard that announcement, I heard the general alarm which meant to me to leave the building even quicker." Interview 1000740 (NIST 2004)

And, in response to this, the occupant kept walking down the stairs to leave the building.

In both towers, occupants reported hearing fire alarms at various floors throughout the tower. For those occupants in WTC 1 and WTC 2 who heard fire alarms on their floors, the fire alarm was not frequently nor specifically mentioned as the reason for evacuating. Instead, the top three reasons for occupants to begin evacuation from either towers were the plane hitting WTC 1, being told to evacuate, or feeling afraid or in danger (in no particular order for each tower).

10.3.3 Public Address Announcements

Public Address announcements were not mentioned in the face-to-face interviews as being heard after each building was hit by aircraft. However, from the telephone survey, 14 percent of the survivors in WTC 1 reported receiving information from a public address system announcement – which suggests that the occupants received an announcement after their tower was struck. There is also information from the 9-1-1 tapes that a second announcement was heard in WTC 2 by people near and above the floors of impact after the building was hit, although NIST found no evidence from face-to-face interviews that survivors below the floors of impact heard this announcement.

A building-wide public address announcement was made to the occupants in WTC 2 approximately three minutes before the aircraft hit their building. Based upon analysis of many face-to-face interviews and published accounts, the first announcement provided to occupants in WTC 2, before their tower was hit, stated the following:

> There is a fire condition in WTC 1, WTC 2 is secure/safe, please return to your offices.

Fifty-four percent of the occupants in WTC 2 reported receiving information from the public address system. Since 40 percent of WTC 2 survivors had evacuated before WTC 2 was attacked, the overwhelming majority of occupants still in the building heard the 9:00 a.m. announcement. While some occupants interpreted the first announcement as a suggested course of action, other interpreted it as an instruction.

Approximately two minutes later, at 9:02 a.m., one minute before WTC 2 was attacked, a second announcement was made, contradicting the first announcement. Recorded in the background of an answering machine receiving a call from an occupant calling home from floor 98, the announcement indicated that it was now permissible to initiate an evacuation:

> "May I have your attention please. The situation is in Building 1. However, if conditions on your floor warrant, you may wish to start an orderly evacuation." Interview 3000001 (NIST 2004)

The 9:02 a.m. announcement was noted by one occupant catalogued in the collection of published accounts (Fahy and Proulx 2003), however, the large discrepancy in the percentage of occupants reporting this announcement when compared to the percentage who reported the 9:00 a.m. announcement remains unresolved.

The majority of occupants in WTC 2 began their evacuation before the first announcement was made. Some of them never heard the announcement (due to evacuating via elevator, starting in the lobby, or possibly evacuating from a lower floor before the announcement was given) and some heard the announcement from either the stairs or a lower floor than their original starting floor. It is known that occupants listened to the announcement from the stairs, left the stairs to hear the announcement more clearly, or were led out of the stairs minutes before the announcement on skylobby floors by security personnel. Those who heard the announcement and had begun the evacuation process were faced with a decision on whether to comply with the instruction and return to their offices or continue their evacuation. The face-to-face interview data shows that while many people did not follow the instruction/suggestion in the announcement, others chose to return to their office. Each individual's decision was affected by a number of factors at the time of the announcement, including:

- their perception of danger and ability to evacuate:

  > "While I was on the steps, I heard a public address system announcement that said the building was secure and to return to our offices. It made me angry to hear this announcement because I felt we were in danger." Interview 1000048 (NIST 2004) This occupant, who had a medical disability, was helped down the stairs by a fellow occupant, until they took an elevator to the ground floor.

- the actions or statements of others in the immediate area (group behavior):

  > An occupant from a floor in the 70s, who used both an elevator and a stairwell, heard an announcement around floor 20: "[I heard] a PA (public address) announcement that told people to return to their offices. I shouted to people to continue down the steps; to keep the flow of traffic going--so that people wouldn't be going past me. I intentionally lied to

> people. I heard the PA [public address] announcement tell people to return to their offices, but I thought it was better for them to evacuate the building and I knew that if the people didn't turn around and try to move past me that I could evacuate faster." Interview 1000024 (NIST 2004)
>
> An occupant from a floor in the 60s in WTC 2: "I heard a public address system announcement that said to stay where we were--that our building was secure and the problem was with the other building, but the fire warden said to ignore the message and to leave the building anyway." Interview 1000050 (NIST 2004)
>
> An occupant from a floor in the 90s heard an announcement around floor 78 in WTC 2: "We heard an announcement that said 'the building is safe; you can go back.' I continued walking down the stairs, to keep moving, to not hold up the others that were behind me." Interview 1000070 (NIST 2004)

- desire to follow instructions:

> An occupant from a floor in the 30s in WTC 2: "The PA (public address) announcement informed us, '. . . You may return to your office.' I exited the stairwell on the [a floor in the 30s] and proceeded to the elevator lobby on that floor. I entered the elevator and took it to [a floor in the 30s] to return to my office as instructed. I [then] called my [spouse] at about 9:03 a.m. to tell [the spouse] that everything was ok – but my conversation was cut short when the second aircraft struck Tower 2." Interview 1000049 (NIST 2004)

- and even serendipity:

> An occupant from a floor in the 10s in WTC 2: "I heard an announcement saying that the problem is in Building One and for us to stay where we are or to return to our floors. I stepped off of the stair into the 9th floor to take the elevator to return to my floor. I was distracted because of conversation and did not realize that the elevator was going down until it started moving." Interview 1000922 (NIST 2004) This occupant did not return to their office, but instead, evacuated the building after exiting the elevator.

Occupants who were led out onto skylobby floors also hesitated after hearing the announcement. They engaged in milling with other coworkers in an attempt to decide what to do. Minutes later, WTC 2 was struck, which caused them to initiate their evacuation.

Other occupants who did not begin the evacuation process were still located on their floor when the PA (public address) announcement was made. The announcement helped to reinforce their original goal of remaining on their floor for some time. Most of these occupants listened to the announcement and remained on their floor.

> "I heard an announcement on the intercom that told us to stay. I decided to stay to avoid getting in more danger. I heard the phones ringing off

> the hook and my boss and I were going from phone to phone answering them. This was to reassure the families that everyone was ok." Interview 1000524 (NIST 2004)

Regardless of where occupants were located in the building and whether they had decided to begin the evacuation process, their final evacuation decision was prompted by the impact of the aircraft into their building, WTC 2, at 9:02:59 a.m.

10.3.4 9-1-1 System

NIST was given access to all emergency calls to the New York City 9-1-1 system related to the World Trade Center attacks on September 11, 2001 from 8:45 a.m. until shortly after 10:30 a.m. The 9-1-1 system was flooded with calls from 8:46:30 a.m., when WTC 1 was attacked, until roughly 8:55 a.m., and experienced a second surge in call volume at 9:03 a.m., when WTC 2 was attacked, which continued for several minutes. The majority of calls were eyewitnesses reporting that they had observed something crashing into the World Trade Center or reporting that the World Trade Center was on fire. Initial reports included descriptions of small planes, helicopters, large (commercial or military) aircraft, as well as a bomb or a missile. A few callers sought advice about whether they should evacuate their nearby buildings or information about what was going on. Other callers reported observations of suspicious activities or people. After several minutes, the first WTC occupants began to call 9-1-1 seeking advice or rescue assistance. Occupants continued to use the 9-1-1 system, both as a resource for information and an outlet for reporting their situation, until around 10:00 a.m., when WTC 2 collapsed.

During the time period between aircraft impacts, advice from 9-1-1 operators to occupants experiencing smoky conditions was largely to shelter in place and await rescue from emergency personnel.

One of the common questions asked by trapped occupants of the 9-1-1 operators was whether to break windows in order to obtain fresh air. The advice given to occupants varied by operator. Some operators encouraged the occupants to assess their own unique situation and determine whether breaking a window would help, sometimes warning the occupants that breaking a window may only serve to introduce more smoke from the outside than it would relieve from the inside. Other operators simply advised occupants not to break windows. The 9-1-1 operators, largely acting without complete knowledge of an evolving and traumatic situation, were forced to strike a balance between efficiently logging incoming calls, compassionately counseling sometimes desperate occupants, and disseminating relevant event information.

Another common question from occupants to 9-1-1 operators was whether they should evacuate, and further, whether that should be upward or downward (in other words, where was the impact region relative to their location). Some 9-1-1 operators did not initially offer advice, routinely telling the occupants to defer to the instructions they were (presumably) receiving from building authorities. Other operators consistently advised occupants to stay in place, rescue was on the way. At least one occupant below the floor of impact in WTC 2 was repeatedly advised to await rescue by emergency personnel who were advised of the occupant's whereabouts. Sometime after 9:02:59 a.m., some operators began to encourage the occupants to evacuate, if possible. Information about the location or magnitude of the impact in either WTC 1 or WTC 2 was not generally communicated to trapped occupants.

Operators routinely collected from callers specific location information, which proved useful during the NIST investigation for establishing the time-evolving building conditions (fire, smoke, damage, number of people), including: building, floor, corner (northwest corner, for example), or office number. Additionally, callers would sometimes relay individual or group observations about the tenability or status of the egress path (i.e., access to stairwells or elevators). For these reasons, the 9-1-1 recordings proved to be a valuable record of the conditions above the impact floors for which there would have been no other method to discover.

10.3.5 Previous Evacuation Experience

Using prior evacuation experience to guide future evacuation decisions, may or may not produce better outcomes. Recall from Section 4.3 that 16 percent of survivors on September 11, 2001 were also present during the 1993 bombing. A survivor from the 70s in WTC 1 described:

> "My response to the '93 bombing wasn't sufficient. I realized there was no real purpose in sticking around. I was going to get out as quickly as I could." Interview 1000525 (NIST 2004)

Another survivor from a floor in the 70s in WTC 1, however, used their 1993 evacuation experience to justify delaying their evacuation:

> "I was there in 1993, and [this time] I wanted to wait for some directions from someone, through the speaker system, fire alarms, etc. I stayed on around the general vicinity where I worked. This is the main reason why I stayed longer on the floor." Interview 1000576 (NIST 2004)

Similarly, 16 percent (n=59) of WTC 2 evacuees on September 11, 2001 also evacuated in 1993. In WTC 2, however, only 75 percent (n=42) felt that they made the right decision in 1993 (compared to 95 percent in WTC 1), possibly due to the fact that many more waited to evacuate in 1993 in WTC 2 (69 percent (n=39)) than did so in WTC 1. Only 31 percent (n=17) who reported their decision evacuated immediately from WTC 2 in 1993, keeping in mind that the bomb had a more significant impact on WTC 1 in 1993.

Nearly every respondent who compared the 1993 bombing evacuation to the 2001 evacuation indicated that the 1993 evacuation was slower, more difficult (presence of smoke in the stairwells and floors), and more stressful. Having participated in the 1993 evacuation, those occupants generally felt much better about the progress and conditions during the 2001 evacuation. As a consequence of their 1993 experience, however, several 2001 survivors who had direct 1993 experience reported having diminished confidence in building announcements (or the lack thereof), exemplified by this occupant from a floor in the 40s in WTC 2:

> "I ... was there during the 1993 bombing. I did evacuate--with a group of people who had no clue as to where we were going. What I learned from that experience was to not trust the Port Authority's announcements. Because of experiencing the '93 bombing, I felt a strong conviction to get out this time. Had I not experienced that, I might have listened to the Port Authority announcements and stayed put." Interview 1000048 (NIST 2004)

10.3.6 Occupant Activities

Occupants of WTC 1 and WTC 2 performed a number of activities before and during evacuation on September 11, 2001. These activities included gathering personal belongings, milling with other occupants, seeking additional information, and calling family or friends, among others. In general, these activities either delayed the start of their evacuation (pre-evacuation activities) or interrupted their evacuation once it was in progress and are described below.

Pre-Evacuation Activities

Occupants performed a variety of activities prior to entering the stairwell (or elevator in WTC 2) to begin their evacuation. An activity such as gathering occupants or warning them to leave has a variable amount of time associated with it, depending upon the floor space to search and how reluctant others are to leave, whereas an activity such as gathering belongings usually requires under a minute to complete. Other activities noted by occupants were milling, seeking information (such as looking out the window, making phone calls, searching the internet), helping others, following emergency procedures, fire fighting, and working or closing up a work desk. The delay reported by survivors in starting their evacuation was predominately one to five minutes, while a small number delayed for more than an hour. The distribution of evacuation initiation delay times was discussed in detail in Chapter 6.

The majority of the survivors, 70 percent of those in WTC 1 and 75 percent in WTC 2, engaged in the activity of talking to others, or milling. The behavior of milling is used by occupants to discuss what they witnessed and to arrive at conclusions for what happened and what to do next.

> For instance, an occupant in the 90s of WTC 2 looked for other coworkers after he heard a sound coming from WTC 1. "I moved back out of my office where I could get in sight with other people to share my observations, to discuss what ought to be done, and to hear what the consensus would be." Interview 1000689 (NIST 2004)

> After hearing an explosion and feeling the building rock, an occupant in the 60s of WTC 1 turned to a coworker. "I discussed with my coworker what we were going to do. The noise of the explosion, the shaking of the building, and seeing the paper falling was what made me decide it was something serious. We left our conference room and went into the hallway to get to the stairs." Interview 1000053 (NIST 2004)

Near the floors of impact in WTC 1, a few survivors worked to secure an area of refuge or perform fire fighting activities. The floors near the impact area were much more difficult to navigate due to the smoke and damage. Because of this, some occupants remained in an office, surrounding the openings with wet towels, before being rescued by Port Authority personnel.

In both towers, the face-to-face data captures the fact that some occupants delayed their evacuation start to wait to receive evacuation instructions, as part of their emergency procedures. Fourteen out of 124 respondents in WTC 1 and 12 out of 69 respondents in WTC 2 waited for instructions. The percentages are higher for WTC 2 because it included those occupants who heard the public address system announcement while still on their floor before they began evacuation.

> On at least one floor in the 30s in WTC 1, occupants followed the emergency procedures. "We knew that we were supposed to go out to the hallway and that there would be someone there with information or information would be given via loudspeaker. We went out to the hallway to listen for any instructions." Interview 100009 (NIST 2004)

Despite the number of pre-evacuation activities of some occupants, most occupants in WTC 2 chose to begin evacuating before their tower was attacked. Eighty-six percent to 91 percent[63] of the survivors in WTC 2 began their evacuation before their building was hit at 9:02:59 a.m. Similar to the telephone interview results (which are generalizable), 12 percent of the face-to-face respondents in WTC 2 stayed until their tower was attacked. Of those who stayed (8 interviews out of 66 from WTC 2), five held positions of corporate leadership or fire warden. The remaining three made multiple decisions to leave before the plane hit, but were delayed by announcements, phones ringing, and the desire to gather belongings.

Helping

September 11, 2001 showed that people are willing to help out others during an emergency, even if they do not know the person ahead of time. Those occupants in need of help during the evacuation included occupants who use canes or wheelchairs, overweight, elderly, pregnant women, and people with asthma. Many of those who supported occupants in need throughout their evacuation were strangers. These helpers often remained with the occupant in need throughout their entire evacuation, even though they were putting themselves at risk. Short-term examples of helping behaviors mentioned in both towers were comforting coworkers in the stairwell, leading occupants in need to the elevators, helping an occupant carry belongings, and encouraging others to keep evacuating in times of stress or exhaustion. Occupants also exhibited major feats of heroism on September 11, 2001 by caring for an individual throughout their entire evacuation, sometimes assisting strangers down more than 60 stories to the building.

Examples of this heroism include:

> A group of coworkers helped to rescue a wheelchair user from a floor in the 60s in WTC 1. 15 minutes after the impact of their tower, WTC 1, they located the evacuation chair and transferred the occupant into it. "We began our descent sliding the evacuation chair, step by step, [with] two helpers holding the chair on top and two helpers holding the chair on the bottom. [Soon] we began carrying [the occupant] down the staircase." Interview 1000123 (NIST 2004)

> Two occupants assisted an overweight occupant in WTC 1 in navigating the stairwell from a floor in the 50s. Towards the bottom of the stair, the occupant's "legs would give out and [the occupant] would fall in our arms. Our descent slowed dramatically as we practically had to carry [the occupant] down each flight of stairs." Interview 1000093 (NIST 2004)

[63] The discrepancy reflects a small difference among responses to two independent questions: 'How long did it take you to evacuate?' and 'Did you evacuate WTC 2 prior to WTC 2 being attacked?', as discussed previously.

> On a floor in the 80s of WTC 1: "I heard the secretary, who was in flames, calling for help near the door. I extinguished the flames with my bare hands, along with a colleague who was using a sweater." Interview 1000113 (NIST 2004)

However, an offer of help was not always accepted. One survivor from a floor in the 60s in WTC 1 recalled:

> "There were some people that stopped in descending because they needed to catch their breath. We stopped about three times and offered help, which was not accepted." Interview 1000878 (NIST 2004)

Resting During Evacuation

Some occupants felt the need to rest at certain points during their evacuation. An occupant coming down from the 90s by the stairs was forced to walk roughly one-half mile before eventually leaving the building.[64] Occupants often chose to rest inside the stairway, either on the steps or, more frequently, on a stairwell landing. Resting during evacuation was noted by respondents beginning evacuation from either the high or medium strata of each building. Most often, resting was reported by occupants with respiratory problems, obesity, or other physical or medical conditions.

From the face-to-face interviews, respondents' experience of resting on the stairs is captured in the following quotes:

> An occupant in WTC 1 had to travel from a floor in the 70s. Around floor 25, the occupant's "legs were really hurting and it was difficult to walk. I slowed down and stopped about three times. The first time, I let people get ahead of me. I stopped at a landing for approximately two minutes. I proceeded down but then stopped for the second time, somewhere between the 15th and tenth floors. I waited there for three or four minutes to think what was the best way to continue. There was water gushing from the fifth floor onto the staircase. I stopped and began to think about the safest way to get down and decided to proceed more slowly and take a firmer grip on the rail." Interview 1000111 (NIST 2004)

> In WTC 2, a group of coworkers found themselves also having to rest multiple times during their evacuation from a floor in the 90s. "On the 78th floor, we felt tired. My coworker, who is a diabetic, hadn't eaten breakfast yet. We stopped on the stairs to rest for a minute. A lot of people seemed to be stopping, probably due to the heat and needing to catch their breath. On the 64th floor, another coworker turned to me and said [he or she] was getting tired and didn't feel well. I said 'We will take a little break' and I gave [the occupant] mints." Interview 1000526 (NIST 2004) The group stopped at least two additional times because a

[64] At roughly 30 degree slope, an occupant descending stairs from 1,000 vertical ft also travels over 1,500 horizontal ft, for a total combined distance of over 2,500 ft, or approximately one-half mile. Travel from stair exit and transfer floors increases this distance.

> coworker wasn't feeling well and didn't think he/she could make it down the stairs.

Occupants also observed other occupants in the stairs who were resting inside the stairwell. Face-to-face interview respondents sometimes mentioned specific categories of individuals who were resting in the stair, including people having trouble breathing (asthma), overweight, elderly, helpers, and firefighters.

Leaving the Stairs

In WTC 1 and WTC 2, occupants left the stairs for a variety of reasons. While occupants left the stairs onto floors throughout the buildings, the most commonly reported floor was one of the skylobbies (floor 44 or 78). In addition, there were a number of occupants who left the stairs at the lower floors of WTC 1, which may be attributed to either debris from the collapse of WTC 2 or the fire department rest station for occupants somewhere between floors 12 and 20.

In WTC 1, the most frequent reasons cited for leaving the stairs were an instruction to do so from firefighters, Port Authority, or building security (33 percent) and the stair condition (41 percent), including crowding or smoke/dust/jet fuel in the stairs. Before the collapse of WTC 2, occupants were directed out of certain stairs to either switch to another stair immediately or wait on the floor for a certain period of time.

> One occupant who originated on a low floor in WTC 1 stated that, "We were directed by a man (I am unsure if he was a security guard). He was telling people to go to the 18th floor in order to scatter the traffic from the stairwell. When we arrived at the 18th floor, we got out of the stairwell and into a vacant floor space." This occupant later stated that, "He said he was instructed to pile up the people into the vacant floors to control the flow of traffic." Interview 1000769 (NIST 2004) The occupant demanded to know why this was happening and decided to find another stair to take out of the building. A group then followed this occupant to another stairwell.

After the collapse of WTC 2, the occupants near the lower part of WTC 1 were faced with an onslaught of debris from the collapse. For this reason, occupants were again instructed to leave the stairs and if not instructed, took it upon themselves to switch stairs at times.

> Two occupants helping an overweight colleague down Stair A in WTC 1 after the collapse of WTC 2 "were told by firemen and rescue workers that [they] had to go up to the fourth floor [because] the exit was blocked." Interview 1000093 (NIST 2004)

Another frequent reason for leaving the stairs in WTC 1, which may have been unknowingly caused by either instruction or stair condition, was occupants following other occupants (9 percent). These people felt comfortable following others out of the stair, without always knowing the reason for leaving or who had initiated the stair move. Other reasons for leaving the stairs in WTC 1 include a jammed exit at the transfer floor (76) of Stair A, occupant's being uncomfortable, the presence of a mobility impairment, retrieving something, helping another person, and seeking information.

In WTC 2, the most frequent reasons for leaving the stairs were instructions to leave the stairs by Port Authority or building security (10 percent) personnel, the public address system announcement made before WTC 2 impact (32 percent), and elevator usage (13 percent). Some occupants in WTC 2 were being instructed out of the stairwells at the skylobbies minutes before the announcement was made. When the announcement was made to occupants throughout the building, some occupants inside the stair walked out onto a floor to hear the announcement more clearly and/or to react to the information given by the announcement. Also, some occupants decided to take the elevators to a different point in the building (to either evacuate or return to their offices) both before and after the announcement was made. Other reasons for leaving the stairwell in WTC 2 included following the crowd, occupants being uncomfortable, and seeking information.

10.3.7 Aids and Constraints to Evacuation

Evacuation incentives are interpersonal interactions or physical features of the built environment that helped people to evacuate. Analysis of the telephone interview data reveals that evacuees that among occupants who received help from other people, 9 percent reported that they were assisted by floor wardens, 44 percent reported that they were helped by police or firefighters, and 65 percent reported that they were assisted by "others."

For occupants who were helped by building features, 33 percent of survivors in WTC 1 and 17 percent of those in WTC 2 reported that they were helped by photoluminescent markings. The discrepancy between towers may be due to the fact that lights were lost in WTC 1 after WTC 2 collapsed, thereby demonstrating the usefulness of the photoluminscent qualities. Additionally, occupants who used elevators in WTC 2 would not have observed the photoluminescent paint.

Conversely, certain conditions presented constraints to evacuation. Table 10–1 shows the most frequently reported constraints to evacuation from the telephone interview data. Three areas were reported by more than half of the evacuees in WTC 1: crowded stairwells, emergency responders in the stairwells, and injured or disabled persons in the stairwells. The findings from the causal model for normalized stairwell evacuation time in WTC 1, however, provide a scientific basis for refuting the occupant's perception that firefighters entering the building adversely affected the overall flow down the stairwells. While more than half (63 percent) reported that the firefighters / police in the stairwells were a constraint, an occupant who encountered firefighter or police did not have a significantly slower stairwell travel time than an occupant who did not encounter firefighter or police in the stairwell, all other factors being held constant.

Table 10–1. Constraints to evacuation.

	WTC 1	WTC 2
Stairwells were too crowded	73 % (321)	69 % (206)
Firefighters/police in stairwell	63 % (275)	27 % (80)
Injured/disabled in stairwell	52 % (226)	33 % (99)
Lack of direction/information	24 % (104)	29 % (106)
Locked doors	16 % (72)	7 % (25)
Poor lighting	11 % (48)	4 % (15)
Bad/missing signage	5 % (23)	5 % (18)

Source: NIST WTC telephone survey data.

A possible explanation for this seeming inconsistency is that while an occupant was required to stop and stand to the side in the stairwell as firefighters and police moved past, they were able to temporarily increase their speed to catch back up to where they would have been before they had met the firefighters or police. This explanation is contingent upon the occupants descending the stairwell at less the maximum speed, which was found to be the case earlier in this chapter (the travel speed was about one-half what would be expected in a non-emergency evacuation).

Elevator Usage in WTC 2

At least 18 percent of the survivors from WTC 2 reported using the elevators for at least part of their evacuation, including those who used elevators from the basement levels. Those who used elevators in WTC 2 did so for various reasons. While most occupants used elevators for evacuation, some had decided to find a quick way to return to their office once the 9:00 a.m. announcement was given. Elevator usage was not necessarily dominated by people with mobility impairments, but used by all people with the intent to evacuate the building quickly. However, one occupant using the elevators out of need started out in the 90s of WTC 2.

> "I wanted to get out of the building as quickly as possible. I was taking a new medication and knew I should not walk down the stairs." Interview 1000553 (NIST 2004) This occupant took an elevator from the 95th floor to the 78th and then switched to another elevator at the 78th floor to travel to the lobby level.

Despite the availability of elevators for occupants with mobility impairments in WTC 2, however, approximately the same percentage of mobility-impaired occupants chose to use elevators in WTC 2 (19 percent), when compared to the surviving population overall (16 percent).

Face-to-face interview respondents also refer to elevator usage after the plane hit. An occupant, injured on a floor in the 70s, was evacuated via elevator by a firefighter and a security guard, along with two other injured occupants, after WTC 2 has hit by the airplane.

> "As we were walking down, we saw a fireman coming up and told us to get to 40 and that someone would take us in an elevator down to the lobby." Interview 1000562 (NIST 2004)

The use of elevators in WTC 2 saved many lives due to the fact that occupants from floors 78 – 107 in WTC 2 used both stairwells and elevators in order to move below the impending impact region prior to the WTC 2 attack. In order to estimate the total number of occupants able to descend below the impact zone prior to the WTC 2 attack, the following assumptions were made: (a), no occupant began evacuating WTC 2 prior to 9:02:59 a.m.; (b), no elevators were usable; and (c), the evacuation rate of WTC 2 mirrored the observed evacuation rate of WTC 1 in Figure 10–2 (starting at 8:46:30 a.m.). Under these three assumptions, over 3,000 people would have remained in the building as it collapsed, with over 2,000 occupants remaining trapped above the 78th floor. Therefore, self evacuation (starting to evacuate prior to 9:02:59 a.m.) and the use of elevators during that time period is estimated to have saved roughly 3,000 lives in WTC 2 on September 11, 2001.

Footwear

Evacuation speed on the stairs can be significantly affected by the choice of footwear worn by the occupants, especially women. High-heeled shoes, especially heels higher than 3 in., dramatically decrease movement capability on the stairs (Templer 1992). People, mostly women, removed their shoes in the stairwell in both towers. This presented a potential hazard for other occupants in the stair, who had to maneuver around the pile of shoes, as well as for the occupants without shoes walking through the damaged portions of the building.

> In WTC 1, an occupant noticed a pile of shoes in a stair near the 28th floor. "There was a pile of shoes that accumulated from people kicking them off. Some of the people around me were tripping on them and warning others to watch out for them." Interview 1000042 (NIST 2004)

Firefighters (Interviews 1000081 and 1000540 (NIST 2004)) and Port Authority personnel (Interview 1000071 (NIST 2004)) occasionally instructed occupants to put their shoes back on.

Transfer Hallways

As described in Chapter 2.2, the stairwells did not descend in a straight vertical alignment in WTC 1 and WTC 2. The horizontal connections, more numerous and lengthy in Stairwells A and C than Stairwell B, could extend more than 100 ft and require several 90 degree turns. In addition to slightly increasing evacuation time (compared to a design with no horizontal transfers), the transfer hallways introduced uncertainty in the minds of the evacuees regarding the correctness of their evacuation path.

> An occupant from a floor in the 60s in WTC1 described the transfer hallways: "As I descended the stairs down to the Mezzanine Level, once or twice I had to exit the staircase through a door and go down a corridor in order to reconnect to the same stairwell. I found this to be extremely disconcerting. Everyone who did this, stopped before they exited the staircase to make sure they were doing the right thing. This slowed us down and there was concern that the door would lock behind us." Interview 1000053 (NIST 2004)

10.3.8 Emergency Responders and Building Authorities

Emergency Responders

In addition to organizing the response to the attacks on the two towers and assisting occupants during their evacuation, building staff and emergency responders had to use the stairwells to attempt access to impacted floors in the buildings. This resulted in small groups of firefighters in bulky bunker gear moving against the flow of occupants down the stairs. This phenomena is often referred to as counterflow. Police and fire department involvement with building occupants was identified by survivors as both an evacuation aid and constraint. The police and firefighters were identified as an evacuation aid by 44 percent of the occupants in WTC 1 and 30 percent of the occupants in WTC 2 and as a constraint to evacuation by 62 percent of the occupants in WTC 1 and 27 percent of the occupants in WTC 2. The lower numbers should be expected since before WTC 2 was hit, emergency responders naturally

concentrated their efforts in WTC 1. Many of those who evacuated early from WTC 2 never encountered police or firefighters in the building.

Inside WTC 1 stairwells, firefighters were sighted by interviewees in all three stairwells, with a concentration on Stair B (from the face-to-face interviews). Also, from the face-to-face interviews, firefighters were sighted as high as the 60s in WTC 1. Interviews 1000576 and 1000645 (NIST 2004) For those meeting firefighters in the stairs, some mentioned slowing down, crowding, and even stopping several times. An occupant in stairwell A of WTC 1 was both slowed down and reassured by the firefighters.

> "We encountered firemen ascending, starting at about the 35th floor. I came to a dead stop numerous times in Stairwell A for about 5 minutes each time to aid the firemen to get up to the problem. The firemen were easy-going, and attempted to put people at-ease. They were also extremely winded and sweating profusely from their climb." Interview 1000103 (NIST 2004)

Figure 10–7 shows an FDNY firefighter ascending a 44 in. (1.1 m) stairwell in WTC 1 on September 11, 2001. Figure 10–8 shows how an occupant and a firefighter in bunker (turnout) gear may not be able to pass one other in a 1.1 m (44 in.) stairwell without either the occupant or the firefighter moving somewhat to the side. Figure 10–8 was not taken in a stairwell from the WTC complex, but was intended to be a generic demonstration of the counterflow phenomena.

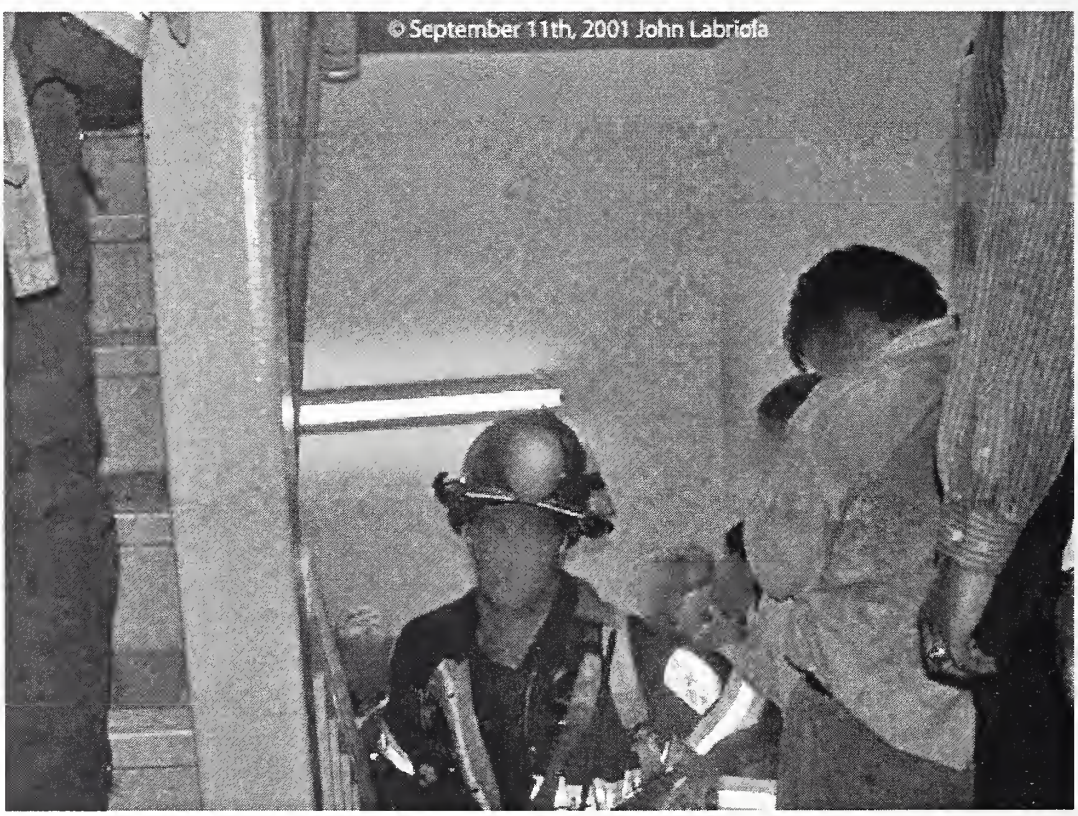

Figure 10–7. Firefighter and occupants using a 44 in. stairwell in WTC 1 on September 11, 2001.

The firefighters provided a sense of security to some occupants in the towers. In some cases, occupants went so far as to show their appreciation. An occupant from WTC 1 Stairwell A recalled encountering firefighters near the 20th floor.

> "Firemen were going up and they were looking exhausted. People were cheering the firemen and some of the firemen said. 'Don't stop, you're almost there.' As we moved aside, we handed the firemen water." Interview 1000722 (NIST 2004)

Throughout the event, emergency responders supported the occupants by performing a variety of actions, including directing occupants to change stairs (especially in WTC 1 when exits were blocked by debris from the collapse of WTC 2), providing directions on how to exit through the Concourse, giving out snacks, water, and oxygen (from air bottles) to occupants in need.

Source: NIST.

Figure 10–8. Occupant and firefighter in bunker gear passing in a generic 44 in. stairwell.

Firefighters reportedly established a rest station somewhere between floors 12 and 20 (Interview 1000543 [NIST 2004]). Firefighters here instructed occupants to drop certain occupants off at this floor for assistance, as well as suggesting that evacuees stop on this floor if they required rest or assistance.

In addition to walking up toward the fire floors, many firefighters moved injured occupants to safety. An occupant inside Stairwell C of WTC 1 heard instruction from floor above to keep to the right.

The respondent then "noticed that the firemen in uniforms were bringing at least two people" down the stairs. "One gentleman had his arms severely burned and one lady who had her head halfway burned and was screaming with pain. After the fireman came down, others came up – several of them. They had gear on their back and each one had an extra hose on their shoulder. I was on the right and was letting them up, and a particular firemen patted me on the left shoulder and said, 'Don't worry, you will be ok.'" Interview 1000697 (NIST 2004)

Impact of Authorities on Occupant Evacuation

In both towers, occupants followed directions from those in a position of authority. In an office emergency, higher rank can mean multiple things. On the floors, occupants followed instructions to leave from supervisors or fire wardens, even though supervisors and wardens may have had the same information as the employee about what was going on. Also, occupants followed directions throughout the building from the building and fire officials who were familiar with the building layout, such as the Port Authority employees, police, firefighters, and building security. Analysis of face-to-face interview data revealed that these instructions included when and where to evacuate the stairs, when and where to change stairs, when to move to the right to let firefighters go up and injured down, or where to travel upon leaving the stairwell.

Workplace Authority

In an emergency, there is usually a combination of reasons why a person begins their evacuation process.[65] However, there is usually one significant reason that finally makes them decide to leave or that weighs more heavily on their decision than the others. When occupants in both towers were asked to name the one thing that made them decide to evacuate, 14 percent of the occupants in WTC 1 and 21 percent of the occupants in WTC 2 said that the reason they evacuated was being told to evacuate. (Telephone Interviews, NIST 2004)

At the first awareness that something was wrong, the occupants could only rely on each other (or themselves, if alone) to understand what had happened and to decide what to do next. Fire alarms sounded in certain areas of WTC 1 (and possibly WTC 2); however, occupants did not generally report the fire alarms as their reason to evacuate. The others on their floor were their subordinates, coworkers, or superiors (supervisors or fire wardens). From a total of 208 face-to-face interviews, 86 people mentioned being instructed to evacuate, as well as their reaction to that instruction. Most respondents began their evacuation when told to leave, whether by a superior or co-worker. Although the percentage was higher when direction came from a superior, it is difficult to draw any conclusion from the face-to-face data since it is not statistically-based and cannot be generalized to the entire population of the buildings. Only one face-to-face interview respondent reported telling their superior to evacuate, and in that isolated case, the superior ignored the instruction.

An occupant from the 40th floor in WTC 1 left the floor due to persuasion by the fire warden:

> "As I was typing the email message, I heard a loud voice say 'Leave.' I kept typing the message when a fire warden grabbed my arm and pulled me out of the seat." The fire warden also pointed this occupant in the direction of the elevators and stairs in addition to instructing the occupant to leave the floor. Interview 1000802 (NIST 2004)

After hearing an explosion from WTC 1, an occupant with workplace authority on a floor in the 60s of WTC 2 instructed others on the floor to leave:

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[65] Nelson and MacLennan. "Emergency Movement." In The SFPE Handbook of Fire Protection Engineering, 2nd Edition. NFPA, Quincy, MA. 1995.

> "I saw fire and burning debris and smelled jet fuel. I ran out of my office and yelled to staff and co-workers to order them to evacuate. We ran to the stairwell." Interview 1000556 (NIST 2004)

And, even after WTC 2 was hit, occupants on a floor in the 50s of WTC 2 remained on their floor discussing what had just happened and what they should do next:

> "Our facilities manager told me it was time to go. We did a quick check of the floor to make sure no one was left behind. In the hallways we saw that everyone was heading in one direction and we followed them to the stair." Interview 1000557 (NIST 2004)

It would appear from the face-to-face interviews that occupants were likely to follow the instruction given by their superior in an emergency. However, even if the final decision to evacuate was prompted by the instruction to evacuate, other factors may have been involved in making that decision, including seeing the plane strike into WTC 1, past experience, or other observations of the event.

Building Authority

Similar to the FDNY role in the WTC towers on September 11, 2001, the building authority played an important role in providing guidance to occupants about where to go once they left their floors, which the occupants frequently followed. The Port Authority personnel were observed giving instructions and directions to occupants at the skylobbies, Mezzanine, and Concourse areas of the WTC towers. Their instructions for some occupants consisted of when and where to leave the stairs, whether to use the elevators, and in WTC 2, when to return to their offices. Port Authority direction consisted of how and where to go through the building and Concourse area in order to leave the WTC complex. In most cases, occupants followed the instructions and welcomed the directions given by the building authority in the towers.

Many noted the tremendous help that building personnel provided at the base of the building. An occupant in WTC 2 noted that the building authorities were present throughout the Concourse:

> "Trade center people were directing us into the Concourse because you couldn't go out Liberty street – they had all those exits closed because there was debris flying all over the street. Security guards were like a human chain telling us which direction to go. We followed the security guards' direction . . . towards Borders." Interview 1000842 (NIST 2004)

An occupant in WTC 1 noted the Port Authority giving directions to occupants on the Mezzanine:

> "As soon as I arrived onto the Mezzanine floor, I saw a chief operating officer giving directions to get onto the stairs [escalator] and go down. He also said not to look out onto the plaza because it was unsafe and dangerous." Interview 1000639 (NIST 2004)

In addition to directing occupants throughout the buildings, there were two cases from the face-to-face interviews where occupants were rescued from their floors by the help of the building authority in

WTC 1. In both cases, the occupants were faced with worsening conditions on their floor and were guided to the stairwells by the official.

> From a floor in the 80s in WTC 1: After preparing their office with wet towels around the doors to prevent the heavy smoke from seeping in, the respondent "saw a beam of light through the smoke, which turned out to be a fireman and a building worker. They told us to drop everything and follow them into the hall that led to the staircase." Interview 1000055 (NIST 2004)

After two unsuccessful attempts to open the jammed door from a floor in the 80s into stairwell A, the heavy smoke on the floor drove the group of coworkers back to their office to wait, until:

> "We heard one of our coworkers in the hall [say that] the Port Authority fellow had opened up the doors to Stairwell A for us." Interview 1000137 (NIST 2004)

10.3.9 Occupant Experience

Experience from the 1993 bombing and other past evacuation experience affected some occupants' actions in 2001. For example, many of those involved in both 1993 and 2001 recalled long evacuation times in 1993, including occupant congestion, smoke in the stairs, and not being allowed to return to the building for weeks after the event. Because of this experience, some occupants started their evacuation as soon as WTC 1 was hit and noted that their experience in 1993 was the principal reason. On the other hand, some occupants performed specific activities that they wished they had performed in 1993, such as calling home so their parents/family wouldn't worry about them and taking certain belongings in case they couldn't return to the building right away.

Even though occupants of the towers may not have been present for the 1993 bombing, the bombing event may have played a role in their 2001 evacuation. Many of those present in 1993 shared their experiences with other employees both before and during the 2001 attack:

> "I was not in the building in 1993, but a lot of people who had been there during the 1993 bombing were very helpful because they were exiting faster. They knew that every second counted based on that previous experience and I took my cue from them." Interview 1000518 (NIST 2004)

> "I wasn't at the building in 1993, but I knew that it took over an hour to get down the stairs, which influenced my decision to use the elevators." Interview 1000731 (NIST 2004)

10.3.10 Mobility-Impaired Occupants

When evacuating a high-rise building, many different physical and medical conditions can affect travel ability on stairs. As the total distance traveled to reach an exit increases, the number of people unable to successfully complete the evacuation without resting or requiring assistance increases. In the WTC, stair travel challenged occupants with certain conditions, such as wheelchair use, pregnancy, asthma, visual

impairment, physical impairment, obesity, arthritis, and old age. The current NYC Building Code defines a physical disability as any one of the following:

- Impairment requiring the use of a wheelchair; or
- Impairment causing difficulty or insecurity in walking or climbing stairs or requiring the use of braces, crutches, or other artificial supports; or
- Impairment caused by amputation, arthritis, spastic condition or pulmonary, cardiac, or other ills rendering the individual semi-ambulatory; or
- Total or partial impairment of hearing or sight causing insecurity or likelihood of exposure to danger in public places; or
- Impairment due to conditions of aging.

Evacuation of WTC 1 and WTC 2 during the 1993 bombing identified an inefficiency at the World Trade Center in evacuating the mobility-impaired. The Report of the World Trade Center Review Committee in 1995 indicated: "Evacuation of persons with disability from the World Trade Center was slow and arduous, the [sic] Committee proposes that methods of evacuation should be studied to provide equally safe egress for these building occupants." (New York City 1995)

Despite introduction of evacuation chairs and a buddy system for pre-identified mobility-impaired occupants, 51 percent of the occupants in WTC 1 and 33 percent of the occupants in WTC 2 in 2001, noted that injured and disabled persons in the stairwell were a constraint to evacuation. However, occupants were quick to aid these individuals by guiding them throughout their evacuation or simply moving to the side of the stairwell to let those who were injured and others in need pass by when they could.

> In WTC 1, "someone was being carried down in some kind of handicapped apparatus and was strapped in. The occupant was being carried by two fellow occupants around the 30s. We stopped to allow them access." Interview 1000834 (NIST 2004)

In some cases, occupants noted passing slower mobility-impaired individuals in the stairs and even slowing or stopping behind them.

> In WTC 2, "we saw an [occupant] who was hyperventilating. [The occupant] was walking down the stairs with assistance. We slowed down and came to a stop [because] we couldn't get around the two [occupants]." Interview 1000556 (NIST 2004)

> In WTC 1, two occupants were helping an overweight occupant evacuate the building. During one of the helper's descent down the stairs, the helper noted that "we took up the entire width of the stairway and no one could get around us until we came to a landing." Interview 1000093 (NIST 2004)

Finally, some occupants reported mobility-impaired occupants waiting on the stairs and/or landings for others to help them or to be rescued by the fire department. Many respondents recalled two specific occupants from WTC 1 who weren't able to evacuate the building in time. These included an occupant in a wheelchair waiting with a friend on the stairs and an occupant with arthritis waiting at a fire department rest stop somewhere between floors 12 and 20.

Mobility-Impaired Occupants and Mortality below the 92nd floor in WTC 1

Several occupants perished assisting mobility-impaired colleagues (Fahy and Proulx 2003) and many more occupants and emergency responders risked their lives assisting mobility-impaired colleagues who successfully evacuated. However, for occupants where a likely mechanism contributing to unsuccessful evacuation could be identified, being trapped by debris on the starting floor, delayed evacuation initiation (of statistical outlier magnitude), or performing emergency response building responsibilities accounts for the majority of the below the impact region deaths.

10.4 EVACUATION SIMULATIONS

The purpose of modeling evacuation from the World Trade Center towers was to obtain evacuation times for a variety of scenarios in order to provide additional context with which to understand the September 11, 2001 evacuation of WTC 1 and WTC 2. Table 10–2 shows each of the six general egress simulations performed, along with details regarding the evacuation type (full building evacuation or phased evacuation, also known as defend-in-place), the number of evacuees included in the simulation, the input response delay, which models were used, and any other relevant information about the simulation. There were five full building evacuations and one phased evacuation simulated. The full building evacuation simulations explored the effect on the total evacuation time (or number of successful evacuees if the time was fixed) with respect to the number of simulated evacuees, the presence or absence of building damage (observed on September 11, 2001), and the type of model used for the simulations. It should be noted that none of the models used in this analysis have been validated for emergency evacuation in buildings as large as 110 stories.

10.4.1 Egress Simulation Results

Phased Evacuation

The following section is a summary of the egress simulation results. For a more complete discussion of egress modeling inputs, assumptions, limitations, and results, refer to Appendix D: Egress Modeling. The purpose of simulation 1, phased evacuation, was to understand not only the time necessary to perform a phased evacuation, but to compare the results using three different egress models: Simulex, EXIT89, and buildingEXODUS.

Table 10–3 shows the total phased evacuation times for each model. The three models simulate a total phased evacuation time between 3½ and 4 minutes for all 600 occupants, assuming that evacuees start evacuating immediately. If the evacuees were randomly assigned a delay time between 0 and 10 minutes, the simulated total evacuation time was between 11 and 11½ min for all 600 occupants. Phased evacuation is an efficient strategy to quickly remove occupants most at risk quickly from 'routine' emergencies, or those that fit within the design envelope of the life safety systems.

Table 10–2. Egress simulation matrix.

Scenario	Full Building or Phased Evacuation	Number of Evacuees Simulated	Response Delay	Model(s) Used	Notes
1	Phased	600	Zero 0 - 10 min	Simulex EXODUS EXIT89	• Occupants travel three floors below fire floor
2	Full Building	19,800	Zero 0 - 10 min	EXODUS EXIT89	• Fully-occupied, without visitors • No damage
3	Full Building	25,000	Zero 0 - 10 min	EXODUS EXIT89	• Fully-occupied, with visitors • No damage
4	Full Building	8,800	Zero 0 - 10 min	EXODUS EXIT89	• September 11, 2001 population • No damage
5a	Calibration Simulation	7,200	6 – 30 min	EXODUS	• Stop and Go • Ground – Floor 90 • Damage above Floor 90
5b	Full WTC 1, with damage	16,000	6 – 30 min	EXODUS	• Stop and Go • Ground – Floor 90 • Damage above Floor 90
6a	Calibration Simulation	7,400	2 – 17 min (Above Floor 77) 6 – 30 min (Ground to Floor 76)	EXODUS	• Stop and Go • Ground – Floor 76 • No Damage
6b	Elevator, WTC 2	19,800	Zero	ELVAC	• 14 Minute Elevator Simulation
6c	Full WTC 2, With Damage	17,260	2 – 17 min (Above Floor 77) 6 – 30 min (Ground to Floor 76)	EXODUS	• Stop and Go • Ground to Floor 107 for first 16 min • Ground to Floor 77 for time range 17 min – 72 min

Table 10–3. Results for phased evacuation simulations.

Evacuation Model	Occupant Type, Characteristics	Evacuation Time (s)	
		No Delay	0 – 10 min Delay
Simulex	All office staff 60 % men 40% women	240	690
EXODUS	5 % males, age 17 - 29 38 % males, age 30 - 50 21 % males, age 51 - 80 3 % females, age 17 - 29 22 % females, age 30 - 50 11 % females, age 51 - 80	243	660
EXIT89	All medium body size Emergency speed	210	690

Full Building Evacuation

The purpose of simulations 2, 3, and 4 was to explore the effect of additional building occupants on the total building evacuation time. The three populations selected were (1) the NIST estimate of building population on September 11, 2001, (2) the NIST estimate of a fully-occupied tower without visitors (19,800 occupants), and (3) the NIST estimate of a fully-occupied tower including visitors (25,500 oceupants). Note that in 2005, Port Authority estimated that the maximum population of WTC 1 or WTC 2 would not likely have exceeded 20,000.[66] Figure 10–9 shows the model results for the three building populations using the results from the buildingEXODUS model. The slope of the regression was identical whether comparing the September 11, 2001 population evacuation time to fully-occupied building evacuation time ([112 min - 55 min] / (19,800 – 8,800) = 5.2 min per thousand additional occupants) or compared to fully-occupied with visitors building evacuation time ([142 min – 55 min] / (25,600 – 8,800) = 5.2 min per thousand additional occupants). Thus, for a given building geometry, and a number of other important simulation assumptions, adding additional occupants to a building population resulted in a linear increase in total building evacuation time.

Extrapolation of Evacuation Time for a Fully-Occupied Tower on September 11, 2001

In Chapter 4.1 of this report, NIST estimated that the number of successful evacuees from WTC 1 on September 11, 2001 was 7,500, the total of which required roughly 100 minutes to exit the building. As shown in Figure 10–9 and Table 10–4, the buildingEXODUS model estimated that a fully-occupied building (population 25,500) required approximately 2.6 times as long (142 / 55 = 2.6) as a building with a September 11, 2001 occupant load; therefore, on September 11, 2001, a fully-occupied WTC tower with visitors, may have required roughly (100 x 2.6) = 260 min (over 4 hours) to fully evacuate.

Using the same logical approach, if WTC 1 had been occupied by approximately 20,000 occupants on September 11, 2001 (fully-occupied without visitors), the evacuation would have taken (112 min / 55 min = 2.0 x 100 min = 200 min) over 3 hours to complete.

Table 10–4. Total building evacuation time (simulated) for various occupant loads.

Evacuation Model	Evacuation Initiation Delay Input	Evacuation Time (min): 8,800 occupants	Evacuation time (min): 19,800 occupants	Evacuation time (min): 25,500 occupants
EXODUS	10 Minute Delay	55	112	142
	No Delay	52	110	141
EXIT89	10 Minute Delay	71 – 74	92 – 113	119 – 139
	No Delay	58 – 78	97 – 117[67]	114 – 140

[66] Bhol, Saroj. PANYNJ (September 21, 2005). Email from S. Bhol to S. Sunder in response to NIST question.

[67] The underlying theory for people movement in EXIT89 is based upon the work of Predtechenskii and Milinskii. They observed an inverse relationship between density and speed for three different types of movement: emergency, normal, and comfortable. The effect of crowding (density) on overall evacuation speed was greater when no delay time was assumed. A delay time when 19,800 occupants were present, according to EXIT89, spaces the occupants out and increases overall evacuation efficiency. This was not found to be the case for all occupant loads (25,500).

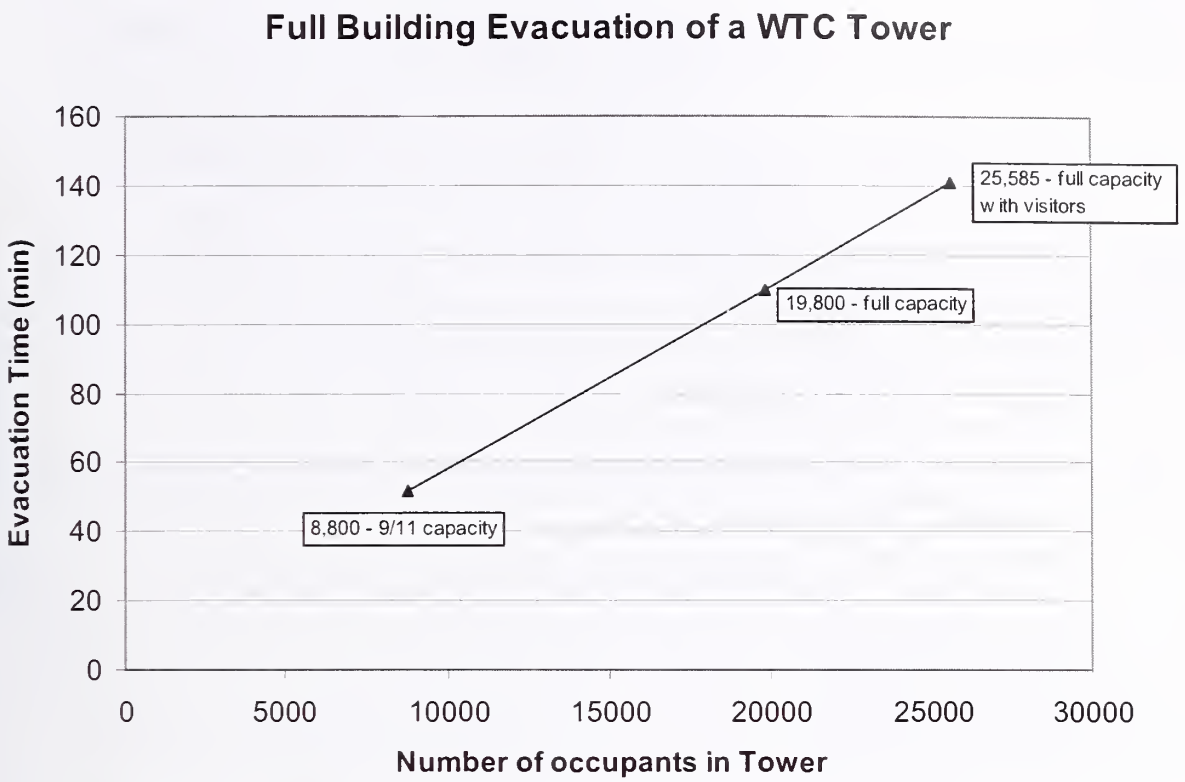

Figure 10–9. Simulation of full building evacuation of a WTC tower with different occupant loads.

Estimated Occupant Mortality from a Fully-Occupied WTC Tower on September 11, 2001

Scenarios 5 and 6 were simulated in order to estimate the consequences of a fully-occupied, without visitors (total building population: 19,800) from WTC 1 or WTC 2 on September 11. Each tower was simulated with a September 11 population, and model assumptions and inputs (such as evacuation initiation delay time) were refined in order to roughly match the actual outcome on September 11. After the buildingEXODUS model results were determined to resemble gross characteristics of the September 11 evacuation, more occupants (fully-occupied building, without visitors) were added, and the results are presented below.

WTC 1 was assumed to have no passable stairwell above floor 91 starting at time zero. Elevators were assumed to be rendered inoperable. The simulation was ended at 103 minutes and any simulated occupant remaining in WTC 1 was assumed to have perished. The simulation shows that 69 percent of all occupants (13,600 occupants out of 19,800) would have evacuated WTC 1 prior to collapse: 0 percent (0 out of 3,800) from above the impact zone and 85 percent (13,600 out of 16,000) from below the impact zone. Table 10–5 summarizes the results of scenarios 5 and 6.

Table 10–5. Simulated evacuation results for fully-occupied WTC 1 and WTC 2 on September 11, 2001.

Building	Total Number of Occupants at t = 0.0	Potential Number of Evacuees	Occupants Remaining in Building at Collapse	Occupants Trapped Above Floors of Impact	Percentage of Occupants Who Successfully Evacuated Relative to Where They Started		
					Total	Below Impact	Above Impact
WTC 1	19,800	16,000	6,200	3,800	69 %	85 %	0 %
WTC 2	19,800	17,260	8,377	3,900	58 %	75 %	44 %
Total	39,600	33,260	14,577	7,700	63 %		

Occupants of WTC 2 were assumed to use elevators for a period of 16 minutes, after which all elevators were assumed inoperable. After 16 minutes, when WTC 2 was attacked, it was assumed that no occupants survived above floor 77. The simulation was ended after 72 minutes, when WTC 2 collapsed. The simulation showed that 11,423 of the 19,800 occupants, or 58 percent of the initial population, would have successfully evacuated. Of the 11,423 simulated occupants, 8,883 evacuated using the stairwells, while 2,540 simulated occupants evacuated using elevators. Of the 8,377 occupants who remained in the building at the time of collapse, 3,900 simulated occupants were trapped above floor 77. Another 4,477 were evacuating from below the 78th floor when WTC 2 collapsed: 1,231 simulated occupants were initially above the 77th floor, while 3,246 did not evacuate despite starting on a floor below the 78th floor. The initial population of occupants below the 78th floor was 12,783. Therefore, (3,246 / 12,783) 25 percent of the occupants who started below the impact floors did not successfully evacuate. Similarly, 3,900 of the initial 7,017, or 56 percent of the occupants at or above the impact region at 8:46:30 a.m. in WTC 2 did not successfully evacuate. The simulation showed that 549 occupants initially above floor 77 successfully evacuated using stairwells, while only 3 of the 549 simulated occupants originated above floor 100.

When combining the evacuation modeling results for WTC 1 and WTC 2, assuming 19,800 occupants in each tower and assuming that the aircraft impacts and collapses occurred at the same times as they did on September 11, 2001, about 14,000 occupants may have perished, not including any emergency responders, aircraft passengers, or bystanders.

10.4.2 Egress Modeling Conclusions

The egress modeling revealed three principal insights into the evacuation of WTC 1 and WTC 2 on September 11, 2001. First, while not an appropriate strategy for an emergency the scale of September 11, 2001, phased evacuation, under certain circumstances, moves occupants most at risk to a place of relative safety much more quickly and with less total impact upon building tenants than full building evacuation. Second, additional occupant load in a WTC tower (compared to September 11, 2001) resulted in a linear increase in total building evacuation time. Third, assuming that the ratio of observed to simulated evacuation time of 2.6 would extend to the fully-occupied with visitors (25,500 occupants), full building evacuation scenario, WTC 1 would have taken over four hours to fully evacuate under the conditions of September 11, 2001.

Chapter 11
FINDINGS

The evacuations of World Trade Center (WTC) 1 and WTC 2 on September 11, 2001, were documented and analyzed. In order to provide context for the 2001 evacuations, relevant historical egress events were explored. The evolution of the egress and communication systems, as well as the emergency procedures within WTC 1 and WTC 2 was documented. Over 1,000 interviews, using advanced interrogatory methods, were conducted. Hundreds of published accounts from a variety of sources were collected and analyzed. Emergency call records, emergency communication transcripts, Occupational Safety and Health Administration complaints, and Port Authority of New York and New Jersey design records and plans were analyzed. Analysis and compilation resulted in the following conclusions.

11.1 BUILDING POPULATION AND DEMOGRAPHICS

- There were 8,900 ± 750 people in WTC 1 at 8:46:30 a.m. on September 11, 2001. Of those, 7,470 (or 84 percent) survived the attacks, while 1,462 – 1,533 occupants were killed in WTC 1. The National Institute of Standards and Technology (NIST) Investigation found that at least 107 occupants were killed below the 92nd floor.

- There were approximately 8,540 ± 920 people in WTC 2 at 8:46:30 a.m. on September 11, 2001. Of those, 7,940 (or 93 percent) survived the attacks, while 630 – 701 occupants were killed in WTC 2. The NIST Investigation found that at least 11 occupants were killed below the 78th floor.

- Sixty-seven percent of WTC 1 occupants and 51 percent of WTC 2 occupants had started working at the World Trade Center during the four years prior to September 11, 2001.

- Two-thirds of WTC 1 and WTC 2 occupants participated in at least one fire drill in the twelve months prior to September 11, 2001. Seventeen percent of the occupants did not participate in a fire drill during that time period, and 17 percent did not remember whether they had participated in a fire drill during that time period.

- Nearly all occupants (93 percent) who participated in a fire drill were instructed about the location of the nearest stairwell.

11.2 EVACUATION

- Approximately 87 percent of WTC occupants, and over 99 percent of those below the floors of impact, were able to successfully evacuate.

  - At 9:02:59 a.m., when WTC 2 was hit and 17 minutes after WTC 1 was hit, 21 percent of survivors had exited WTC 1 and 41 percent of survivors had exited WTC 2.

  - By 9:37 a.m., 22 minutes before collapse, 95 percent of survivors had exited WTC 2.
  - At 9:58:59 a.m., when WTC 2 collapsed, 88 percent of survivors had exited WTC 1.
  - By 10:12 a.m., 16 minutes before collapse, 95 percent of survivors had exited WTC 1.

- Occupants of WTC 1 overwhelmingly initiated their own evacuation. The NIST Investigation found no evidence that public address system announcements were heard by occupants of the building, although the fire command station was attempting to make announcements.

- Self-evacuation and use of elevators for 16 minutes in WTC 2 saved roughly 3,000 lives.

- During the last 20 minutes before each building collapsed, the evacuation rate in both buildings had slowed to about one-fifth the immediately prior evacuation rate. This suggests that *for those seeking and able to reach and use the undamaged exits and stairways*, the egress capacity (the number and width of exits and stairways) was adequate to accommodate survivors.

- In WTC 1, the average surviving occupant spent approximately 48 seconds per floor in the stairwell. That does not include any time prior to entering the stairwell, which was often substantial.

- Some occupants of WTC 1 delayed or interrupted their evacuation resulting in over 100 deaths below the impact region.

- The NIST Investigation found no evidence to indicate that anyone who was above the 91st floor in WTC 1 after the airplane impact survived. This was due to the fact that the stairwells and elevators were destroyed and helicopter rescue, despite several attempts by both occupants and aircraft, was not possible.

- In WTC 2, approximately 75 percent of the occupants above the 78th floor at 8:46:30 a.m. had successfully descended below the 78th floor prior to the airplane impact at 9:02:59 a.m. This occurred in spite of conflicting announcements, first urging people to return to their offices around 9:00 a.m., and then informing them that they may initiate an evacuation if conditions warranted around 9:02 a.m.

- The NIST Investigation found evidence that 18 people successfully used Stairwell A in WTC 2 to leave the building after being on or above the 78th floor when Flight 175 hit the building. One of the 18 later died from injuries sustained on September 11, 2001. Additionally, at least two people went to or above the 78th floor after having been below the 78th floor at the time of impact in order to assist trapped people and did not survive the collapse of WTC 2.

- Minutes prior to the collapse of WTC 2, an NYPD Emergency Services Unit (ESU) officer radioed from a floor in the 20s to the outside that he was having trouble ascending the stairwell due to the large number of occupants descending (Interview 24 NYPD [NIST 2004]). While the origin of the occupants remains unknown, only 11 occupants who started evacuating below the impact region were known not to have survived.

- Computer egress modeling indicated that a full capacity evacuation of a single WTC tower with approximately 20,000 occupants required a minimum evacuation time of 1 h and 50 min. Given that the actual evacuation time on September 11, 2001, was about 100 min without elevator use, a full capacity evacuation of the WTC towers by 20,000 people would likely have required somewhat greater than 3 h (2 times 100 min). To achieve a significantly faster total evacuation at full capacity would have required increases in egress capacity (number and width of exits and stairways).

- Egress modeling indicates that, had WTC 1 and WTC 2 been fully-occupied on September 11, 2001, with approximately 20,000 occupants each, about 14,000 occupants may have perished in the building collapses.

11.3 DELAYS IN EVACUATION

- Occupants in WTC 1 delayed starting their evacuation because environmental cues (information from the physical environment that something was terribly wrong) and floor (increased distance to safety) caused people to seek additional information. Next, the act of seeking additional information, that is "milling" about to make sense out of the situation, led people to take actions to prepare to evacuate. Finally, taking those actions to prepare to evacuate delayed the initiation of actually evacuating. Although there were other factors that had lesser influence on what people did, the paths of causal influence that defined the main process that led people to delay in the evacuation of WTC 2 on September 11, 2001 were identical to those for WTC 1, with one decided difference. Perceived risk was predicted by environmental cues and initial floor and also contributed to seeking additional information and taking pre-evacuation actions in WTC 2, while the effect of perceived risk was substantially lower in WTC 1.

- Starting floor (increased distance to safety) substantially increased the odds that people would encounter environmental cues. Floor also increased delay in starting evacuation (this relationship is elaborated upon in much greater detail in Chapter 10 of this report), which, in turn, also increased the chances that people would encounter environmental cues. Observation of environmental cues (information from the physical environment that something was terribly wrong) in the stairwell had a large and direct effect on increasing the amount of time that people spent, on average, in their evacuation stairwell. In addition to this multi-step process with environmental cues as the key predicting variable, interrupting the process of evacuation for any reason increased the amount of time, on average, that people used to descend their evacuation stairwell.

- Contrary to the perceptions of the occupants, counterflow in WTC 1 was determined by causal modeling analysis not to be a significant predictor of increased total evacuation time while in the stairwells when compared to other factors, including evacuation interruption and environmental cues.

- Occupants in WTC 1 delayed starting their evacuation because environmental cues (information from the physical environment that something was terribly wrong) and floor (increased distance to safety) caused people out to find additional information, most likely information about what was going on and what they should do about. Next, the act of seeking additional information, that

is "milling" about to make sense out of the situation, led people to take actions to prepare to evacuate. Finally, taking those actions to prepare to evacuate delayed the initiation of actually evacuating. Although there were other factors that had lesser influence on what people did, the main paths of causal influence that defined the main process that led people to delay in the evacuation of WTC 2 on September 11th were identical to WTC 1 with one decided difference. This was that perceived risk was predicted by environmental cues and initial floor and also contributed to seeking additional information and taking pre-evacuation actions in WTC 2 while the effect of perceived risk was substantially lower in WTC 1. This was likely the case because WTC 1 was hit without warning, and only the people in WTC 2 had time to wonder (perceive) if their tower was going to be a target.

11.4 EMERGENCY MANAGEMENT AND PLANNING

- Building occupants, 9-1-1 operators, fire department dispatch, WTC building officials, and Port Authority personnel lacked adequate situational awareness despite nearly constant cross-communications. Many opportunities to communicate important information in a timely manner were missed, such as telling building occupants the general location of the impact region or whether to evacuate or not.

- Faced with an uncertain situation, occupants of both buildings received conflicting feedback / advice from a variety of sources (including 9-1-1 operators, FDNY, family and friends, and the Port Authority) regarding whether to evacuate, whether to break windows, and what the nature of their situation was.

- World Trade Center occupants were inadequately prepared to encounter horizontal transfers during the evacuation process and were occasionally delayed by confusion as to whether the hallway led to a stairwell and confusion about whether the transfer hallway doors would open or be locked.

- In addition to an announcement in WTC 2 just prior to the airplane impact, announcements were made from the fire command station in the lobby of WTC 2 after the aircraft impact, although the NIST Investigation found no evidence that any surviving occupants heard these announcements.

- The decision to establish the primary evacuation route underground through the Concourse (mall) and out up to street level by WTC 5 (commonly recalled as being by the Borders Bookstore) prevented a significant number of injuries and/or deaths.

- The first "first responders" were colleagues and regular building occupants. Acts of everyday heroism saved many people whom traditional emergency responders would have been unable to reach in time.

11.5 OCCUPANTS WITH MOBILITY IMPAIRMENTS

- Approximately 1,000 surviving occupants (a projection of the 6 percent reported in the telephone interviews) of WTC 1 and WTC 2 had a limitation that impacted their ability to evacuate, including recent surgery or injury, obesity, heart condition, asthma, elderly or otherwise requiring

assistance to walk, pregnancy, and others. The most frequently reported disabilities were recent injuries and chronic illnesses; the number of occupants requiring use of a wheelchair was very small, relative to the frequency of other mobility impairments.

- While many mobility-impaired individuals were able to successfully evacuate, often with assistance from co-workers or emergency responders, others were temporarily removed from the stairwells in order to allow more able occupants to evacuate the building (such as the rest station low in WTC 1 [somewhere between floors 12 and 20]). It remains unclear whether all of the mobility-impaired occupants and the helpers were able to successfully evacuate on September 11, 2001. No evidence of a similar rest station in WTC 2 was found.

- While the mobility status of every decedent known to be below the impact region (107) in WTC 1 could not be determined, it does not appear that mobility-impaired individuals were significantly overrepresented among the decedent population.

- Mobility-impaired occupants were not universally accounted for by existing evacuation procedures, as some were left by colleagues (later assisted by strangers), while others chose not to identify their mobility impairment to any colleagues.

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Chapter 12
REFERENCES

1912. The Equitable Building Fire. *Quarterly of the National Fire Protection Association* 5, no. 4:408-445.

1977. Triangle Shirtwaist Toll Of 145 Is Still Largest for U.S. Industrial Fires. *Fire Engineering* 130, no. 8:55-58.

Adler, J. 2002. Five Who Survived. *Newsweek*, September 9.

ASME 2000. Safety Code for Elevators and Escalators ASME 17.1, American Society of Mechanical Engineers, New York.

Blalock, H. 1972. *Social Statistics*. New York: McGraw Hill.

BOMA 2001. Experience Exchange Report, Building Owners and Managers Association, New York.

Bouchard, J. 1982. NFPA Summary Report on the Holiday Inn Fire, Kerney, Nebraska. *NFPA Journal* 76, no. 6:20-24.

Breasted, Mary. 1977. 100,000 Leave New York Offices As Bomb Threats Disrupt City; Blast Kills One and Hurt Seven. *New York Times*.

Bukowski, R.W. and Kuligowski, E.D. 2003. The Basis for Egress Provision in U.S. Building Codes, Proceedings of InterFlam 2004, Interscience Communications, London.

Bukowski, R.W. and Moore, W. D. 2003. Fire Alarm Signaling Systems. 3rd (Third) Edition. National Fire Protection Association, Quincy, MA.

Bukowski, R. W. and W. D. Moore. 2003. *Fire Alarm Signaling Systems*. Quincy, MA: National Fire Protection Association.

Cochrane, W. G. 1977. *Sampling Techniques*. New York: John Wiley & Sons.

Couchon, D. 2001. For Many on Sept. 11, Survival Was No Accident . *USA Today*, December 19.

Demers, D. 1980. Familiar Problems Cause 10 Deaths in Hotel Fire. *NFPA Journal* 74, no. 1:52-56.

DiMarco, D. 2004. Tower Stories, The Autobiography of September 11, 2001, Revolution Publishing, New York.

Fahy, R. F. 2001. Verifying the Predictive Capability of EXIT89. Paper presented at 2nd International Symposium on Human Behaviour in Fire.

Fahy, R. F. 1999. User's Manual, EXIT89 v 1.01, An Evacuation Model for High-Risc Buildings. Quincy, Ma, National Fire Protection Association.

Fahy, R. F. and G. Proulx. 2003. Database of First-Person Accounts from Survivors of the World Trade Center Evacuation on September 11, 2001 conducted as part of report NIST NCSTAR 7-A.

Fasullo, E. 1995. The Port Authority of New York and New Jersey, New York, personal communication to R. Visconti, New York City Dept. of Buildings. January 27. WTCI-159-P

Fisher, R. P., K. H. Brennan, and M. R. McCauley. 2002. The Cognitive Interview Method to Enhance Eyewitness Recall. In *Memory and Suggestibility in the Forensic Interview*, edited by Eisen, M. L., J. A. Quas, and G. S. Goodman (Mahweh, New Jersey: Lawrence Erlbaum).

Fisher, R. P., K. L. Falkner, M. Trevisan, and M. R. McCauley. 2000. Adapting the cognitive interview to enhance long-term (35 years) recall of physical activities. *Journal of Applied Psychology* 85, no. 2:180-189.

Fruin. J. J. 1987. Pedestrian Planning and Design, Revised Edition. Elevator World, Incorporated, Mobile, AL.

Galea, E. R., P. Lawrence, S. J. Blake, S. Gwynne, and Westeng H 2004. A Preliminary Investigation of the Evacuation of the WTC North Tower Using Computer Simulation. 167-180. London, England, Interscience Communications Limited. 3rd International Symposium on Human Behaviour in Fire.

Geiselman, R. E., R. P. Fisher, D. Mackinnon, and H. Holland. 1986. Enhancement of eyewitness memory with the cognitive interview. *American Journal of Psychology* 99:385-401.

Gwynne, S., E.R. Galea, P. J. Lawrence, M. Owen, and L. Filippidis. 1999. A Review of the Methodologies used in the Computer Simulation of Evacuation from the Built Environment, Building and Environment, 34, 741-749.

Gwynne, S., E. R. Galea, P. J. Lawrence, and L. Filippidis. 2001. Modeling Occupant Interaction with Fire Conditions Using the buildingEXODUS Model. *Fire Safety Journal*, 36, 327-357.

Gwynne, S., E. R. Galea, P. J. Lawrence, M. Owen, and L. Filippidis. 1998. A Systematic Comparison of Model Prediction Produced by the buildingEXODUS Model and the Tsukuba Pavilion Evacuation Data, *Applied Fire Science*, Vol. 7, No. 3, 235-266.

Hayne, W. G. 1945. Report of the Collision of U.S. Army Air Force Bomber with the Empire State Building at 78th and 79th Floors. 1-15. New York, New York Board of Fire Underwriters.

IES 2000. Simulex Technical Reference; Evacuation Modeling Software. Integrated Environmental Solutions, Inc.

IES 2001. Simulex User Manual; Evacuation Modeling Software. Integrated Environmental Solutions, Inc.

Isner, M. S. 1990. Five Die in High-Rise Office Building Fire. *NFPA Journal* 84, no. 4:50-59.

Isner, M. S. and T. J. Klem. World Trade Center Explosion and Fire, New York, New York, February 26, 1993. Fire Investigation Report. 1993a. Quincy, MA, National Fire Protection Association.

Isner, M. S. and T. J. Klem. 1993b. Explosion and Fire Disrupt World Trade Center. *NFPA Journal*:91-104.

Ivins, Molly. 1977. Most Stay Calm As Evacuations Halt Workday. *New York Times*.

Jones, W. W., G. P. Forney, R. D. Peacock, and P. A. Reneke. Technical Reference for CFAST: An Engineering Tool for Estimating Fire and Smoke Transport. Tech. Note 1431. 2000. Natl. Inst. Stand. Technol.

Keating, J. and E. Loftus. Post Fire Interviews. 1984. Development and Field Validation of the Behavioral Sequence Interview Technique. NBSIR 84-477. 1984. Nat. Bur. Stand. (U.S.).

Klote, J. H. 1993. A Method of Calculation of Elevator Evacuation Time. *Journal of Fire Protection Engineering* 5, no. 3:83-95.

Levy, M. P. 1965. The Port of New York Authority, New York, personal communication to M. Yamasaki, Minoru Yamasaki & Associates, New York. September 29.

Memorandum from John M. Kyle (PONYA) to Guy F. Tozzoli (PONYA), May 9, 1966. "World Trade Center – New York City Building Code – Proposed Revision."

Murphy, Dean E. 2002. *September 11: An Oral History*. New York: Doubleday.

New York 1973. Fire Safety in Office Buildings, New York City - Local Law 5, The City of New York. January 18.

New York 1984. Fire Safety in Buildings, Including Hotels, New York City - Local Law 16, The City of New York. .

New York 1995. The Report of the World Trade Center Review Committee. The City of New York.

Nillson, L. 2000. Remembering actions and words. In *The Oxford handbook of Memory*, edited by Tulving, E. and F. I. M. Craik (New York: Oxford University Press).

NIST 2004a. NIST WTC Face-to-Face Interview Data Set. 2004. Gaithersburg, MD, Natl. Inst. Stand. Technol.

NIST 2004b. NIST WTC Emergency Responder Interview Data Set. 2004. Gaithersburg, MD, Natl. Inst. Stand. Technol.

NYCBC 1968. Building Code – Local Law No. 76 of the City of New York, New York.

NYCBC 2001. Building Code of the City of New York, 2001 Edition, Gould Publications, Binghamton, NY.

PANYNJ Undated. "WTC – CHANGES TO EVACUATION SYSTEMS AFTER 1993." The Port Authority of New York and New Jersey. WTC-115-P

PANYNJ 1995. The Port Authority of NY & NJ World Trade Center Fire Safety Plan (Towers One and Two), The Port Authority of New York and New Jersey, New York. WTCI-13-NYC.

PANYNJ 1996. WTC Fire Safety 1996. Video. WTCI-463-P

PANYNJ 2001a. Port Authority of New York and New Jersey Radio Communications Transcripts from September 11, 2001.

PANYNJ 2001b World Trade Center Emergency Procedures Manual 2001 – Confidential. The Port Authority of New York and New Jersey.

PANYNJ 2001c. World Trade Center Space Book Plan, Building 1 and Building 2, Port Authority Real Estate Department, The Port Authority of New York and New Jersey, New York.

Powers, W. R. 1975. One World Trade Center Fire New York, N.Y., February 13, 1975. 1-15. Boston, MA, National Fire Protection Association.

Powers, W. R. 1970. One New York Plaza Fire, New York, N.Y., August 5,1970. 1-15.. New York, New York Board of Fire Underwriters.

Predtechenskii, V. M. and A. I. Milinskii. 1978. Planning for Foot Traffic in Buildings. New Delhi: Amerind Publishing Co. Pvt. Ltd.

Schank, R. C. and R. Abelson. 1977. *Scripts, Plans, Goals, and Understanding*. Nillsdale, NJ: Erlbaum.

Sharry, J. A. 1974. South America Burning. *Fire Journal*, 1974, 23-33.

Solomon, J., 1968. Emory Roth and Sons, New York, personal communication to M. Levy, The Port of New York Authority, New York. January 25. WTCI-477-P

Solomon, J., 1975. Emory Roth and Sons, New York, personal communication to M. Levy, The Port of New York Authority, New York. February 18.

Templer, J. 1992. Staircase: History and Theories. MIT Press , Cambridge, MA.

Willey, A. E. 1972. High Rise Building Fire, São Paulo, Brazil. *Fire Journal*, 1972, 7-108.

Williams, F. D. 1990. SLAM: The Influence of S.L.A. Marwill on the United States Army. In *TRADOC*, (Ft. Monroe, VA: U. S. Army).

Appendix A
TELEPHONE INTERVIEW SCRIPT

I would like to start by getting some background information. What year did you first start working at the World Trade Center? RANGE: 1975 - 2001

SE 1975 2001

DK 9998

RF 9999

«YRWRK»

On September 11th, 2001, were you in any of the following positions with the World Trade Center?

Port Authority Staff 1

Fire Safety Staff 2

Floor Warden or Searcher 3

Maintenance or Security Staff 4

NONE OF THESE 0 X

DK 8

RF 9

«ROLES_01»

«ROLES_02»

«ROLES_03»

«ROLES_04»

During the year from September 11th, 2000 to September 11th, 2001, how many fire drills did you take part in at the World Trade Center?

SE 0 99

NONE 00 => SWLOC

DK 98 => SWLOC

RF 99 => SWLOC

«FIRED»

During these drills, were you ever instructed about the location of the emergency stairwell nearest to your office?

YES 1

NO 2 => SWLOC

DK 8 => SWLOC

RF 9 => SWLOC

«DEXIT»

How many emergency stairwells were you shown?

ONE 1

TWO 2

THREE3 => LVFSW

OTHER, SPECIFY 7 O

DK 8

RF 9

«HMEXT»

«O_HMEXT»

Before September 11th, had you learned in other ways about the locations of the three emergency stairwells?

YES 1

NO 2

DK 8

RF 9

«SWLOC»

SKIP IF NO FIRE DRILLS

=> USESW

Else => +1

if FIRED=00,98-99

«SOUT1»

During any of the fire drills, did you leave your floor using one of the stairwells?

YES 1

NO 2 => USESW

DK 8 => USESW

RF 9 => USESW

«LVFSW»

Which stairwells did you use?

STAIRWELL A 1

STAIRWELL B 2

STAIRWELL C 3

OTHER, SPECIFY 7 O

DK 8

RF 9

«WHSW1_01»

«WHSW1_02»

«WHSW1_03»

«WHSW1_04»

«O_WHSW1»

Which side of the building was the stairwell located on?

=> +1

if NOT WHSW1=8

NORTH 1

SOUTH 2

EAST 3

WEST 4

OTHER, SPECIFY 7 O

DK 8

RF 9

«WHSL1»

«O_WHSL1»

Had you ever used any of the emergency stairwells prior to September 11th?

=> DHELP

if LVFSW=1

YES 1

NO 2 => DHELP

DK 8 => DHELP

RF 9 => DHELP

«USESW»

SKIP FOR NO DRILLS AND NO USE OF STAIRWELLS

=> AEVOF

Else => +1

if FIRED=00,98,99 AND USESW>1

«SOUT2»

Which stairwell did you use?

STAIRWELL A 1

STAIRWELL B 2

STAIRWELL C 3

OTHER, SPECIFY 7 O

DK 8

RF 9

«WHSW2_01»

«WHSW2_02»

«WHSW2_03»

«WHSW2_04»

«O_WHSW2»

SKIP IF NO FIRE DRILLS

=> AEVOF

Else => +1

if FIRED=00,98-99

«SOUT3»

When you were evacuating on September 11th, how helpful was your experience during these drills?

=> +1

if FIRED=00

Very Helpful 1

Somewhat Helpful 2

Somewhat Unhelpful 3

Very Unhelpful 4

DK 8

RF 9

«DHELP»

Prior to September 11th, were you aware of the evacuation procedures for your floor?

YES 1

NO 2 => FLWAR

DK 8 => FLWAR

RF 9 => FLWAR

«AEVOF»

Prior to September 11th, what was the evacuation procedure you were told to follow?

LEAVE BUILDING IMMEDIATELY 1

GO TO ELEVATOR LOBBY 2

GO TO FLOORS UP OR DOWN 3

GO TO ROOF 4

STAY WHERE YOU ARE 5

OTHER, SPECIFY 7 O

DK 8

RF 9

«EVACP»

«O_EVACP»

Did you know that there was a Floor Warden for your floor?

=> +1

if ROLES=1-4

YES 1

NO 2

DK 8

RF 9

«FLWAR»

The next questions ask about 3 different time periods. The first series of questions asks about when you first became aware that something had happened at the World Trade Center. This is a period of just a few seconds. The next series of questions asks about the time from when you first became aware that something had happened, to the time you first entered a stairwell or elevator to exit the building. The third series of questions asks about what happened during your evacuation, meaning the time from when

you first entered a stairwell or elevator until you exited the tower. At the end of the interview, I will ask you if there is anything else about your experience on September 11th that you would like to contribute.

CONTINUE 1 D

«IFAWA»

Now thinking back to the morning of September 11th, how did you first become aware that something had happened at the World Trade Center?

$E 1 9

HEARD SOMETHING (BOOM, CRASH, EXPLOSION, BLAST, ROAR, RUMBLING, ALARM) 01

SAW SMOKE OR FLAMES 02

SAW DEAD BODIES 03

SAW A PLANE 04

SAW DEBRIS 05

FELT SOMETHING (BUILDING MOVING, IMPACT, SHAKING, SWAYING, ROCKING, JOLT, EARTHQUAKE) 06

FELL DOWN/FELL OFF CHAIR 07

WARNED BY SOMEONE AROUND ME 08

CONTACTED VIA PHONE 09

CONTACTED VIA EMAIL 10

PUBLIC ADDRESS SYSTEM 11

NEWS MEDIA (TELEVISION, RADIO) 12

OFFICE FURNITURE OR FIXTURES FALLING 13

FURNITURE OR OTHER ITEMS FALLING OVER/DOWN 14

OTHER, SPECIFY 97 O

DK 98

RF 99

«FAWAR»

«O_FAWAR»

What were you doing when you first became aware that something had happened to the World Trade Center? PROBE: Anything else?

$E 1 9

WORKING INDEPENDENTLY 01

IN MEETING 02

ON PHONE 03

CHECKING/WRITING EMAIL 04

WAITING FOR ELEVATOR 05

RIDING IN ELEVATOR 06

CHATTING WITH COWORKERS 07

EATING/HAVING COFFEE 08

ENTERING BUILDING 09

OTHER, SPECIFY 97 O

DK 98 X

RF 99 X

«ACTV1_01»

«ACTV1_02»

«ACTV1_03»

«ACTV1_04»

«ACTV1_05»

«ACTV1_06»

«ACTV1_07»

«ACTV1_08»

«ACTV1_09»

«ACTV1_10»

«O_ACTV1»

At the moment when you first became aware that something had happened at the World Trade Center, did you notice any of the following? FOLLOW UP: Was that in your immediate area or outside the Tower?			
	Did Not Notice	Noticed in Immediate Area	Noticed Outside the Tower
Smoke			
Fire or Flames			
Fireballs			
Collapsed walls			
Jet Fuel			
Severely or fatally injured people			
Sprinklers going on			
A fire alarm sounding			
Power outage or flickering lights			
Fallen ceiling tiles			
Extreme heat			

«NOT01_01»

«NOT01_02»

TIME PERIOD: 1

Were there any disaster related events going on around you at this time?

=> WHTW2

if OR[NOT01-NOT11]=2-3

YES 1

NO 2 => WHTW2

DK 8 => WHTW2

RF 9 => WHTW2

«OEVEN»

TIME PERIOD: 1

What was going on?

ENTER RESPONSE 1 O

DK 8

RF 9

«GOING»

«O_GOING»

TIME PERIOD: 1

Were you still in<WHTOW>at this time? IF YES, SELECT APPROPRIATE CHOICE IF NO, ASK WHICH TOWER THEY WERE IN

TOWER 1 1

TOWER 2 2

DK 8

RF 9

«WHTW2»

TIME PERIOD: 1

And were you still on the<WHFLO>floor at this time? RANGE: 1st - 110th FLOOR IF YES, SELECT/ENTER FLOOR IF NO, ASK WHICH FLOOR THEY WERE ON AND SELECT/ENTER IT

$E 1 110

BASEMENT 990

CONCOURSE/LOBBY 991

PLAZA 992

IN ELEVATOR 993

OTHER, SPECIFY 997 O

DK 998

RF 999

«WHFL2»

«O_WHFL2»

TIME PERIOD: 1

At the moment when you first became aware that something had happened to the World Trade Center, approximately how many people were with you? RANGE: 0 - 999 PEOPLE WE WANT THE NUMBER OF PEOPLE THAT WERE IN THE SAME LOCATION AS THE RESPONDENT. (IN THEIR LINE OF SIGHT)

SE 0 999

NONE 00 => YOUIN

DK 98 => YOUIN

RF 99 => YOUIN

«PEOP1»

TIME PERIOD: 1

Were any of these people injured at that time as a result of the event?

YES 1

NO 2

DK 8

RF 9

«PEOIN»

TIME PERIOD: 1

Were you injured at that time, as a result of the event?

YES 1

NO 2 => ORISK

DK 8 => ORISK

RF 9 => ORISK

«YOUIN»

TIME PERIOD: 1

Would you say your injury was a …

An injury that did not impact your ability to evacuate, 1

An injury that did impact your ability to evacuate but was not life threatening, or 2

A life threatening injury 3

OTHER, SPECIFY 7 O

DK 8

RF 9

«NATIN»

«O_NATIN»

TIME PERIOD: 1

Still thinking about the moment when you first became aware that something had happened at the World Trade Center, did you believe that other people were in danger of being killed?

YES 1

NO 2

DK 8

RF 9

«ORISK»

TIME PERIOD: 1

Did you believe you were in danger of being killed?

YES 1

NO 2

DK 8

RF 9

«YRISK»

TIME PERIOD: 2

Now please think about the time period between when you first became aware that something had happened and when you first entered a stairwell or elevator to leave the tower. During this entire time period, were you given any additional information about what was going on? AFTER BECOMING AWARE OF THE EVENT, BUT BEFORE EVACUATION

YES 1

NO 2 => SEEKI

DK 8 => SEEKI

RF 9 => SEEKI

«GETIN»

TIME PERIOD: 2

Who gave you this information? PROBE: Anyone else?

MANAGER/SUPERVISOR 1

COWORKER INSIDE BUILDING 2

FAMILY/FRIEND OUTSIDE BUILDING 3

POLICE/FIREFIGHTER 4

FLOOR WARDEN 5

MEDIA PERSON (TV/RADIO) 6

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X

«WHINF_01»

«WHINF_02»

«WHINF_03»

«WHINF_04»

«WHINF_05»

«WHINF_06»

«WHINF_07»

«O_WHINF»

TIME PERIOD: 2

What information did you get? PROBE: Any other information?

INFORMATION ABOUT WHAT HAD HAPPENED 1

INSTRUCTIONS TO LEAVE 2

INSTRUCTIONS TO STAY 3

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X

«WHATI_01»

«WHATI_02»

«WHATI_03»

«WHATI_04»

«O_WHATI»

TIME PERIOD: 2

How did you get this information? PROBE: Any other way?

FACE TO FACE 1

TELEPHONE 2

EMAIL/BLACKBERRY 3

PA ANNOUNCMENT 4

TV/RADIO 5

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X

«HOWGT_01»

«HOWGT_02»

«HOWGT_03»

«HOWGT_04»

«HOWGT_05»

«HOWGT_06»

«O_HOWGT»

TIME PERIOD: 2

And during this same time period, did you try to get additional information about what was going on? AFTER BECOMING AWARE OF THE EVENT, BUT BEFORE EVACUATION

YES 1

NO 2 => ORIS2

TRIED, BUT WAS UNABLE TO GET INFORMATION 3 => ORIS2

DK 8 => ORIS2

RF 9 => ORIS2

«SEEKI»

TIME PERIOD: 2

Who did you go to for this information? PROBE: Anyone else?

MANAGER/SUPERVISOR 1

COWORKER INSIDE BUILDING 2

FAMILY/FRIEND OUTSIDE BUILDING 3

POLICE/FIREFIGHTER 4
FLOOR WARDEN 5
MEDIA PERSON (TV/RADIO) 6
OTHER, SPECIFY 7 O
DK 8 X
RF 9 X
«GOINF_01»
«GOINF_02»
«GOINF_03»
«GOINF_04»
«GOINF_05»
«GOINF_06»
«GOINF_07»
«O_GOINF»

TIME PERIOD: 2
What type of information did you try to find? PROBE: Anything else?
INFORMATION ABOUT WHAT HAD HAPPENED 1
INSTRUCTIONS TO LEAVE 2
INSTRUCTIONS TO STAY 3
OTHER, SPECIFY 7 O
DK 8 X
RF 9 X
«WHAI2_01»
«WHAI2_02»
«WHAI2_03»
«WHAI2_04»
«O_WHAI2»

TIME PERIOD: 2
How did you get this information? PROBE: Any other way?
FACE TO FACE 1
TELEPHONE 2
EMAIL/BLACKBERRY 3
PA ANNOUNCMENT 4

TV/RADIO 5

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X

«HOWG2_01»

«HOWG2_02»

«HOWG2_03»

«HOWG2_04»

«HOWG2_05»

«HOWG2_06»

«O_HOWG2»

TIME PERIOD: 2

And during the time between when you first became aware that something had happened at the World Trade Center and when you first entered the stairwell or elevator to leave the tower, did you believe that other people were in danger of being killed? AFTER BECOMING AWARE OF THE EVENT, BUT BEFORE EVACUATION

=> YRIS2

if ORISK=1

YES 1

NO 2

DK 8

RF 9

«ORIS2»

TIME PERIOD: 2

During that time period, did you believe you were in danger of being killed?

=> PEODO

if YRISK=1

YES 1

NO 2

DK 8

RF 9

«YRIS2»

TIME PERIOD: 2

During this time period, what were the people around you doing? PROBE: Were they doing anything else? AFTER BECOMING AWARE OF THE EVENT, BUT BEFORE EVACUATION

SE 0 10

NOONE AROUND/WAS ALONE 00 X

TALKING TO OTHERS 01

GATHERING PERSONAL/WORK ITEMS 02

SEARCHING FOR OTHERS 03

CALLING OTHERS 04

FIGHTING FIRE/SMOKE 05

LOCKING UP 06

WORKING 07

EVACUATING THE TOWER 08

CRYING, RUNNING AROUND, IN SHOCK 09

HELPING OTHERS 10

OTHER, SPECIFY 97 O

DK 98 X

RF 99 X

«PEODO_01»

«PEODO_02»

«PEODO_03»

«PEODO_04»

«PEODO_05»

«PEODO_06»

«PEODO_07»

«PEODO_08»

«PEODO_09»

«PEODO_10»

«O_PEODO»

TIME PERIOD: 2

Did the people around you start evacuating before you did?

=> DOBEF

if PEODO=08

YES 1

NO 2

DK 8

RF 9

«EVACB»

TIME PERIOD: 2

Did you do any of the following before starting your evacuation?

$E 1 9

Talk to another person face to face 01

Gather personal items 02

Telephone other people 03

Continue working 04

Save or transfer computer files 05

Search for others 06

Fight fire or smoke 07

Move to another floor 08

Help others 09

Logging off/shutting down computer 10

NONE OF THESE 11 X

«DOBEF_01»

«DOBEF_02»

«DOBEF_03»

«DOBEF_04»

«DOBEF_05»

«DOBEF_06»

«DOBEF_07»

«DOBEF_08»

TIME PERIOD: 2

Did you do anything else during this time?

ENTER RESPONSE 1 O

NO OTHER ACTIVITIES 0

DK 8

RF 9

«OACTI»

«O_OACTI»

TIME PERIOD: 2

Before you began your evacuation, was there anything you wanted to do, but couldn't?

YES 1

NO 2 => SEE01

DK 8 => SEE01

RF 9 => SEE01

«WANTD»

TIME PERIOD: 2

What was that? PROBE: Anything else?

SE 1 7

GATHER WORK ITEMS 01

GATHER PERSONAL BELONGINGS 02

CALL FRIEND/FAMILY MEMBER 03

FIND FRIEND/COWORKER 04

HELP FRIEND/COWORKER 05

LOCK UP 06

EVACUATE IMMEDIATELY 07

OTHER, SPECIFY 97 O

DK 98 X

RF 99 X

«WANAC_01»

«WANAC_02»

«WANAC_03»

«WANAC_04»

«WANAC_05»

«WANAC_06»

«WANAC_07»

«WANAC_08»

«O_WANAC»

TIME PERIOD: 2

Why couldn't you do that/those things?

SE 1 9

AFRAID 01

LOCKED DOORS 02

PHONE LINES DEAD 03

INJURED 04

EXIT BLOCKED 05

TOO CROWDED 06

TOLD TO STAY IN BUILDING 07

TOLD TO LEAVE 08

FATIGUE 09

DISABLED 10

SMOKE 11

DAMAGE TO FLOOR 12

WAS HELPING OTHERS 13

OTHER, SPECIFY 97 O

DK 98

RF 99

«WHYNO_01»

«WHYNO_02»

«WHYNO_03»

«WHYNO_04»

«WHYNO_05»

«WHYNO_06»

«WHYNO_07»

«WHYNO_08»

«WHYNO_09»

«WHYNO_10»

«WHYNO_11»

«WHYNO_12»

«WHYNO_13»

«WHYNO_14»

«O_WHYNO»

Still thinking about the time between when you first became aware that something had happened at the World Trade Center and when you entered the stairwell or elevator to leave the tower, did you notice any of the following? FOLLOW UP: Was that in your immediate area or outside the Tower?			
	Did Not Notice	Noticed in Immediate Area	Noticed Outside the Tower
Smoke			
Fire or Flames			
Fireballs			
Collapsed walls			
Jet Fuel			
Severely or fatally injured people			
Sprinklers going on			
A fire alarm sounding			
Power outage or flickering lights			
Fallen ceiling tiles			
Extreme heat			

«SEE01_01»

«SEE01_02»

TIME PERIOD: 2

Were there any disaster related events going on around you at this time?

=> EVACF

if OR[SEE01-SEE11]=2-3

YES 1

NO 2 => HELPY

DK 8 => HELPY

RF 9 => HELPY

«ODISE»

TIME PERIOD: 2

What was going on?

ENTER RESPONSE 1 O

DK 8

RF 9

«GOIN2»

«O_GOIN2»

TIME PERIOD: 2

Were you still on the<WHFL2>floor at this time? RANGE: 1st - 110th FLOOR IF YES, SELECT/ENTER FLOOR IF NO, ASK WHICH FLOOR THEY WERE ON AND SELECT/ENTER IT

SE 1 110

=> +1

if (AND[SEE01-SEE11]=1) AND PEODO>0 AND PEODO<98

BASEMENT 990

CONCOURSE/LOBBY 991

PLAZA 992

ELEVATOR 993

OTHER, SPECIFY 997 O

DK 998

RF 999

«EVACF»

«O_EVACF»

TIME PERIOD: 2

Did anyone help you in any way before you started your evacuation?

YES 1

NO 2 => DECID

DK 8 => DECID

RF 9 => DECID

«HELPY»

TIME PERIOD: 2

Who helped you? PROBE: Anyone else? WE WANT THEIR ROLE NOT THE NAME OF THE PERSON

POLICE OFFICER/FIREFIGHTER 1

COWORKER 2

STRANGER 3

FLOOR WARDEN 4

MANAGER/SUPERVISOR 5

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X
«WHOHE_01»
«WHOHE_02»
«WHOHE_03»
«WHOHE_04»
«WHOHE_05»
«WHOHE_06»
«O_WHOHE»

TIME PERIOD: 2
What did they help you with? PROBE: Anything else?
SE 1 7
LOCATING OTHERS 01
HELPING OTHERS 02
FINDING EXITS 03
TREATING YOUR INJURIES 04
PROVIDED INFORMATION/INSTRUCTIONS 05
GATHER BELONGINGS 06
CALM DOWN/EMOTIONAL ASSISTANCE 07
OTHER. SPECIFY 97 O
DK 98 X
RF 99 X
«WHATD_01»
«WHATD_02»
«WHATD_03»
«WHATD_04»
«WHATD_05»
«WHATD_06»
«WHATD_07»
«WHATD_08»
«O_WHATD»

TIME PERIOD: 2
What was the one thing that made you decide to evacuate?
WAS TOLD TO EVACUATE 1

FRIENDS CO-WORKERS EVACUATED 2

AFRAID/FELT IN DANGER 3

FIRE ALARM WAS GOING OFF 4

SAW SMOKE 5

SAW FIRE 6

OTHER, SPECIFY 7 O

DK 8

RF 9

«DECID»

«O_DECID»

How many minutes had passed before you started to evacuate? IF NEEDED: How much time passed between when you first became aware that something had happened to the World Trade Center and when you entered the stairwell or elevator to leave the tower. THIS IS NOT TIME TO EVACUATE. PLEASE CLARIFY WITH RESPONDENT IF TIME APPEARS TOO LONG. RESPONDENT WAS IN<WHTW2> RANGE FOR TOWER 1: 1 - 103 MINUTES RANGE FOR TOWER 2: 1 - 75 MINUTES

SE 1 103

DK 998

RF 999

«TIMEP»

SKIP FOR TOWERS

=> EVAC2

Else => +1

if WHTW2=2

«SKIP1»

Did you begin your evacuation… WE ARE INTERESTED IN WHAT THEY KNOW NOW. THEY MAY NOT HAVE KNOWN WHEN THEY WERE EVACUATING, BUT NOW THEY CAN TELL US WHEN IT WAS.

Before the plane hit Tower 2 1

After the plane hit Tower 2, but before the Tower 2 collaspe 2

After the Tower 2 collaspe 3

DK 8

RF 9

«EVAC1»

SELECT1

SS NS=2 CO=1 IN=EVAC1<=1 ;CO=2 IN=EVAC1<=2 ;

Before the plane hit Tower 2 1

After the plane hit Tower 2, but before the Tower 2 collaspe 2

After the Tower 2 collaspe 3

DK 8

RF 9

«SEL1»

SELECT2

Before the plane hit Tower 2 1

After the plane hit Tower 2, but before the Tower 2 collaspe 2

After the Tower 2 collaspe 3

DK 8

RF 9

«SEL2»

Did you begin your evacuation…

=> EVCSO

if EVAC1>0

Before the plane hit Tower 2 1

After the plane hit Tower 2 2

DK 8

RF 9

«EVAC2»

SELECT4

SS CO=1 IN=EVAC2<=1 ;

Before the plane hit Tower 2 1

After the plane hit Tower 2 2

DK 8

RF 9

«SEL3»

Was there anything that kept you from evacuating sooner?

YES, RECORD RESPONSE 1 O

NO 2

DK 8

RF 9

«EVCSO»

«O_EVCSO»

TIME PERIOD: 3

When you began your evacuation, were you alone or with other people? PEOPLE THAT THEY KNOW, PEOPLE THAT THEY WERE TALKING WITH

ALONE 1

WITH OTHER PEOPLE 2

DK 8

RF 9

«ALONE»

TIME PERIOD: 3

Which stairwell did you use for your evacuation?

STAIRWELL A 1

STAIRWELL B 2

STAIRWELL C 3

USED ELEVATOR 4 => FOLA1

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X

«STAIR_01»

«STAIR_02»

«STAIR_03»

«STAIR_04»

«STAIR_05»

«O_STAIR»

TIME PERIOD: 3

Which side of the building was the stairwell located on?

=> /WHYST

if NOT STAIR=8,7

NORTH 1

SOUTH 2

EAST 3

WEST 4

OTHER, SPECIFY 7 O

DK 8

RF 9

«WHISI»

«O_WHISI»

TIME PERIOD: 3

Why did you choose that/those stairwell(s) for your evacuation? PROBE: Any other reason?

CLOSEST ONE 1

FOLLOWED OTHER PEOPLE TO IT 2

OTHER EXITS WERE BLOCKED 3

SAME AS I USED IN PREVIOUS EMERGENCY 4

I WAS TOLD TO USE THIS STAIRWELL 5

OTHER, SPECIFY 7 O

DK 8 X

RF 9 X

«WHYST_01»

«WHYST_02»

«WHYST_03»

«WHYST_04»

«WHYST_05»

«WHYST_06»

«O_WHYST»

TIME PERIOD: 3

At any time during your evacuation, did you leave that/those stairwell(s)? DO NOT INCLUDE PEOPLE WHO FOLLOWED THE PASSAGE WHERE THE STAIRWELLS START AND END.

YES 1

NO 2 => FOLA1

DK 8 => FOLA1

RF 9 => FOLA1

«LEVST»

TIME PERIOD: 3

Which floor were you on when you left the stairwell? IF RESPONDENT UNSURE, SELECT 997 AND RECORD RANGE OF FLOORS EXAMPLE: 34-40

SR 1 110

UNSURE, RECORD RESPONSE 997 O

«FLLST»

«O_FLLST»

TIME PERIOD: 3

Why did you leave the stairwell? PROBE: Any other reason?

SE 1 9

I GOT LOST 01

WAS TOLD TO LEAVE STAIRWELL 02

TO HELP SOMEONE 03

TO GO BACK AND GET SOMETHING 04

TOO CROWDED 05

SMOKE IN STAIRWELL 06

PATH OBSTRUCTED 07

A LOCKED DOOR 08

STAIRWELL LED TO A FLOOR 09

OTHER, SPECIFY 97 O

DK 98

RF 99

«WHYLS_01»

«WHYLS_02»

«WHYLS_03»

«WHYLS_04»

«WHYLS_05»

«WHYLS_06»

«WHYLS_07»

«WHYLS_08»

«WHYLS_09»

«WHYLS_10»

«O_WHYLS»

Screen [Template 3] -> FLOA5

=> +1

if FLWAR>1

Did any of the following help you evacuate while you were in the building?				
	Yes	No	DK	RF
Instructions or assistance from your floor warden				
Instructions or assistance from Police or Firefighters				
Support and encouragement from others				
Exit signs				
Photo luminescent paint in stairwells				

«FOLA1»

Screen [Template 3] -> EVCM7

=> +1

if NOT STAIR<4

Did any of the following make your evacuation more difficult while you were in the building?				
	Yes	No	DK	RF
Crowded stairwells				
Firefighters or Police moving up stairwell				
Disabled or injured people being taken down stairwell				
Locked doors				
Poor lighting				
Confusing or missing signs				
Lack of clear instructions				

«EVCM1»

Screen [Template 3] -> EXP11

Please tell me if you noticed any of the following at any time during your evacuation. FOLLOW UP: Was that in your immediate area or outside the Tower?			
	Did Not Notice	Noticed in Immediate Area	Noticed Outside the Tower
Smoke			
Fire or Flames			
Fireballs			
Collapsed walls			
Jet Fuel			
Severely or fatally injured people			
Sprinklers going on			
A fire alarm sounding			
Power outage or flickering lights			
Fallen ceiling tiles			
Extreme heat			

«EXP01_01»

«EXP01_02»

TIME PERIOD: 3

During your evacuation, did you turn back at any time? "TURN BACK" MEANS "GO BACK UP".

YES 1

NO 2 => EXITS

DK 8 => EXITS

RF 9 => EXITS

«TURNB»

TIME PERIOD: 3

Why did you turn back? PROBE: Any other reason?

SE 1 7

I GOT LOST 01

I WAS TOLD TO TURN BACK 02

TO HELP SOMEONE 03

TO GET SOMETHING 04

IT WAS TOO CROWDED 05

SMOKE IN THE STAIRWELL 06

MY PATH WAS OBSTRUCTED 07

OTHER. SPECIFY 97 O

DK 98 X

RF 99 X

«WHYTB_01»

«WHYTB_02»

«WHYTB_03»

«WHYTB_04»

«WHYTB_05»

«WHYTB_06»

«WHYTB_07»

«WHYTB_08»

«O_WHYTB»

TIME PERIOD: 3

Did you exit the stairwell or elevator to the mezzanine or to the concourse?

MEZZANINE 1

CONCOURSE 2

OTHER, SPECIFY 7 O

DK 8

RF 9

«EXITS»

«O_EXITS»

TIME PERIOD: 3

How much time passed between the moment you first began your evacuation to when you exited the Tower? PLEASE CLARIFY WITH RESPONDENT IF TIME APPEARS TOO LONG. RESPONDENT WAS IN<WHTW2> RANGE FOR TOWER 1: 1 - 103 MINUTES RANGE FOR TOWER 2: 1 - 75 MINUTES

SE 1 103

DK 998

RF 999

«TIMP2»

SKIP FOR TOWERS

=> +2

Else => +1

if WHTW2=2

«SKIP2»

TIME PERIOD: 3

Did you exit the tower…

Eliminate -> 2

According to NOT SEL1-SEL2

Before the plane hit Tower 2 1 => GETOU

After the plane hit Tower 2 but before the Tower 2 collapse, or 2 => GETOU

After the Tower 2 collapse 3 => GETOU

DK 8 => GETOU

RF 9 => GETOU

«EXIT1»

TIME PERIOD: 3

Did you exit the tower…

Eliminate -> 1

According to NOT SEL3

Before the plane hit Tower 2, or 1

After the plane hit Tower 2 2

DK 8

RF 9

«EXIT2»

Please remember that this study is intended as a fact finding mission and not a fault finding mission. It is crucial that we determine why some people were successful in their evacuation while others were not. Was there anyone on your floor that was not successful in their evacuation?

YES 1

NO 2 => PHYSI

DK 8 => PHYSI

RF 9 => PHYSI

«GETOU»

Why didn't they make it out? PROBE: Any other reason?

SE 1 8

WAS INJURED 01

WAS DISABLED 02

REFUSED TO LEAVE 03

DID NOT THINK IT WAS SERIOUS 04

STAYED BACK TO HELP SOMEONE 05

WAS TOLD TO STAY 06

STRUCTURAL DAMAGE 07

SMOKE OR FIRE 08

OTHER, SPECIFY 97 O

DK 98 X

RF 99 X

«WHYNG_01»

«WHYNG_02»

«WHYNG_03»

«WHYNG_04»

«WHYNG_05»

«WHYNG_06»

«WHYNG_07»

«WHYNG_08»

«WHYNG_09»

«O_WHYNG»

On September 11th, 2001, did you have any physical problems that made it more difficult for you to leave the tower? Please do not include injuries caused by the incident or evacuation.

YES 1

NO 2 => AGE

DK 8 => AGE

RF 9 => AGE

«PHYSI»

What type of physical problem? PROBE: Anything else?

SE 1 9

BLIND/PARTIALLY BLIND 01

DEAF 02

IN WHEELCHAIR 03
NEED WALKING ASSISTANCE 04
OBESITY 05
HEART CONDITION 06
PREGNANT 07
ASTHMA 08
ELDERLY 09
OTHER, SPECIFY 97 O
DK 98 X
RF 99 X
«LIMIT_01»
«LIMIT_02»
«LIMIT_03»
«LIMIT_04»
«LIMIT_05»
«LIMIT_06»
«LIMIT_07»
«LIMIT_08»
«LIMIT_09»
«LIMIT_10»
«O_LIMIT»

What is your age? RANGE: 1 - 98 YEARS
$E 1 99
RF 99
«AGE»

READ ONLY IF YOU CAN'T TELL. What is your gender?
MALE 1
FEMALE 2
RF 9
«GEND»

What language do you speak best?
ENGLISH 1

SPANISH 2

OTHER, SPECIFY 7 O

DK 8

RF 9

«PLANG»

«O_PLANG»

Were you working in Tower 1 or Tower 2 during the 1993 bombing?

=> SAY11

if YRWRK>1993

YES 1

NO 2 => CONCR

DK 8 => CONCR

RF 9 => CONCR

«WBOMB»

During the 1993 bombing, did you evacuate immediately or wait to evacuate?

EVACUATE IMMEDIATELY 1

WAIT TO EVACUATE 2

DK 8 => +2

RF 9 => +2

«EVBOM»

At the time of the 1993 bombing, did you feel you that your decision to<EVBOM>was the right decision?

YES 1

NO 2

DK 8

RF 9

«DEC93»

After the 1993 bombing how concerned were you that terrorists would attack the World Trade Center? Were you...

Extremely Concerned 1

Very Concerned 2

Moderately Concerned 3

Slightly Concerned 4

Not at all Concerned 5

DK 8

RF 9

«CONCR»

Is there anything else you would like to say about your experience on September 11th?

YES, RECORD RESPONSE 1 O

NO 2

DK 8

RF 9

«SAY11»

«O_SAY11»

IMPACT FLOOR FLAG

=> *

if IF(((WHTW2=1 AND WHFL2>91 AND WHFL2<99) OR (WHTW2=2 AND WHFL2>77 AND WHFL2<111)),1,0)

IMPACT FLOOR FLAG 1

«FFLAG»

163: LFLAG

Single

min = 1 max = 1 1 = 1

2003/09/18 15:21

LOCATION FLAG

=> *

if IF((WHFL2>990 AND WHFL2<994),1,0)

LOCATION FLAG 1

«LFLAG»

EVENT FLAG

=> *

if IF(((AND[NOT02-NOT06]=2-3) OR (AND[SEE02-SEE06]=2-3) OR (AND[EXP02-EXP06]=2-3)),1,0)

EVENT FLAG 1

«EFLAG»

DISABILITY FLAG

=> *

if IF((PHYSI=1),1,0)

DISABILITY FLAG 1

«DFLAG»

ROLE FLAG

=> *

if IF((ROLES=1-4),1,0)

ROLE FLAG 1

«RFLAG»

We may be interested in learning more about your experience on September 11th. Would it be okay if we follow up with you sometime in the future to get more detailed information on your evacuation experience?

=> +1

if FFLAG+LFLAG+EFLAG+DFLAG+RFLAG==0

YES 1

NO 2

«FOLUP»

PRESS ENTER TO CONTINUE

Those are all the questions we have. The valuable information you provided will help designers and engineers improve building safety, and help emergency planners improve building evacuation procedures. Thank you so much for taking the time to talk with me, and have a good day/evening. Good-bye.

END OF SURVEY 1 D => /INT99

«THANK»

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Appendix B
Qualitative Analysis Coding

The qualitative data from the face-to-face interviews was used to enrich the statistically-based telephone interview data by providing detailed descriptions of the experiences of occupants of the two towers on September 11, 2001. These data identified unknown information, evaluated technical hypotheses, and explored conscious and subconscious motivations for occupant behaviors, while allowing for comparisons to the telephone interview data. This appendix provides an annotated listing of the coding used by National Institute Standards and Technology (NIST) to analyze the face-to-face interview data. It was intended to serve the dual purposes of the project by identifying 1) building damage and environmental conditions before or during evacuation and 2) patterns of behavior before or during evacuation that may have helped or hindered occupants' evacuation. Some of the codes would apply to an entire interview (for example, the tower 1, tower 2, or Building 7 code simply indicates the building where the respondent was located at the beginning of the event), some part of their evacuation experience (such as the counterflow, crowded, or elevator codes), or an observation of their surroundings (such as the floor damage, building damage, saw fire, or saw smoke codes). The codes are simply presented in alphabetical order.

Alarm: Heard fire or other alarm (not public address system)

Alternative Activity: Decision to suspend evacuation in favor of another activity (call, get drink/food/possession ...)

Antisocial Behavior: Any directly observed behavior which presents obstacle to people getting out

Assist: Assisted or motivated an injured / handicapped / reluctant person

Bldg Employee: Building service employee (janitor, elevator operator, contract service employee -- not building security) as an information source

Boss or higher: Boss, manager, or higher as an information source

Building 7: Occupant was in Building 7 when Tower 1 was struck

Building Damage: Directly observed damage to building structure after beginning evacuation (see floor damage for damage on floor where they began their evacuation)

Building Security: Uniformed building security personnel (not Port Authority, NYPD, or FDNY)

Cellular Phone: Use of a cellular phone as an information source

Concourse: Occupant mentions being in the Concourse during their evacuation. Autocoded with phrases such as Concourse Borders shopping mall,...

Confusion: Unaware of where to go because of a lack of visual certainty

Counterflow: Movement of people or responders against the flow of egress delayed evacuation

Coworker: Coworker as an information source

Crowded: Egress slowed because of density, but no specific identifiable cause

Elevator - Considered: Occupant considered using elevators but did not make use of elevators for evacuation. Code should also be used when occupant states they knew not to use elevators.

Elevator - Used: Used an elevator during evacuation

Email: Used email or PDA device as an activity

Email/PDA: Use of email or PDA as an information source

Evacuation Decision: Marks when respondent decided they needed to leave. Note that his may occur more than once if the occupant decides to interrupt their evacuation on it has begun.

Experience Aid: Prior experience aided evacuation

Experience Obstacle: Experience caused them to delay evacuation

FBI: Occupant specifically mentioned seeing someone identified with the Federal Bureau of Investigation

FDNY: Fire department personnel as an information source

Fire Affecting Egress: Observed fire in egress path

Firefighting by Occupants: Occupant engaged in firefighting activities prior to or during evacuation

First Awareness: First indication that respondent became aware that something was wrong on the morning of September 11

Floor Damage: Directly observed damage to building structure on floor where they began evacuation prior and to beginning evacuation (see building damage for damage during evacuation and not on floor where they began their evacuation)

Floor Start: Starting floor for evacuation that is different from the employer assigned floor

Floors 1 to 9: Occupant began their evacuation in the stated range of floors

Floors 10 to 19: Occupant began their evacuation in the stated range of floors

Floors 100 to 110: Occupant began their evacuation in the stated range of floors

Floors 20 to 29: Occupant began their evacuation in the stated range of floors

Floors 30 to 39: Occupant began their evacuation in the stated range of floors

Floors 40 to 49: Occupant began their evacuation in the stated range of floors

Floors 50 to 59: Occupant began their evacuation in the stated range of floors

Floors 60 to 69: Occupant began their evacuation in the stated range of floors

Floors 70 to79: Occupant began their evacuation in the stated range of floors

Floors 80 to 89: Occupant began their evacuation in the stated range of floors

Floors 90 to 99: Occupant began their evacuation in the stated range of floors

Floors below ground: Occupant began their evacuation in the stated range of floors

Followed Crowd: Respondent reports following a crowd, or else avoiding a crowd, eg a stair looks too crowded.

Fruin: An indication of Fruin level of service for crowding in the stairwells

Get Information: Looking for more information (not milling)

Get Out Instruction: Identifying the instruction to evacuate the building - it is of interest as to who this instruction came from (secretary or supervisor, for instance).

Health: Occupant reports being tired, sick, in pain ... effecting egress

Helping: Stopped or slowed by helping other who needed assistance

High: Floors 77 to 110 in the Towers and 26 to 47 in Building 7

Immediate Evacuation: Where occupant made an immediate decision to evacuate

Instruction: Instruction to take action counter to continuing or commencing evacuation (any source).

Instruction Aid: Received an instruction (any source) that aided evacuation

Interesting behavior: This code is a chance to identify any interesting behavior to highlight for the report.

Internal Aids: Any thoughts or techniques which calmed occupant during evacuation (counting, humming, thinking of family ...)

Know 1993: While not there, occupant was influenced by second-hand knowledge of the 1993 WTC bombing

Left Stairwell: Occupant left stairwell during evacuation

Location: Indicates a specific location within a building before or during evacuation

Location – Concourse: Indicates the occupant was on the Concourse Level

Locked/Jammed Door: First hand observation of a locked or jammed door effecting egress

Low: Floors 1 to 40 in the Towers and 1 to 25 in Building 7

Media: Use of the media (TV, radio ...) as an information source

Medical Disability: Asthma, illness, pregnancy

Medium: Floors 43 to 74 in the Towers

Mill: Talked with other people inside the building as an activity

Milling Aid: Milling as an aid to evacuation

No alarm: Occupant specifically reports not hearing an alarm at any time during their evacuation

Other Activity: Activities of interest to the NIST investigation not otherwise categorized

Other Egress Aid: Aid to egress of interest to the NIST investigation not otherwise categorized

Other Info: Other information source of interest to the NIST investigation not otherwise categorized

Other Mobility Challenge: Mobility-impaired information of interest to the NIST investigation not otherwise categorized

Other Obstacle: Obstacle effecting egress not otherwise categorized

Overweight: Overweight or out of shape

Pager: Occupant reported using a pager at some time before or during their evacuation

Phone: Used a phone to receive information (not cellular phone)

Phone Call: Respondent made use of a telephone as an activity (not cell phone). Typically to inform someone of status -- family, 911, etc. For phone as an information source, use cellular phone or phone

Photoluminscent Paint: Photoluminescent paint mentioned as an aid to evacuation

Physical Assistance: Received physical assistance which aided evacuation

Physical Disability: Wheelchair, crutches, cane, bad knees, ...

Police: NYPD or other official gun-carrying officers as an information source

Port Authority: PAPD or person with building responsibility as an information source

Practice Drill: Participated in practice drills at WTC

Present 1993: Occupant was present at the 1993 WTC bombing

Prior Evac Experience: Participated in previous building evacuation (WTC or not), except for the 1993 bombing.

Prosocial Behavior: Letting people in line, crowd calming conversations, singing, counting out loud, emergent leadership or other behaviors which aid evacuation

Public Address Aid: Information from public address system assisted evacuation

Public Address System: Public address system as an information source

Quote: A short quotation that may warrant inclusion in the final report because it creates, supports, or refutes a hypothesis or is particularly compelling account of a particular event

Rest on stairs: This code identifies when the respondent actually rests in the stairs and/or observes this behavior.

Retrieve: Retrieved a personal or business belonging

Risk - High Level: High perception of danger faced by the occupant

Risk - Low Level: Low perception of the danger faced by respondent

Saw Airplane: Directly observed airplane hitting occupant's building (saw other impact for observation of plane hitting other building)

Saw FDNY: Respondent mentions the presence of firefighters during their egress whether or not they helped or hindered egress or gave instructions

Saw Fire: Directly observed flames within the building before or during evacuation (does not include observation of fire on exterior of another building)

Saw Injured: Directly observed an injured or dead person, not including themselves

Saw Other: Saw something relevant to NIST investigation not otherwise categorized

Saw Other Impact: Directly observed impact of plane into a building other that the one the respondent was in (for example someone in T2 seeing plane hit T1)

Saw People: Observed someone doing something noteworthy, but it did not impact egress

Saw Smoke: Directly observed smoke within the building before or during evacuation (does not include observation of smoke on exterior of another building)

Saw Water: Directly observed water within the building before or during evacuation (not drinking water)

Saw/Felt/Heard Impact: Indication of the impact of a plane hitting the building. (If you saw the impact of the plane hitting the other building and felt it in your building, it would get coded twice; once with this code and once with Saw other impact)

Search: Searched for a person or people

Shoes: Poor footwear choice or other's footwear cluttering pathway effects egress

Signage: Signs posted in evacuation route aided evacuation

Slow Occupant: A slow occupant ahead of respondent in line impeded egress

Smell/Saw Fuel: Direct observation or smell of jet fuel in the building

Smoke Affecting Egress: Observed smoke in egress path

Stair Unknown: Direct mention that respondent did not know which stairwell was used for evacuation

Stairway from basement: Occupant used stairs from below-ground levels during evacuation

Stairwell A: Occupant was in Stairwell A

Stairwell A or C: Occupant was in Stairwell A or C (narrow stairwell)

Stairwell B: Occupant was in Stairwell B

Stairwell C: Occupant was in Stairwell C

Strange: For something that just doesn't make sense and is worth further investigation

Superflow: Prosocial behavior of letting higher priority evacuees (i.e., injured) pass faster delayed evacuation

Superflow Aid: By helping someone injured or handicapped, was able to egress faster than they otherwise would have

T2 Collapse: Note by respondent of collapse of Tower 2

T2 hit: Note by respondent of Tower 2 being hit

Time: Indicates a relative or absolute time

Tower 1: Occupant was in Tower 1 when Tower 1 was struck

Tower 2: Occupant was in Tower 2 when Tower 1 struck

Training Aid: Prior training aided evacuation

Transfer Floor: Occupant notes use of a transfer floor during egress by stairwell

Trapped: Occupant was trapped prior to or during evacuation

Victim: Mention of people who died in the event

Visibility: low light condition or dust (but not smoke) effecting egress

Visitor: Respondent specifically mentions being a visitor or being with a visitor at some point during their evacuation

Walkie-Talkie: Respondent mentions the use of a walkie-talkie either by the respondent or by someone else

Warden: Activities associated with responsibilities of the floor wardens

Warden Info: Floor warden as a source of information

Water: Water within the building before or during evacuation (not drinking water) was an obstacle to evacuation

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Appendix C
CAUSAL MODELING

The telephone interview results permit rigorous statistical analysis of individual components (questions). In order to understand what factors impacted the overall evacuation time of the average occupant in World Trade Center (WTC) 1 or WTC 2, two primary dependent variables were predicted: how long an individual delayed initiating their evacuation, where initiation is defined as entering a stairwell or elevator with the intention of exiting the building; and how long an individual spent traversing the stairwells. The sum of these two times was the total evacuation time. Multivariate regression modeling was utilized to rigorously establish factors which contributed to increasing the overall evacuation time.

C.1 PREDICTING EVACUATION DELAY IN THE WORLD TRADE CENTER

This project analyzed the factors (variables) and social processes (the major paths of causal links between variables) that influenced people delaying the initiation of their evacuation out of WTC 1 and WTC 2 on September 11, 2001. Evacuation delay was defined as the number of minutes that passed from when a person first became aware that something was wrong until they began their evacuation.

Method

The purpose of the Telephone Interviews was to collect 800 computer assisted telephone interviews (CATI) of persons occupying either of the two WTC towers (WTC 1 and WTC 2) at the time of the terrorist attacks on September 11, 2001 in order to explore occupants' evacuation experiences. A total sample size of 800, with an allocation of 400 to each tower, was determined to simultaneously maximize the statistical precision within each tower. Estimates of percentages from tower specific survey data at 400 exhibit sampling errors not greater than 2.5 percent, and 98 percent confidence intervals of percentages are no greater than ± 5 percent. This level of precision is more than adequate for examining characteristics of occupants and egress attributes. Additionally, mutlivariate modeling requires the use of F tests to determine significance of the regression models, i.e., testing the null hypothesis that the ratio of explained variance to error/residual variance is equal to or less than zero. The sample size of 400 per tower is more than adequate for this analysis since, for example, in a model featuring 20 independent variables, a sample size of 400 and a .05 level of significance (Type I error), the power of the F test to detect an R-squared of .06 is just over 81 percent.

Attempts were made to equally divide the respondents among WTC 1 and WTC 2 occupants (i.e., n=400 occupant telephone interviews from each tower). Within each of the WTC buildings, independent proportionate stratified samples of survivors were drawn. In other words, each occupant of a particular tower had an equal probability of being selected. The sample was collected and weighted in accordance with the analysis presented in Section 3.2.2 of this report. The questions posed to the respondents are included in earlier in this report.

Pre Modeling Analysis

Two bodies of research and theory were reviewed to inform our consideration of what explanatory factors/variables should be used to predict occupant evacuation from the towers.

First, we compiled a comprehensive list of the 300 publications in the research record on human response/evacuation to risk events/information for natural and technological hazards and disasters, for example, research on floods, hurricanes, earthquake predictions, tornadoes, nuclear power plant accidents, hazardous chemical spills and many others. These studies included not only examinations of evacuations, but also events in which other protective actions were warranted. This literature was reviewed, summarized, and synthesized for salient theoretical constructs and the relationships between them. This bibliography is available in both standard and annotated formats from the Natural Hazards Research and Applications Information Center at the University of Colorado at Boulder.

Second, we accessed the record of research on human evacuation during high rises fires. Experts in both areas of research developed a list of the most salient factors to include in this segment of our research.

A range of key possible explanatory variables on which to gather data to use to predict evacuation delay in towers 1 and 2 were selected. We collected telephone interview data on these factors, and then statistically examined their import in predicting evacuation delay time. The list of factors follows.

- Location in Building
- Social Context
- Demographic Characteristics
- Pre-event Experience
- Roles of Responsibility
- Preparedness and Training
- Environmental Cues
- Social Cues
- Receiving Information about the Event
- Perceived Risk
- Seeking Additional Information
- Injuries
- Obtaining Help from Others
- Pre-evacuation Activities

Preliminary statistical analyses were performed to determine which of these had and did not have salience in predicting evacuation delay out of WTC 1 and WTC 2. Those that had no significant impact on evacuation delay were excluded from further consideration. The factors that had salient impacts on evacuation delay were carried forward into the analysis to model tower evacuation.

The Model That Was Estimated

The model used to predict evacuation delay in WTC 1 and WTC 2 of the World Trade Center on September 11, 2001 used factors that preliminary analyses suggested as salient, closely followed general evacuation theory from the social and fire sciences, and is diagrammatically illustrated in Figure C–1. Note that $e_4 - e_7$ are the unexplained variance for variables 4 – 7, respectively. The model can be described as follows: (1) delay in evacuation initiation is a direct consequence of environmental cues, floor, obtaining information without seeking it, perceived risk, seeking additional information, and taking pre-evacuation actions; (2) taking pre-evacuation actions is a direct consequence of environmental cues, floor, obtaining information without seeking it, perceived risk, and seeking additional information; (3) seeking additional information is a direct consequence of environmental cues, floor, obtaining information that was not sought, and perceived risk; and, finally, (4) perceived risk is a direct consequence of environmental cues, floor, and obtaining information without seeking it. This model is parsimonious, consistent with the evacuation theory that stems from research on existing evacuation and risk communication research, and it well-represented the positive findings of our preliminary analyses of the many variables that could have impacted evacuation delay.

Measurement

Environmental cues (X_1) was measured by asking respondents about the number and type of environmental cues (severe signs of danger, and non-severe signs of danger) that they saw prior to initiating there evacuation. Answers to these questions were coded as dummy variables (0 or 1) and then added to form an environmental cues scale that could vary between 0 and 2.

Floor (X_2) was measured by asking respondents what floor they were on when the event started. Responses were coded as -7 (basement floors) to 105. Negative floor values were transposed into positive ones since this measure sought to determine how many floors people were from their building's floor of exit. Missing data was coded to the mean.

Obtaining information without seeking it (X_3) was measured by asking respondents: "Now please think about the time period between when you first became aware that something had happened and when you first entered a stairwell or elevator to leave the tower. During this entire time period were you given any additional information about what was going on?" Answers were coded as a dummy variable where 1 = yes and 0 = no or missing data.

Perceived risk (X_4) was measured by asking whether the occupant whether they believed that other people were in danger of being killed during the time when they first became aware that something had happened and when they first entered the stairwell or elevator to leave. Once again, answers were coded as a dummy variable, where 1 = yes and 0 = no or missing data. This measure of perceived risk was used instead of danger to self of being killed because the latter contained insufficient variance to include in the analysis.

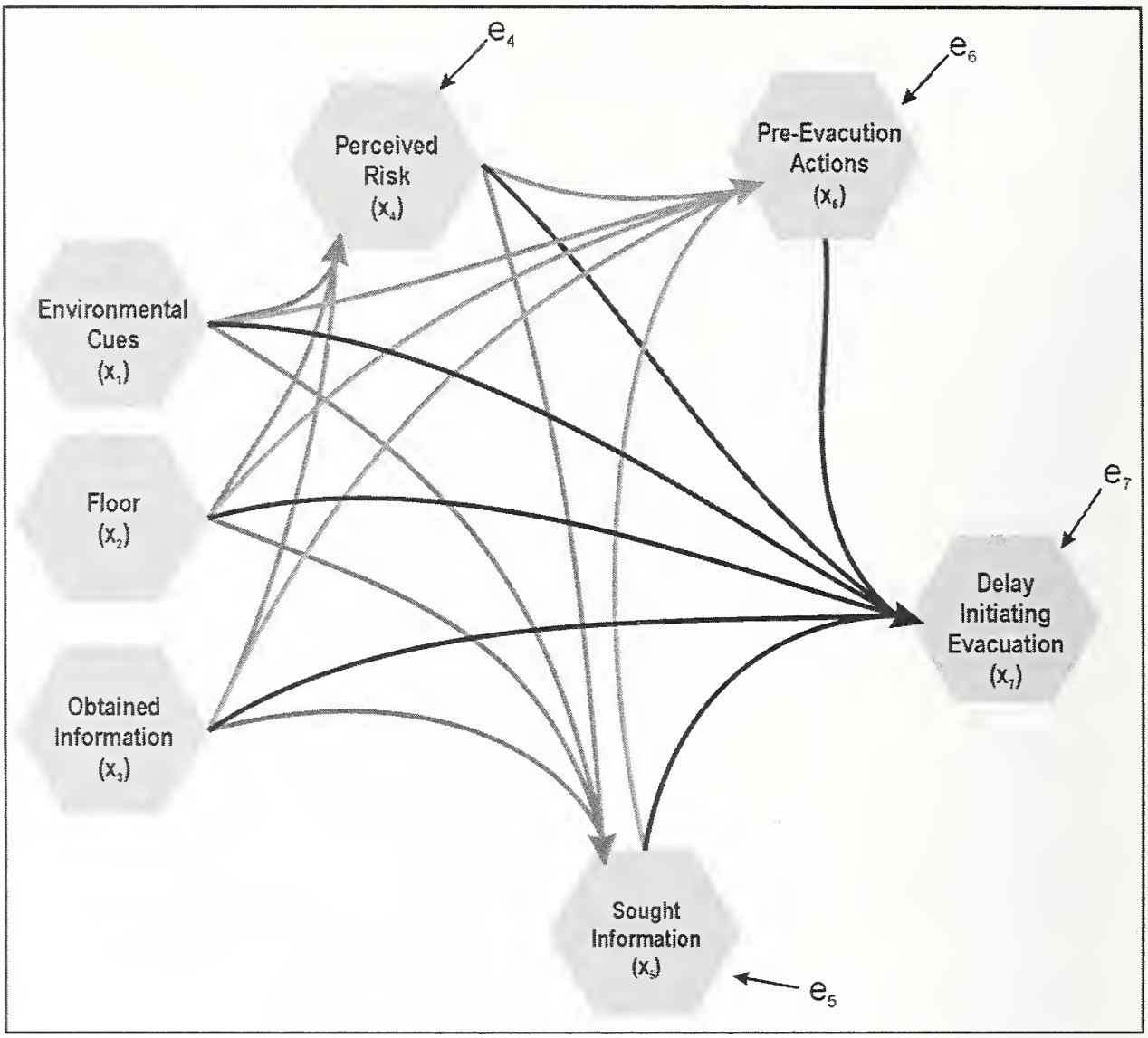

Figure C–1. Model of evacuation delay.

Seeking additional information (X_5) was measured by asking the respondent whether they tried to get additional information about what was going on. Answers were coded a 1 = yes (for both successful and unsuccessful attempts to get additional information), and 0 = no.

Taking pre-evacuation actions (X_6) was measured by asking respondents whether or not they performed any of the following tasks: talk to another person face-to-face, gather personal items, telephone other people, continue working, save or transfer computer files, search for others, fight fire or smoke, move to another floor, or help others. These nine items were added to create a scale of taking actions (post-first became aware that something was wrong but pre-evacuation initiation) that varied between 0 and 9.

Finally, respondents were asked about evacuation delay (X_7) that is how many minutes passed from the time when they first became aware that something was wrong until they actually began their evacuation. Their responses were coded as an interval scale of minutes that varied between 1 to 80 minutes for WTC 1, and 1 to 75 minutes for WTC 2. The means, medians, and modes for WTC 1 were 5.61 minutes,

3.00 minutes, and 1 minute. These same values for WTC 2, respectively, were 6.04 minutes, 4.00 minutes, and 5 minutes. As discussed previously, however, a significant bias for a segment of the WTC 2 population may exist: occupants above floor 78 whose evacuation delay time exceeded 16 minutes did not successfully evacuate WTC 2 on September 11, 2001. NIST has estimated that approximately 75 percent of the occupants above the 78th floor at 8:46:30 a.m. were able to evacuate on September 11, 2001, therefore this bias accounts for less than 10 percent of the overall WTC 2 population.

The Structural Equations for the Model

The theoretical model presented in Figure 1 was represented by the following structural equations:

$$X_4 = \beta_{41}X_1 + \beta_{42}X_2 + \beta_{43}X_3 + e_4 \quad \text{(Eq. C–1)}$$

$$X_5 = \beta_{51}X_1 + \beta_{52}X_2 + \beta_{53}X_3 + \beta_{54}X_4 + e_5 \quad \text{(Eq. C–2)}$$

$$X_6 = \beta_{61}X_1 + \beta_{62}X_2 + \beta_{63}X_3 + \beta_{64}X_4 + \beta_{65}X_5 + e_6 \quad \text{(Eq. C–3)}$$

$$X_7 = \beta_{71}X_1 + \beta_{72}X_2 + \beta_{73}X_3 + \beta_{74}X_4 + \beta_{75}X_5 + \beta_{76}X_6 + e_7 \quad \text{(Eq. C–4)}$$

These equations cast perceived risk (X_4) as a direct linear function of environmental cues (X_1), floor (X_2), and obtained information (X_3). Seeking information (X_5) is a direct linear function of environmental cues (X_1), floor (X_2), obtained information (X_3), and perceived risk (X_4). Pre-evacuation actions (X_6) is a direct linear function of environmental cues (X_1), floor (X_2), obtained information (X_3), perceived risk (X_4), and seeking information (X_5). Finally, evacuation delay (X_7) was cast as a direct linear function of environmental cues (X_1), floor (X_2), obtained information (X_3), perceived risk (X_4), seeking information (X_5), and pre-evacuation actions (X_6).

Estimation of the Model and Assessing for Regression Assumptions

The model was estimated on the data from both WTC 1 and WTC 2. The estimated model parameters included path coefficients (β), explained variance for each equation (R^2), and other estimates. These are presented in Table C–1 and Table C–2, respectively, for WTC 1 and WTC 2.

The models were assessed for specification error, multicolinearity, nonlinearity, and heteroscedasticity in order to determine if basic regression assumptions could be reasonably made, and if the estimated model parameters were unbiased.

Specification error was not determined to be a problem. The model included only major variables of import suggested by evacuation theory and excluded variables shown in our preliminary analyses as non-predictive in the data sets being analyzed.

Multicolinearity can bias model estimates because it can increase the standard errors of estimated regression coefficients. The models for both WTC 1 and WTC 2 were assessed for multicolinearity in two ways. First multicolinearity does not impose a problem unless it is nearly perfect. The zero-order correlation matrices for both models (Table C–3 and Table C–4) were inspected to determine if any

Table C–1. Estimated parameter of the model for WTC 1.

Variables[a]		Path			Equation	
Endogenous	**Exogenous**	**Coefficient**	**Estimate**	**α**	**α**	**R^2**
X_4	X_1	β_{41}	.38	.00	.00	.55
	X_2	β_{42}	.37	.00		
	X_3	β_{43}	.14	.00		
X_5	X_1	β_{51}	.21	.00	.00	.25
	X_2	β_{52}	.21	.00		
	X_3	β_{53}	.01	N/S		
	X_4	β_{54}	.15	.02		
X_6	X_1	β_{61}	.27	.00	.00	.68
	X_2	β_{62}	.41	.00		
	X_3	β_{63}	.05	.06		
	X_4	β_{64}	.08	.04		
	X_5	β_{65}	.20	.00		
X_7	X_1	β_{71}	.29	.00	.00	.49
	X_2	β_{72}	-.17	.00		
	X_3	β_{73}	.20	.00		
	X_4	β_{74}	-.02	N/S		
	X_5	β_{75}	.10	.01		
	X_6	β_{76}	.47	.00		

a. Where X_1 = environmental cues, X_2 = floor, X_3 = obtained information, X_4 = perceived risk, X_5 = sought information, X_6 = pre-evacuation actions, and X_7 = delay in evacuation initiation.

Table C–2. Estimated parameters of the model for WTC 2.

Variables[a]		Path			Equation	
Endogenous	Exogenous	Coefficient	Estimate	α	α	R^2
X_4	X_1	β_{41}	.30	.00	.00	.59
	X_2	β_{42}	.49	.00		
	X_3	β_{43}	.12	.00		
X_5	X_1	β_{51}	.25	.00	.00	.25
	X_2	β_{52}	.11	N/S		
	X_3	β_{53}	.07	N/S		
	X_4	β_{54}	.17	.02		
X_6	X_1	β_{61}	.20	.00	.00	.69
	X_2	β_{62}	.36	.00		
	X_3	β_{63}	.07	.04		
	X_4	β_{64}	.23	.00		
	X_5	β_{65}	.17	.00		
X_7	X_1	β_{71}	.13	.01	.00	.56
	X_2	β_{72}	-.19	.00		
	X_3	β_{73}	.23	.00		
	X_4	β_{74}	.05	N/S		
	X_5	β_{75}	.11	.01		
	X_6	β_{76}	.51	.00		

a. Where X_1 = environmental cues, X_2 = floor, X_3 = obtained information, X_4 = perceived risk, X_5 = sought information, X_6 = pre-evacuation actions, and X_7 = delay in evacuation initiation.

Table C–3. Zero-order correlation matrix for WTC 1.[a]

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1	.68	.25	.67	.45	.71	.59
X_2	-	1	.26	67	.45	.76	.46
X_3	-	-	1	.34	.17	.29	.37
X_4	-	-	-	1	.43	.64	.47
X_5	-	-	-	-	1	.55	.44
X_6	-	-	-	-	-	1	.64
X_7	-	-	-	-	-	-	1

a. Where X_1 = environmental cues, X_2 = floor, X_3 = obtained information, X_4 = perceived risk, X_5 = sought information, X_6 = pre-evacuation actions, and X_7 = delay in evacuation initiation.

Table C–4. Zero-order correlation matrix for WTC 2.[a]

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1	.60	.43	.64	.46	.67	.56
X_2	-	1	.44	.72	.41	.75	.48
X_3	-	-	1	.46	.30	.47	.55
X_4	-	-	-	1	.44	.72	.55
X_5	-	-	-	-	1	53	.47
X_6	-	-	-	-	-	1	.68
X_7	-	-	-	-	-	-	1

a. Where X_1 = environmental cues, X_2 = floor, X_3 = obtained information, X_4 = perceived risk, X_5 = sought information, X_6 = pre-evacuation actions, and X_7 = delay in evacuation initiation.

correlations between the regressors where around .80 or higher—this is a typical cutoff value below which multicolinearity does not seriously bias model estimates. An inspection of the zero-order correlations in Table C–3 and Table C–4 led to the conclusion that coefficients were not sufficiently high for multicolinearity to be a problem. Second, multicolinearity was assessed by regressing each exogenous variable in each equation on all other exogenous variables in that equation, and the explained variances for these regressions were inspected to see if any approached 1.00, which would indicate a biasing level of multicolinearity. This assessment also led to the conclusion that multicolinearity was not a source of

bias in the estimated parameters of the model in either the data set for WTC 1 or the data for WTC 2. Therefore, it was concluded that the regressors in both models were orthogonal.

The models were then assessed to determine if the assumption of linearity could be met. Exogenous variables in each equation were transformed to alternative nonlinear forms, for example, the natural logarithm of X, the square of X, the reciprocal of X, and the square-root of X. These transformed variables were then correlated with each of the pre-determining and endogenous variables in both models. None of the correlations involving the transformed exogenous variables increased substantially beyond the linear correlations presented in Table C–3 and Table C–4. A visual inspection of scatter plots also confirmed the conclusion that relationships were linear.

The assumption of homoscedasticity was also assessed by visual inspection of regression residuals in scatter plots for each relationship in both models; and it was concluded that this assumption was met.

The observed means, standard deviations, and ranges for all of the variable included in the models for both towers are presented in Table C–5.

Table C–5. Observed means, standard deviations, and ranges for variable measurements in WTC 1 and WTC 2.

	WTC 1			WTC 2		
Variable[a]	Mean	SD	Range	Mean	SD	Range
X_1	.84	.73	2.00	.68	.70	2.00
X_2	41.87	25.71	90.00	48.99	30.56	104.00
X_3	.11	.32	1.00	.21	.41	1.00
X_4	.63	.48	1.00	.67	.47	1.00
X_5	.28	.44	1.00	.29	.45	1.00
X_6	2.08	1.50	7.00	2.37	1.46	8.00
X_7	5.61	8.34	79.00	6.04	8.06	74.00

a. Where X_1 = environmental cues, X_2 = floor, X_3 = obtained information, X_4 = perceived risk, X_5 = sought information. X_6 = pre-evacuation actions, and X_7 = delay in evacuation initiation.

Judging the Success of the Models

The estimated parameters of the models for WTC 1 and WTC 2 (see Tables 1 and 2) revealed that the model had a very high degree of success in explaining evacuation initiation delay, pre-evacuation actions, seeking information, and perceived risk in both towers. The adjusted explained variance (R^2) for perceived risk was 55 and 60 percent in WTC 1 and WTC 2, respectively. The adjusted explained variance for sought information was 25 percent in both towers. Respectively, the adjusted R^2 for pre-evacuation actions was 68 and 69 percent for WTC 1 and WTC 2, respectively. Finally, the adjusted R^2 for delay in evacuation for WTC 1 and WTC 2 was, respectively, 49 and 56 percent. These are extraordinarily high levels of adjusted explained variance to observe in a study of human evacuation and these R^2s, thereby, establish the strong predictive power of the models for both towers. All of the equations in the models for both towers were statistically significant at the .001 level or higher.

Direct Effects

With a few exceptions, similar findings emerged in both towers. This lends validity to the conclusions that can be drawn from the analyses. The findings are presented below. First, we consider each of the four equations in both models for both towers (see Figure 1), and then the models are interpreted as a whole so that the most significant paths of influence for each tower can be distinguished.

Predicting perceived risk. The findings that emerged regarding predicting the risk that people perceived were virtually identical across the two towers. The R^2 for perceived risk was 55 percent in WTC 1 and 60 percent in WTC 2 (see Tables 1 and 2). In WTC 1, both environmental cues and floor had strong and similar impacts on predicting perceived risk, respectively, β_{41} and β_{42} were .38 and .37, while obtained information had a weaker but statistically significant impact, β_{43} was .14. In WTC 2, once again, both environmental cues and floor had strong impacts on predicting perceived risk, respectively β_{41} and β_{42} were .30 and .49, and, once again, obtained information had a weaker but statistically significant impact, β_{43} was .12. These findings suggest that the risk that people perceived before they began their evacuation increased largely as a function of floor height and being exposed to environmental cues. It is most likely that floor had this effect due to the perceived increased time needed to evacuate as a result of being higher in the towers. Environmental cues likely had this effect since seeing, hearing, feeling, and so on physical cues that indicate danger make discounting danger—most people's natural inclination--harder to achieve. Obtained information likely increased perceived risk because people learned more about the seriousness of the event through the information they obtained. Clearly, however, information had a lesser impact on risk perception than did the two more salient variables of experiencing environmental cues and floor height. The only difference in findings between the towers was that, in WTC 2, floor height was by far the strongest predictor of perceived risk.

Predicting seeking information. Once again, the findings that emerged for predicting seeking information were, almost, identical across both towers. Explained variance (R^2) for seeking information was 25 percent in both towers. In WTC 1, environmental cues and floor both had the strongest and identical impacts on seeking information, β_{51} and β_{52} were both .21; obtained information had no impact on seeking information, β_{53} was not statistically significant; and perceived risk had a slight impact on seeking information, β_{54} was .15. In WTC 2, environmental cues had the strongest impact on seeking information, β_{51} was .25; the impacts of floor and obtained information, β_{52} and β_{53}, were not significant; and perceived risk had a slight impact on seeking information, β_{54} was .17. Seeking information in times of rapid onset emergencies is a typical human response since people need to interpret and make sense out of an event before they act on it. The finding that environmental cues were the strongest predictor of seeking additional information is consistent with this theoretical finding about "milling" from past research. Obtained information had no impact on seeking information in either tower. This was likely because information to make sense out of the event had already been obtained. Perceived risk had a similar effect on seeking information—albeit lesser of an effect than environmental cues—in both towers, likely because it increased the urgency people had to interpret the situation. Interestingly, floor height (or distance from the exit) had a significant effect on seeking information in WTC 1, but not in WTC 2. Evacuation theory would predict that this effect would be present, it was in the tower that was struck first, and it was not present in the tower stuck second likely because the event began for the occupants of WTC 2 long before the second plane struck their tower.

Predicting pre-evacuation actions. The explained variance (R^2) for taking pre-evacuation actions in WTC 1 was 68 percent, and it was 69 percent in WTC 2 (See Tables 1 and 2). In both towers, the strongest predictor of taking pre-evacuation actions was floor, β_{62} in WTC 1 was .41 and it was .36 in WTC 2. Environmental cues was also predictive of pre-evacuation actions, β_{61}, respectively, in WTC 1 and WTC 2 was .27 and .20, respectively. Once again, observing clues that one is at risk and being high in the building with a longer path to safety emerged as strong predictors, in this case of taking actions to ready to leave. Obtaining information had virtually no impact in either tower; β_{63} was .05 in WTC 1 and .07 in WTC 2. Seeking information impacted pre-evacuation action, β_{65} was .20 in WTC 1 and it was .17 in WTC 2; likely because the information obtained supported the need to evacuate and, hence, related to getting ready to leave. Finally, the impact of perceived risk on taking pre-evacuation actions (β_{64}) was .23 in WTC 2, but it was weaker in WTC 1 where is was .08.

Predicting delay in evacuation. Explained variance (R^2) in evacuation delay was 49 percent in WTC 1 and 56 percent in WTC 2. The impacts of environmental cues (β_{71}), floor (β_{72}), obtained information (β_{73}), perceived risk (β_{74}), sought information (β_{75}), and pre-evacuation action (β_{76}) on delay in evacuation initiation, respectively, were .29, -.17, .20, -0.2, .10, and .47 for WTC 1; and for WTC 2 they were .13, -.19, .23, .05, .11, and .51. The greatest predictor of evacuation delay in both towers was taking pre-evacuation actions. Obviously, doing anything before initiating evacuation—including things to ready to leave—delayed departure. Setting this factor aside, some clear differences emerged between the two towers in terms of the relative impacts of the remaining variables in the model. Perceived risk (β_{74}) had no direct effect on evacuation initiation delay. This finding is consistent with general evacuation theory where perceived risk's impact on actual behavior is indirect through other factors. The three factors with the strongest direct effects on evacuation delay were the same in both towers. These were environmental cues, floor, and obtained information. In both towers, floor's effect was negative, that is, the more floors one was from the exit, the quicker people were to initiate their evacuation. Environmental cues and information that was received passively both increased delay in the initiation of evacuation. Finally seeking additional information had a minimal impact on evacuation delay.

Paths of Greatest Influence and Conclusions

Although each of the aforementioned findings are interesting in and of themselves, perhaps the most important findings that we can offer are those that emerge when all of the individual findings offered above are brought together and viewed at the same time in the context of the entire model.

Bias. As discussed previously, any conclusions about evacuation initiation delay time in WTC 2 should consider the impact of disproportional decedent location, particularly as a source of the disproportionality may be highly correlated to the variable of interest, evacuation delay. In other words, those who exhibited long delay times in one region of the building were unable to be interviewed, thus artificially shortening the average delay time for one-third of the building. In the causal modeling, this would affect the relationship between 'floor' and 'delay initiating evacuation,' likely tending towards zero a slightly negative estimate (-0.19) of the beta value between the two variables. As floor was not a primary path which directly predicted evacuation initiation delay in WTC 2, the impact of this bias was considered secondary. The effect of this bias as it worked through other variables was not considered.

WTC 1. Although there were other factors that had some lesser impacts on influencing what people did, the paths of causal influence that defined the main process that led to delay in the evacuation of WTC 1 on September 11, 2001, follows.

Environmental cues (information from the physical environment that something was terribly wrong) and floor (increased distance to safety) caused people to set out to find additional information, most likely information about what was going on and what they should do. Next, the act of seeking additional information, that is, "milling" about to make sense out of the situation, led people to take actions to prepare to evacuate. Finally, taking those actions to prepare to evacuate delayed the initiation of actually evacuating.

In addition to this four step causal process, environmental cues and floor also had indirect impacts on evacuation delay as follows. Both factors increased the odds of seeking information and both factors increased the chances that people would take pre-evacuation actions prior to evacuating. Both factors also had direct impacts on actual evacuation delay. Environmental cues increased delay while floor decreased delay.

WTC 2. Although there were other factors that had lesser influence on what people did, the paths of causal influence that defined the main process that led people to delay in the evacuation of WTC 2 on September 11, 2001 were identical to WTC 1 with one decided difference.

Environmental cues (information from the physical environment that something was terribly wrong) and floor (increased distance to safety) predicted perceived risk. Environmental cues, floor, and perceived risk caused people to set out to find additional information. Next, the act of seeking additional information, that is "milling" about to make sense out of the situation, and perceived risk both led people to take actions to prepare to evacuate. Finally, taking those actions to prepare to evacuate delayed the initiation of actually evacuating.

In addition to this five step causal process, environmental cues and floor also had indirect impacts on evacuation delay. Both factors increased the odds of seeking information and both factors increased the chances that people would take pre-evacuation actions prior to evacuating. Both factors also had direct impacts on actual evacuation delay. Environmental cues increased delay, while floor decreased delay.

C.2 Predicting Normalized Stairwell Evacuation Time In WTC 1 On September 11, 2001

This project analyzed the factors and social processes that influenced the normalized stairwell evacuation time per story of stairs for the people who evacuated out of WTC 1 on September 11, 2001. WTC 2 was excluded from this analysis because evacuees used stairs, elevators, and/or a combination of both for their evacuation. Evacuation time was defined as the average number of seconds per story of stairs that it took people from the time they entered a stairwell until they completed their evacuation out of the building. For a discussion of the data collection method, see Section 10.2.1 of this report.

Pre-Modeling Analysis

The model estimated to predict normalized stairwell evacuation time was specified as follows:

First, we accessed the record of research on human evacuation during high rises fires. A group of individuals selected for the expertise on human evacuation during high rise fires was assembled. The individual experts developed the final list of variables, and the relationships between them, to use to specify the model used in this analysis.

Second, preliminary statistical analyses were performed to determine which variables thought to be important predictors of normalized stairwell evacuation time by the team of experts had and did not have predictive salience in WTC 1. Those that had no significant impact on normalized stairwell evacuation time were excluded from further consideration. The factors that had salient impacts on normalized stairwell evacuation time were carried forward into the model used in this analysis.

The Model that was Estimated

The model used to predict normalized stairwell evacuation time in WTC 1 of the World Trade Center on September 11, 2001, is diagrammatically illustrated in Figure C–2. This model can be described as follows: (1) normalized stairwell evacuation time is a direct consequence of floor, evacuation decision delay, environmental cues, emergency responders, crowding, and evacuation interruption; (2) evacuation interruption is a direct consequence of floor, evacuation decision delay, environmental cues, emergency responders, and crowding; (3) crowding is a direct consequence of floor, evacuation decision delay, environmental cues, and emergency responders; (4) emergency responders is a direct consequence of floor, evacuation decision delay, and environmental cues; (5) environmental cues is a direct consequence of floor and evacuation decision delay; and, finally, (6) evacuation decision delay is a direct consequence of floor. This model is parsimonious, consistent with the input received from high rise fire evacuation experts, and it well-represented the positive findings of our preliminary analyses of the many variables that could have impacted normalized stairwell evacuation time.

Measurement

Since multiple regression analysis requires that all responses be analyzed in numerical form, answers had to be 'coded' or converted to numbers. By convention, 0 = 'no', and 1 = 'yes.' Further, 2 is always a greater quantity of whatever the measurement is evaluating than 1.

Floor (X_1) was measured by asking respondents which floor they were on when the event started. Responses were coded from negative seven (basement floors) to 105. Negative floor values were transposed into positive ones since this measure sought to determine how many floors people were from their building's floor of exit. Missing data was coded to the mean.

Evacuation decision delay (X_2) was measured by asking respondents how minutes passed from the time when they first became aware that something was wrong until they actually began their evacuation. Their responses were coded as an interval scale of minutes.

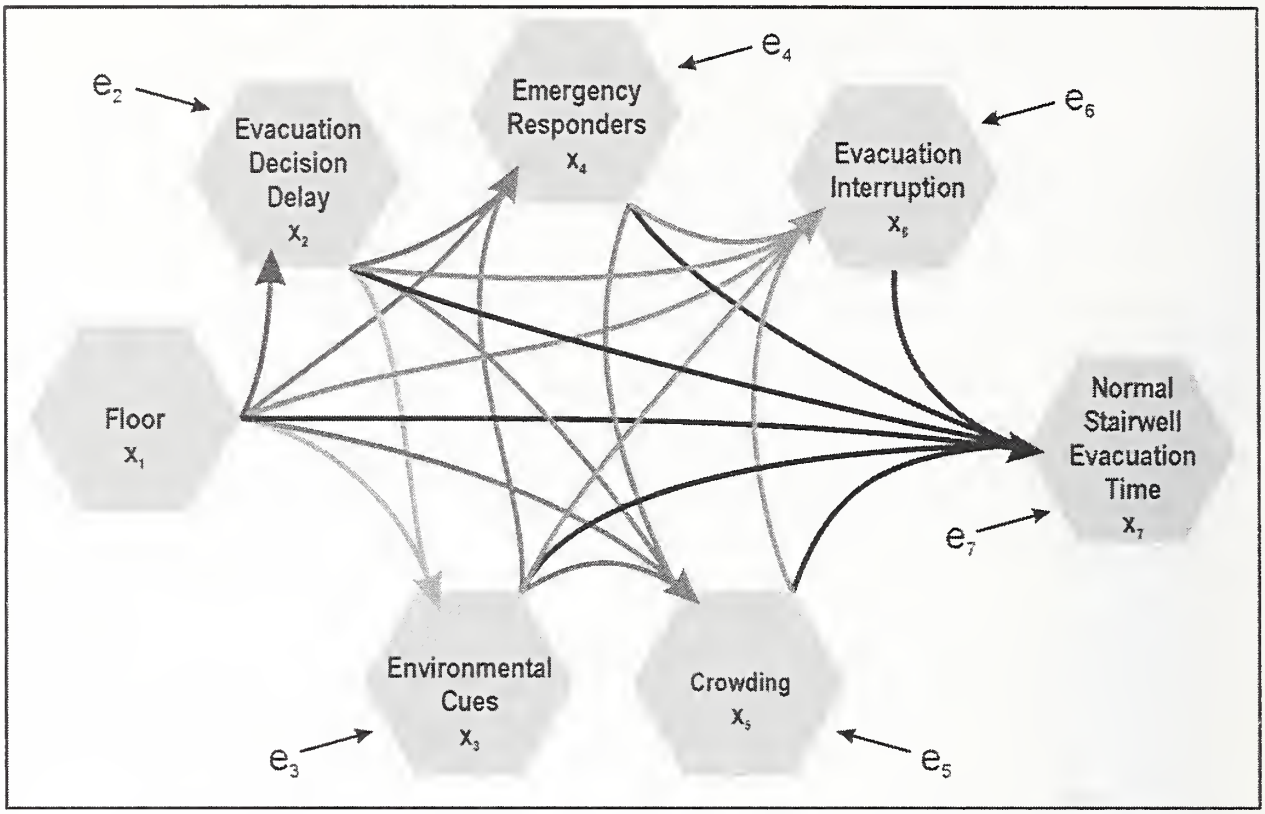

Figure C–2. Model of normalized stairwell evacuation time.

Environmental cues (X_3) was measured by asking respondents about the number and type of environmental cues (severe signs of danger, and non-severe signs of danger) that they saw prior to initiating their evacuation. Answers to these questions were coded as dummy variables (0 or 1) and then added to form an environmental cues scale that could vary between 0 and 2.

Emergency responders (X_4) was measured by asking respondents whether items from a list made their evacuation more difficult. Affirmative answers to the "firefighters/police" choice were coded as 1, and "no" answers and missing data were coded as 0.

Crowding (X_5) was measured by asking respondents whether items from a list made their evacuation more difficult. "Yes" answers to "crowded stairwells" were coded as 1, and "no" answers and missing data were coded as 0.

Evacuation interruption (X_6) was measured by asking respondents whether they turned back at any time during their evacuation. "Yes" answers were coded as 1, and "no" answers and missing data were coded as 0.

Finally, normalized stairwell evacuation time (X_7) was measured by asking respondents how much time passed between the moment they first began their evacuation until they exited the tower. Answers were coded on an interval scale; "don't know" and "refused to answer" responses were coded to the mean. These raw numbers were then normalized. The hydraulic model of people movement dominates the average evacuation time per floor, so it had to be removed from normalized stairwell evacuation time so as to fully explain the fluctuations (denoted by a prime) in reported evacuation time. This was

accomplished by a least squares analysis of reported evacuation time against floor for each tower, with statistical outliers removed. The final WTC 1 estimate was:

$$AETF'_j = RET_j - .056_i \quad \text{(Eq. C–5)}$$

where:

AETF′ = Average fluctuation in evacuation time per floor for occupant j,

i = Floor evacuation began from for occupant j. and

RET = Reported evacuation time for occupant j.

The Structural Equations for the Model

The theoretical model presented in Figure 1 was represented by the following structural equations.

$$X_2 = \beta_{21} X_1 + e_2 \quad \text{(Eq. C–6)}$$

$$X_3 = \beta_{31}X_1 + \beta_{32}X_2 + e_3 \quad \text{(Eq. C–7)}$$

$$X_4 = \beta_{41}X_1 + \beta_{42}X_2 + \beta_{43}X_3 + e_4 \quad \text{(Eq. C–8)}$$

$$X_5 = \beta_{51}X_1 + \beta_{52}X_2 + \beta_{53}X_3 + \beta_{54}X_4 + e_5 \quad \text{(Eq. C–9)}$$

$$X_6 = \beta_{61}X_1 + \beta_{62}X_2 + \beta_{63}X_3 + \beta_{64}X_4 + \beta_{65}X_5 + e_6 \quad \text{(Eq. C–10)}$$

$$X_7 = \beta_{71}X_1 + \beta_{72}X_2 + \beta_{73}X_3 + \beta_{74}X_4 + \beta_{75}X_5 + \beta_{76}X_6 + e_7 \quad \text{(Eq. C–11)}$$

These equations cast evacuation decision delay (X_2) as a direct linear function of floor (X_1). Environmental cues (X_3) was set as a direct linear function of floor (X_1) and evacuation decision delay (X_2). Emergency responders was seen as a direct linear function of floor (X_1), evacuation decision delay (X_2), and environmental cues (X_3). Crowding was cast as a direct linear function of floor (X_1), evacuation decision delay (X_2), environmental cues (X_3), and emergency responders (X_4). Evacuation interruption (X_6) was cast as a direct linear function of floor (X_1), evacuation decision delay (X_2), environmental cues (X_3), emergency responders (X_4), and crowding (X_6). Finally, normalized stairwell evacuation time was cast as a direct linear function of floor (X_1), evacuation decision delay (X_2), environmental cues (X_3), emergency responders (X_4), crowding (X_5), and evacuation interruption (X_6).

Estimation of the Model and Assessing for Regression Assumptions

The model was estimated on the data from WTC 1. The estimated model parameters included path coefficients (betas), explained variance for each equation, and other estimates. These are presented in Table C–6. The zero-order correlations between each of the variables are presented in Table C–7.

Table C–6. Estimated parameters of the model for WTC 1.

Variables[a]		Path			Equation	
Endogenous	Exogenous	Coefficient	Estimate	α	α	R^2
X_2	X_1	B_{21}	.58	.00	.00	.34
X_3	X_1	B_{31}	.78	.00	.00	.79
	X_2	B_{32}	.17	.00		
X_4	X_1	β_{41}	.23	.00	.00	.57
	X_2	β_{42}	-.01	N/S		
	X_3	β_{43}	.56	.00		
X_5	X_1	β_{51}	.18	.00	.00	.72
	X_2	β_{52}	.03	N/S		
	X_3	β_{53}	.37	.00		
	X_4	β_{54}	.35	.02		
X_6	X_1	β_{61}	.12	N/S	.00	.11
	X_2	β_{62}	.04	N/S		
	X_3	β_{63}	.15	N/S		
	X_4	β_{64}	.01	N/S		
	X_5	β_{65}	.07	N/S		
X_7	X_1	β_{71}	.03	N/S	.00	.44
	X_2	β_{72}	-.05	N/S		
	X_3	β_{73}	.46	.00		
	X_4	β_{74}	.09	N/S		
	X_5	β_{75}	.08	N/S		
	X_6	β_{76}	.18	.00		

a. Where X_1 = floor, X_2 = evacuation delay, X_3 = environmental cues, X_4 = emergency responders, X_5 = crowding, X_6 = evacuation interruption, and X_7 =normalized stairwell evacuation time.

Table C–7. Zero-order correlation matrix for WTC 1.[a]

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1	.58	.88	.71	.77	.84	58
X_2	-	1	.63	.47	.53	.25	.34
X_3	-	-	1	.75	.81	.35	.58
X_4	-	-	-	1	.77	.28	.54
X_5	-	-	-	-	1	.31	.57
X_6	-	-	-	-	-	1	.39
X_7	-	-	-	-	-	-	1

a. Where X_1 = floor, X_2 = evacuation delay, X_3 = environmental cues, X_4 = emergency responders, X_5 = crowding, X_6 = evacuation interruption, and X_7 =normalized stairwell evacuation time.

The model was assessed for specification error, nonlinearity, and heteroscadasticity in order to determine if basic regression assumptions could be reasonably made, and if the estimated model parameters were unbiased. The multicolinearity assumption did not have to be assessed since the model contained only one exogenous variable.

Specification error was determined not to be a problem. The model included only variables of import suggested by individual experts, and excluded variables shown in our preliminary analyses as non-predictive in the data sets being analyzed.

The model was then assessed to determine if the assumption of linearity could be met. Exogenous variables in each equation were transformed to alternative nonlinear forms, for example, the natural logarithm of X, the square of X, the reciprocal of X, and the square-root of X. These transformed variables were then correlated with each of the pre-determining and endogenous variables in the model. None of the correlations involving the transformed exogenous variables increased substantially beyond the linear correlations presented in Table C–7. A visual inspection of scatter plots also confirmed the conclusion that relationships were linear.

The assumption of homoscedasticity was assessed by visual inspection of regression residuals in scatter plots for each relationship in both models, and it was concluded that this assumption was met.

The observed means for each of the variables contained in the model were: 47.2 for floor, 5.36 for evacuation delay, 1.73 for environmental cues, 0.60 for emergency responders, 0.73 for crowding, 0.12 for evacuation interruption, and 13.01 for normalized stairwell evacuation time.

Judging the Success of the Models

The estimated parameters of the model for WTC 1 (Table C–6) revealed that the model had a very high degree of success in explaining normalized stairwell evacuation time. The adjusted explained variance (R^2) for normalized stairwell evacuation time was 44 percent, 11 percent for evacuation interruption, 72 percent for crowding, 57 percent for emergency responders, 79 percent for environmental cues, and 34 percent for evacuation initiation delay. With the exception of evacuation interruption, these are extraordinarily high levels of adjusted explained variance to observe in a study of human evacuation. These R^2's, thereby, establish the strong predictive power of the model. All of the equations in the model were statistically significant at the .001 level or better.

Direct Effects in the Model

We first consider each of the six equations in the model (see Figure 1), and then the model is interpreted as a whole so that the most significant paths of influence can be distinguished.

Predicting evacuation initiation delay. The findings that emerged regarding predicting delay in the initiation of evacuation from floor were that the R^2 was 34 percent with a value of .58 for β_{21} significant at the .001 level. This relationship was elaborated earlier in this appendix.

Predicting environmental cues. Explained variance (R^2) for observing environmental cues was 79 percent, and the equation was statistically significant at the .001 level. Floor had a very strong direct impact on observing environmental cues; β_{31} was .78 and it was significant at the .001 level. The effect of delay in the initiation of evacuation (β_{32}) was .17, and it was also statistically significant at the .001 level. It appears that the longer a person took to begin their evacuation, the more the physical impacts of the event grew and the more likely people were to experience them.

Predicting emergency responders. The explained variance (R^2) for the third equation in the model predicting encountering emergency responders was 57 percent, and the equation was statistically significant at the .001 level. The relative effects of floor, delay in beginning evacuation, and environmental cues, respectively, were as follows: β_{41} was .23 statistically significant at the .001 level, β_{42} was -.01 and was not statically significant, and β_{43} was .56 statistically significant at the .001 level. Floor height and experiencing environmental cues both predicted encountering emergency responders. This makes sense when one considers that emergency responders would be most likely to go to areas experiencing the impacts that would also yield environmental cues, and the higher one was in the tower, the more stairwells one had to traverse and the greater the odds of encountering emergency responders.

Predicting crowding. The explained variance (R^2) for the fourth equation in the model that predicted perceived crowding on the evacuation stairwells was 72 percent. The four variables in the equation had the following effects on perceived crowding: floor (β_{51}) was .18, significant at the .001 level; evacuation delay (β_{52}) was .03, and it was not statistically significant; environmental cues (β_{53}) was .37, significant at the .001 level; and encountering emergency responders (β_{54}) was .35, significant at the .001 level. Perceived crowding largely increased as a result of environmental cues and encountering emergency responders.

Predicting evacuation interruption. The explained variance (R^2) for interrupting evacuation was only 11 percent. Even though this equation was statically significant at the .001 level, none of the 5 predictor

variables in the equation had a statistically significant impact on evacuation interruption. The beta weights for these variables (floor, evacuation delay, environmental cues, emergency responders, and crowding) were, respectively (β_{61} through β_{65}) .12, .04, .15, .01, and .07. At best, we can interpret these findings to mean that there was a slight but not statistically significant tendency for people to interrupt their evacuation if they had more rather than fewer floors to traverse to safety, and if they encountered environmental cues (perhaps obstacles) in the process of evacuation.

Predicting normalized stairwell evacuation time. Explained variance (R^2) in predicting normalized stairwell evacuation time was 44 percent, and the equation was statistically significant at the .001 level. The impacts of floor (β_{71}), evacuation delay (β_{72}), environmental cues (β_{73}), emergency responders (β_{74}), crowding (β_{75}), and evacuation interruption (β_{76}), on normalized stairwell evacuation time, respectively, were .03, -.05, .46, .09, .08, and .18. Of these, only two factors in the equation were statistically significant both at the .001 level. These were environmental cues (β_{73} was .46) and evacuation interruption (β_{76} was .18). Clearly, the single factor that had the biggest impact on increasing the amount of time people spent, on average, per stairwell was environmental cues. The only other factor that had a significant impact was interrupting evacuation, obviously, because stopping egress would increase the amount of time needed to complete evacuation.

Conclusions

Although each of the aforementioned findings are interesting in and of their own right, the most important findings that we can offer are those that emerged when all of the above findings are brought together and viewed at the same time in the context of the model as a whole (see Figure 1). What doing so revealed was that, based on this analysis, the main process that led to increased normalized stairwell evacuation time in the evacuation of World Trade Center WTC 1 on September 11, 2001, was straightforward and clear. It can be described as follows.

Floor (increased distance to safety) substantially increased the odds that people would encounter environmental cues. Floor also increased delay in starting evacuation, which, in turn, also increased the chances that people would encounter environmental cues. But it was encountering environmental cues (which likely blocked egress) that had a large and direct effect on increasing the amount of time that people spent, on average, to traverse their evacuation stairwell. In addition to this multi-step process with environmental cues as the key predicting variable, interrupting the process of evacuation for any reason also increased the amount of time, on average, that people used to descend their evacuation stairwell.

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Appendix D
EGRESS MODELING

The purpose of modeling evacuation from the World Trade Center (WTC) towers was to obtain evacuation times for a variety of scenarios which provide context to understanding the actual evacuation on September 11, 2001. The following six scenarios were selected and modeled:

Phased evacuation

- Scenario 1: Occupants in an emergency situation have to travel 3 floors below the fire floor, floor 48

Total evacuation

- Scenario 2: Full capacity tower without visitors or damage
- Scenario 3: Full capacity tower including visitors without damage
- Scenario 4: Sept. 11th capacity tower without damage
- Scenario 5: Full capacity tower with plane damage blocking floors 91 and above in WTC 1
- Scenario 6: Full capacity with plane damage blocking floors 78 and above in WTC 2 after 16 minutes, including estimates of elevator usage

D.1 METHOD FOR THE SIMULATING PHASED EVACUATION (SCENARIO 1)

The purpose of simulating a phased evacuation was to understand how the evacuation strategy would have worked during an emergency at the WTC towers. For a phased evacuation, the occupants of the emergency floor, the occupants on the floor above, and the occupants on the floor below were to evacuate to three floors below the emergency floor. On floors 47 through 49, 200 occupants were placed on each floor. These 600 occupants traveled to the 45th floor where they would be considered "safe." Floor 48, the emergency floor, was a transfer floor; therefore, occupants from floor 49 were faced with moving through the horizontal corridor on the 48th floor. Figure D–1 shows a three-dimensional view of the 45th – 50th floors, as entered into the buildingEXODUS model. The occupants were placed on floors 47 – 49 and the three stairwells connected all 6 floors together.

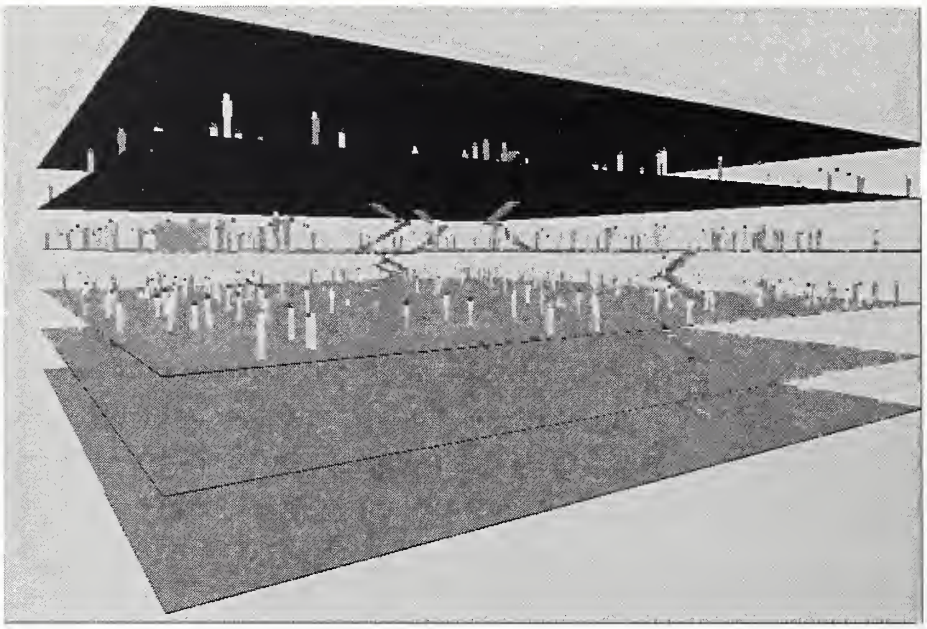


Figure D–1. 3-D view of a phased evacuation showing floors 45 – 50 (Exodus).

Figure D–2 shows occupants traveling through one of the transfer corridors on floor 48. Occupants are traveling on the stairs that connects floor 49 and 48, walking through the transfer corridor and eventually onto the stair connecting floor 48 to 47.

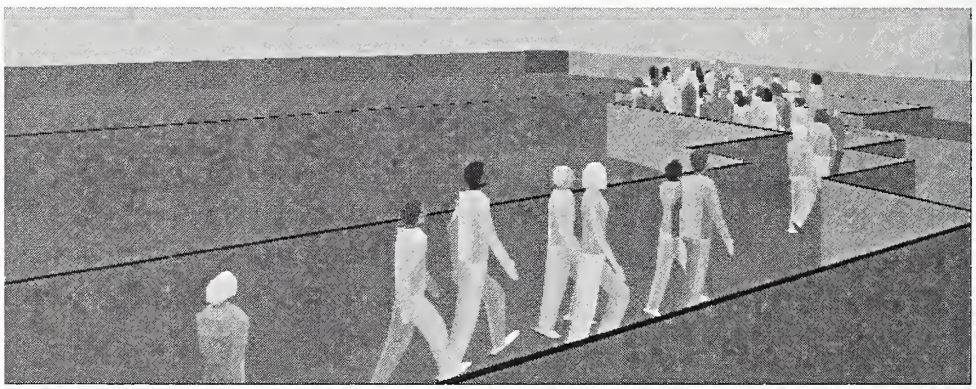


Figure D–2. Transfer corridor on floor 48 (Exodus).

D.2 METHOD FOR SIMULATING TOTAL EVACUATION (SCENARIOS 2-6)

Total building evacuation represented an emergency in which all occupants of the building evacuated simultaneously. Scenarios 2 – 6 were total evacuation simulations, which varied the total occupant population inside a tower and the damage to the building at the time of evacuation.

D.2.1 Population Estimates

Scenarios 2 – 4 required population estimates. Scenario 2 required an estimate of the number of occupants in the building, without the inclusion of visitors. Furniture and egress floor plans were studied from a sampling of floors: in WTC 1 – floors 94-100 and in WTC 2 – floor 77. On each floor, the

number of offices, cubicles, and other workstations was counted. From these numbers, the usable floor area (square footage) of the floors was divided by the corresponding number of persons to obtain an occupant density (area per person). Each floor in the towers received an average density (14 m^2/person), and the number of occupants per floor changed according to the total usable area of each floor. This resulted in a total of 19,800 persons to be simulated in Scenario 2.

For scenario 3, the full-capacity population with visitors, the number of occupants inside the towers was determined by the same method as Scenario 2, adjusted for visitor spaces. Visitor spaces included conference rooms, waiting areas, lunch tables, and library chairs. The same floor plans were used from Scenario 2 population development to count these additional spaces. Then, as in the previous calculation, the usable floor area of each floor in the towers was used to calculate the number of occupants, including visitors in each tower. With these calculations, the occupant density was 11 m^2/person when including visitors. This resulted in an estimate of 25,500 people. The findings of each step of the estimation method are summarized in Table D–1. Note, however, that in 2005, PANYNJ estimated that the maximum population of WTC 1 or WTC 2 would not likely have exceeded 20,000.[68]

Table D–1. Floor and occupant modeling parameters.

Zone	Represented Floors	Approx. area (m^2)	No. of chairs (w/o visitors)[a]	No. of chairs (with visitors)[a]
1	9 - 26 27 - 34 35 - 40	2,723 2,826 2,922	200	260
2	43-47	2,679	190	240
3	49 - 54 55 - 56 57 - 74	2,974 2,935 3,007	210	270
4	77 - 81	2,860	200	260
5	83 – 95 103 - 104 96 – 102 105 - 106	3,188 3,309 3,245 3,245	230	300

a. Averaged over variations within each zone.

The population for Scenarios 4, 5, and 6 was based upon the National Institute of Standards and Technology (NIST) estimate of the number of occupants present at WTC 1 and WTC 2 on September 11, 2001, or approximately 8,800. The purpose of Scenario 4 was to obtain a lower bound evacuation time for a September 11, 2001 population in the absence of constraints to evacuation or elevator usage. The 8,800 estimate was used to 'calibrate' (refine the model output to match the gross evacuation characteristics from the actual evacuation of WTC 1 and WTC 2) the model for Scenarios 5 and 6, where additional occupants were added in combination with building damage (Galea 2004).

For the total building evacuation scenarios, occupants were placed on all floors of the building, excluding mechanical spaces. Floors 1 through 107 were modeled (floors 108-110 were not normally occupied). During each simulation, the occupants left their floors and traveled into one of the three stairwells, in

[68] Bhol, Saroj. PANYNJ (September 21, 2005). Email from S. Bhol to S. Sunder in response to NIST question.

which they remained throughout the entire evacuation. The stairwells included all transfer corridors and emptied into the Mezzanine or the lobby area, depending upon the stairwell. Occupants reached safety as soon as they exited the tower (either to the outside or into the Concourse mall area).

Finally, the value of 8,800 occupants for the number of occupants in a WTC tower on September 11, 2001 was based upon the statistical projection derived from the telephone survey data described previously in Table 4–1.

D.3 WTC Tower Geometry Development

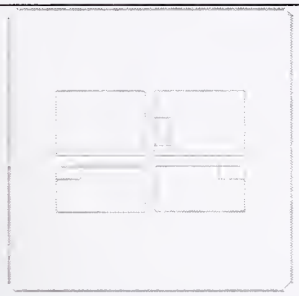
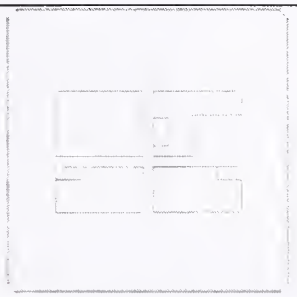
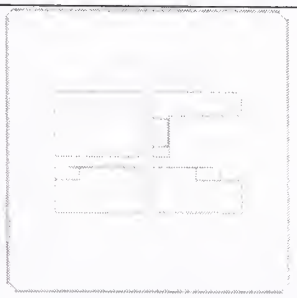
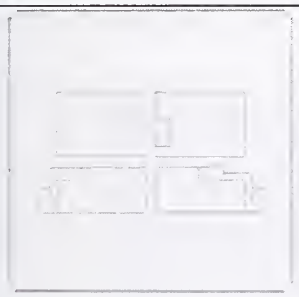
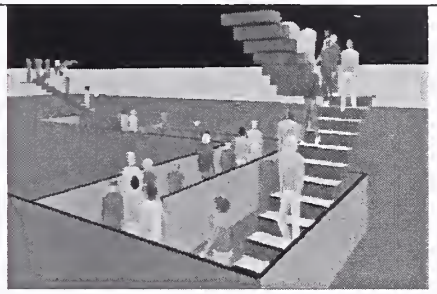
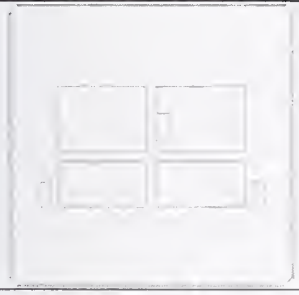
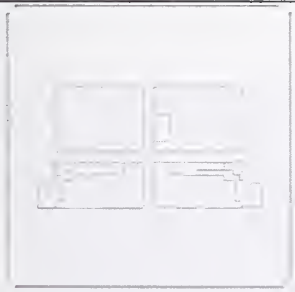
Each Tower, without including the basement floors, contained a total of 110 floors. In order to ease the difficulty of floor plan input in each evacuation model, 11 representative floor plans were created and replicated throughout the building. The core layout and stair position did not change significantly in between the transfer floors. Therefore, knowing the floor location of core and stair walls, the tower was divided into zones, the boundaries of which were transfer floors. Either tower (since they were identical in core layout and stair position) was divided into 5 zones, in addition to the four significant transfer floors (floors 42, 48, 76, and 82). The 11 representative floors were the Concourse, Mezzanine, a representative floor from each of the 5 zones, and the 4 unique transfer floors. Using representative floor plans greatly simplified floor plan input into each evacuation model used, with little loss of accuracy.

Even though floor duplication was used, each floor had to be created individually to achieve an accurate tower description within the evacuation model. At and around the mechanical spaces, the floor to ceiling measurements increased, meaning that throughout the building, the number of stair risers between floors ranged from 18 to 26 risers throughout the tower. Therefore, each floor was developed individually to ensure it contained the correct number of stairs to connect to the floor above. Also, even though occupants were not placed on these floors, mechanical floors were added to each model to include the sets of stairs that led throughout the mechanical spaces.

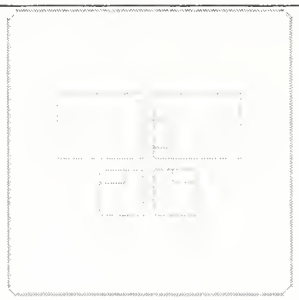
Three additional stairwell movements were not modeled, as the stairwell translation was less than 5 m: floors 26-41 (Stair A) and 66-68 (Stairs A and C). Note that the stair movement on floors 26-41 was input into the buildingEXODUS evacuation model only, as stair positioning was more important in this model, as discussed below.

Table D–2 shows the major floors plans contained in each zone. In Zones 1, 3, and 5, there were minor changes to the core walls from floor to floor, shown in the additional floor plans. The table outlines which floors these changes take place. However, due to the size of the building and the relative insignificance of a core wall change to the evacuation (since most of an occupant's travel time was spent in the stairwells), the floor plan of the majority of floors within a zone was used as the representative floor in each evacuation model. Table D–2 shows that floor plan Zone 1-1 was used as a representative of Zone 1, Zone 3-3 as a representative of Zone 3, and Zone 5-1 as representative of Zone 5.

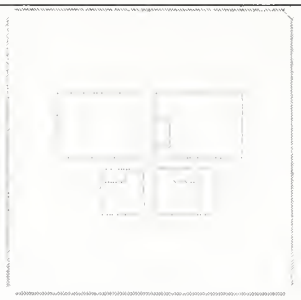
Table D–2. WTC floor plan with core walls and stairwell locations.

Zone 1: Floors 3-41		
		
Zone 1-1: Floors 9-26 There is a slight change in Stair A at floor 25. ****Used for all of Zone 1**	Zone 1-2: Floors 27-34 Variations are found in the upper right quadrant throughout this zone.	Zone 1-3: Floors 35-41 Variations are found in the upper right quadrant throughout this zone.
Transfer Floor 42		
		
Stairs A and C transfer	View of Stair A transfer	
Zone 2: Floors 43-47		
	Escalator positions: There is an escalator on the right side of the upper right quadrant between floors 44-45; Escalator on left side of upper left quadrant between floors 43-45 – these will not be used for evacuation purposes.	
Transfer Floor 48		
		
Stairs A and C transfer	View of Stair C Transfer	

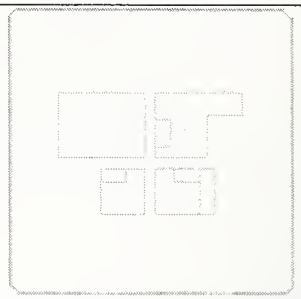
Zone 3: Floors 49-75



Zone 3-1: Floors 49 – 54

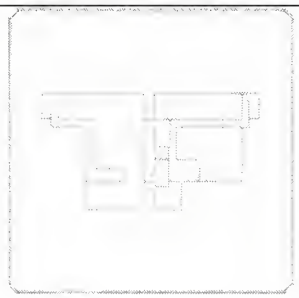


Zone 3-3: Floors 55-56



Zone 3-3: Floors 57-75
1) Variations are found in the upper left and right quadrants throughout this zone.
2) There is a slight change in Stairs A, C between floors 66-68.
***Used for all of Zone 3**

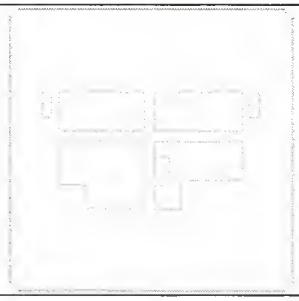
Transfer Floor 76



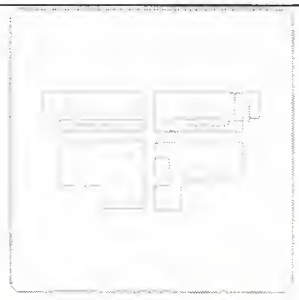
Stairs A, B, and C transfer

View of Stair B Transfer

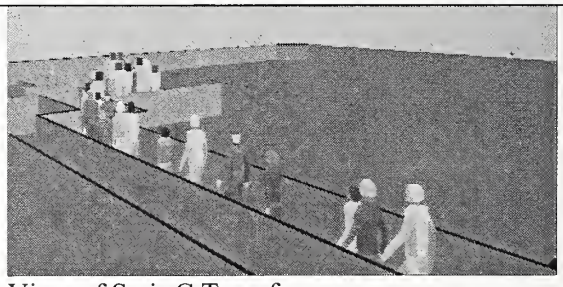
Zone 4: Floors 77-81



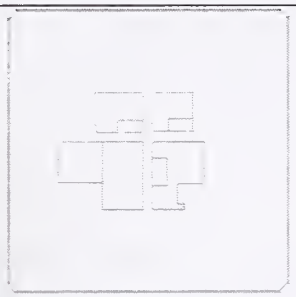
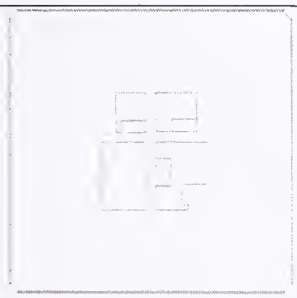
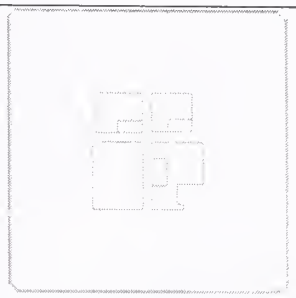
Transfer Floor 82



Stairs A and C transfer



View of Stair C Transfer

Zone 5: Floors 83-107		
		
Zone 5-1: Floors 83-95 Variations are found in the lower left quadrant throughout this zone. ***Used for all of Zone 5**	Zone 5-2: Floors 103-104, 107 Variations are found in the lower left quadrant at floor 107.	Zone 5-3: Floors 96-102, 105-106 Variations are found in the lower left quadrant throughout this zone.

D.3.1 Single-Tenant and Multi-Tenant Floor Plans

The floor plans shown in Table D–2 (used in the evacuation modeling) were single-tenant (open) floor plans, which contained only the outer walls, the core walls, and the stairwells. This section evaluates the quality of the assumption that the subdivision of a floor space into multiple tenancies did not significantly change the model results when compared to modeling the space as a single open floor plan. The assumption was based upon the premise that in a building as large as WTC 1 or WTC 2, most of the average occupant's evacuation time would be spent in the stairwell. Specific multi-tenant floor plans were chosen to study, developed based upon the demising wall layouts found in the WTC Space Book Plan (PANYNJ 2001c). The Simulex model was used for this analysis.

An open, single-tenant floor plan from each zone (1-5) was simulated by placing the appropriate number of occupants on each floor, running the model, and recording the numbers of occupants using each stair. The percentage of occupants who used each stairwell was calculated for each zone. Then, by factoring in the number of floors in each zone (that the sample floor represents), the weighted percentages of occupant use of each stair was calculated for the entire building. These percentages are shown in on the left hand side, labeled as the single-tenant floor plan percentages.

Using the Space Book Plans, at least three representative multi-tenant floor plans were selected from each zone. Each multi-tenant floor plan contained at least 3 corridors, and/or at least 10 different companies. In each of the five zones, the movement of occupants within the multi-tenant floor plans was simulated, and the percentages of stair use were averaged over each zone. The number of multi-tenant floors and single-tenant plans per zone were calculated and assigned their appropriate average percentages. As shown in Table D–3, the weighted percentages of occupant use of each stairwell were calculated for the entire building.

Table D–3. Stair use percentages for single-tenant versus multi-tenant floor plans.

Single-tenant Floor Plans only			Single- and Multi-tenant Floor Plans		
Stairwell C	Stairwell B	Stairwell A	Stairwell C	Stairwell B	Stairwell A
32.96 %	31.71 %	35.33 %	33.50 %	32.40 %	34.10 %
Number of people in each stair with 19,800 population					
6526	6279	6995	6633	6415	6752
Difference (Gross)			-107	-136	243
Difference (Percent)			-0.5 %	-0.68 %	1.2 %

In summary Table D–3 shows that there was approximately 1 percent difference between assuming all floors to be single tenant (open) floor and modeling both single- and multi-tenant floors with respect to the choice of stairwells. Therefore, representative single-tenant (open) floor plans were used in the subsequent evacuation modeling.

D.4 EVACUATION MODELS

Three evacuation models were used. The Simulex model (IES 2001) was used to perform the single-tenant and multi-tenant floor plan analysis and the phased evacuation scenario (Scenario 1). The buildingEXODUS (Gwynne et al. 1998) model was used for all scenarios from the WTC towers (Scenarios 1-6). Finally, the EXIT89 model (Fahy 1999) was used for the phased evacuation and the total evacuation scenarios (without damage) from the WTC towers (Scenarios 1-4). This section provides brief descriptions of each of the three models used in this project as well as the reason for picking these three among all other available evacuation models.

Simulex

The Simulex model was developed by Thompson, from IES, Inc. in Scotland, and is a widely used model in the field of fire safety. The model has been validated and focuses on the movement of occupants throughout a structure (IES 2001), (IES 2000). The model allows the user to specify a distribution of occupant types, associated with a certain body size and unimpeded movement speed, throughout the building. The model includes important occupant movements, such as overtaking, side-stepping, back-stepping, and others. Simulex predicts that occupant movement throughout building spaces will slow (in speed) as the inter-person distance between occupants and / or obstacles decreases. The model has fixed limitations on the number of floors and exits that the model can handle, however the developer is willing to expand these to meet the needs of the users. Also, Simulex provides a 2-D visualization of the evacuation throughout the building and allows the user to input CAD drawings of the building for ease in building geometry development.

The input required for this model included the following:

- Floor plans in the form of CAD drawings
- Connections of floor levels by stairways or ramps (involving user input on stair width and length)
- Distance maps that can be created to block certain exits or paths from groups of occupants

- Occupant movement characteristics for each individual or a group of individuals with a corresponding body size, initial horizontal speed, and percentage decrease of speed on stairs (the user can use default values provided by Simulex or create his / her own)

- Occupant delay times to be assigned from a random, triangular, or normal distribution

buildingEXODUS

buildingEXODUS (Gwynne et al 1999; 1998; 2001) was developed by Galea at the University of Greenwich, UK. buildingEXODUS is a well-documented and well-validated model, claimed to be limited only by the storage capacity of the computer used to run the program. The model contains six submodels that work together to form the evacuation simulation: occupant, movement, behavior, hazard, geometry, and toxicity submodels. Any time occupants wish to occupy the same node, or a node that is already occupied, a conflict resolution time is added to their total evacuation time. The method of conflict resolution is how the model simulates congestion throughout the building. Individual abilities of the occupants and conflict resolution are probabilistic. The behavioral model makes route choices depending upon the environmental situation of the building and then passes this information onto the movement model. Familiarity and awareness variables can be assigned to exits, and drive and patience variables are assigned to the occupant. These variables are random and difficult for the user to specify for any evacuation. buildingEXODUS provides the user with 2-D and 3-D visualization capabilities of the building evacuation and allows for the input of CAD drawings of the building for ease in building geometry development.

The input required for this model included the following:

- Floor plans in the form of CAD drawings (other methods are available to provide building information)

- Connections of floor levels via stairways, with an option for including effective width inside the stairwell

- Distribution of occupant types throughout the building (user can specify information about each individual or group such as speed, ability, drive, patience, etc.)

- Option of including special nodes at certain points in the building to regulate occupant paths through building and flow through the exits/doors

- Option of including boundary nodes used to predict slower movement near walls, obstacles

- A series of simulation options such as stair packing, occupant randomization throughout the building, response time distribution, stair edge preference, and extreme behavior

EXIT89

EXIT89 (Fahy 1999), (Fahy 2001) is an evacuation model developed by Fahy at the National Fire Protection Association (NFPA). The model has been tested on tall buildings in the past and has the capability of modeling a large number of occupants in a building. The model relies on the density versus

speed data from Predtechenskii and Milinskii (Predtechenskii and Milinskii 1969) for different building components, such as horizontal components, doorways, up stairs, and down stairs. It also uses conditional movement, depending upon the presence and density of smoke in the evacuation path. All occupants in the building are made up of the same body size and density versus speed distribution, both specified by the user. EXIT89 uses a series of nodes and arcs instead of CAD drawings to represent any type of structure. In this type of model, the floor plan is entered as a series of nodes (rooms, corridor, stair sections, etc.) and arcs (distance between nodes). When using a node/arc model for a single-tenant (open) floor plan such as those used for the WTC Towers, the user determines how to segment and link the building space, and then should check to make sure that occupants are traveling in realistic patterns to the exits. While EXIT89 does not provide visualization capability, the model does provide a particularly detailed output that notes where each occupant is at each time period throughout the evacuation. EXIT89 contains a variety of input choices for the user pertaining to each evacuation simulation:

- Shortest travel route or user-defined route for occupants
- The use of CFAST smoke data, user-defined blockages, or none
- The choice of a body size for occupants which applies to entire population of the building - Large (0.1458 m^2), Medium (0.113 m^2), or Small (0.0906 m^2)
- The choice of speed for the entire population of the building – Emergency (horizontal unimpeded speed = 1.36 m/s) or Normal (horizontal unimpeded speed = 0.91 m/s)
- A random delay time (uniform distribution)
- The modeling of disabled occupants, including the percentage of decrease in travel speed for these occupants compared with the rest of the population

The three models described above were used in different capacities for this project. Simulex was used in a limited capacity to provide analyses of occupant movement on individual floors and to simulate the phased evacuation. EXIT89 and buildingEXODUS were used to model scenarios of an entire WTC Tower with a large number of occupants within the building.

The three models were chosen for this project for different reasons. The Simulex model was chosen to perform certain aspects of the project due to its heavy focus on understanding and accurately predicting occupant movement, and was used for some of the smaller aspects of the project. The following reasons justified buildingEXODUS and EXIT89 as reasonable choices to model WTC 1 and WTC 2:

- Both had the capacity to simulate evacuation from a 110-story building with 25,500 people.
- Both provided the output that was needed to answer evacuation questions, including visualization capabilities from buildingEXODUS
- Both could handle the complexity of the building, such as the transfer floors and differences in floor to ceiling heights in different part of the Tower
- Both provided explanation for the underlying data used for the movement of occupants throughout the Tower

- Both provided sufficient knowledge and direction to NIST, through personal contact and/or user manuals, on how to use the model
- Both developers had published validation studies on the model
- Both models had been used by NIST or outside of NIST. This way NIST could identify their inefficiencies ahead of time and compensate for these during this project.

D.4.1 Phased Evacuation (Scenario 1) Inputs and Results

All three models were used to perform the phased evacuation analysis, Scenario 1. Each model required building geometry, population, and behavioral input conditions. The phased evacuation scenario involved the simulation of floors 45-49, and the emergency floor was floor 48. All three stairs, containing 19 risers per floor from floors 45-49, were added to the models with the appropriate diagonal length, stair width, and door width into and out of the stairwell. The number of occupants used in the phased evacuation was 200 per floor on floors 47-49, which totaled to 600 occupants. The number of six hundred occupants was used as a rounded estimate of the number of occupants seen on three floors within Zone 2 of the building. The movement response delay was set to zero for one set of simulations, and ranged between zero and ten minutes for the other set of simulations.

The difference between models for the phased evacuation scenario was the population characteristics of the occupants. The population type used in the Simulex model was the "office staff" type which distributed 60 percent males and 40 percent females throughout the building. The population distribution input into buildingEXODUS for the phased evacuation scenario was taken from WTC 1 telephone survey demographic data: 5 percent males age 17-29, 38 percent Males age 30-50, 21 percent Males age 51-80, 3 percent Females age 17-29, 22 percent Females age 30-50, and 11 percent Females age 51-80. All 600 occupants simulated with the EXIT89 model were assigned the medium body size and emergency speed parameters.

The total evacuation time for the phased evacuation, Scenario 1, was similar across all three models. Without a time delay, Simulex predicted that occupants would travel to floor 45 in approximately 240 seconds, buildingEXODUS predicted 243 seconds, and EXIT89 (emergency conditions) predicted 210 seconds. With a 0 to 10 minute time delay, Simulex predicted that occupants would travel to floor 45 in approximately 690 seconds, buildingEXODUS predicted 660 seconds, and EXIT89 (emergency conditions) predicted 690 seconds. These results are shown in Table D–4. From the three evacuation models, the average minimum time to complete a phased evacuation in WTC 1 or WTC 2 building was approximately 230 seconds, or around four minutes, assuming no evacuation delay and approximately 680 seconds, or around eleven minutes, assuming a 0 to 10 minute time delay.

Table D–4. Phased evacuation model input conditions.

Evacuation Model	Occupant Type/ Characteristics	Evacuation Time, No Delay (s)	Evacuation Time, 0 – 600 s Delay (s)
Simulex	All office staff; 60 % men, 40% women	240	690
EXODUS	WTC 1 distribution: 5 % Males age 17-29, 38 % Males age 30-50, 21 % Males age 51-80, 3 % Females age 17-29, 22 % Females age 30-50, and 11 % Females age 51-80	243	660
EXIT89	All Medium body size and emergency speed	210	690

D.4.2 Scenarios 2 and 3: Inputs and Results

Two models, buildingEXODUS and EXIT89, were used to perform the total building evacuation analysis of a full-capacity tower with and without visitors, Scenarios 2 and 3. Each model required building geometry, population, and behavioral input conditions.

buildingEXODUS

The buildingEXODUS model was used to simulate Scenarios 2 and 3, a total building evacuation of a fully-occupied tower both with and without the inclusion of visitors. Without visitors, the population totaled 19,800 people and with visitors, the population totaled 25,500 people. As discussed earlier, the tower was input into the model using 11 representative floor plans from CAD, including the four transfer floors. Mechanical floors were input into the model; however, no occupants were placed on these floors. All usable floor space had to be filled with nodes measuring 0.5 m x 0.5 m on which the occupants would travel throughout the building.

On each floor throughout the Tower, three stairs were added in their appropriate position on the floor and number of risers, depending upon the floor. These stairs were added to the model with the appropriate diagonal length, stair width, door width into and out of the stairwell, number of landings, and accurate stair riser and tread distances.

Figure D–3 shows a representation of a stair configuration of a 1.1 m (44 in.), 19 riser stair (Stairs A or C) in the buildingEXODUS model. The solid blue nodes represent the landing space and the green patterned nodes represent the stair steps. The figure shows a "spiral" stair that is 2 nodes wide with the distances in

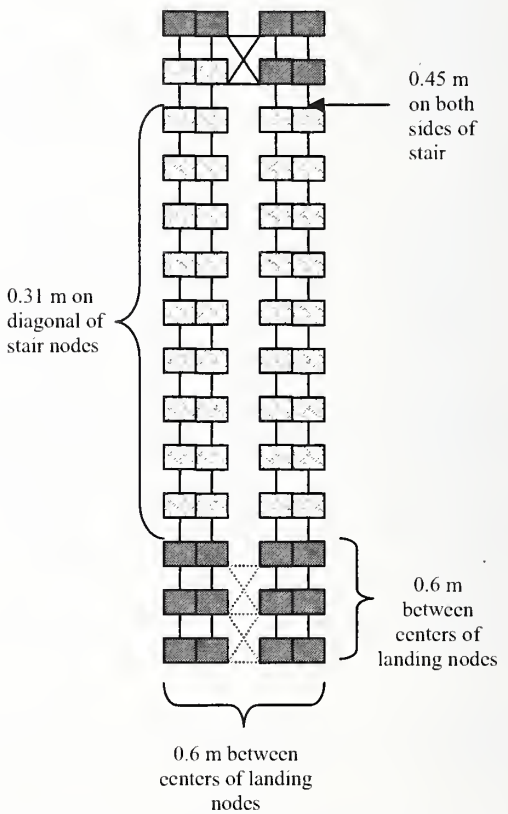


Figure D–3. 44 in stair configuration in buildingEXODUS.

between the centers of the nodes. The occupants can also move diagonally between the outer and inner track of the stair, which is not shown in the figure to prevent confusion. Also, the dotted lines in between the landing nodes are used to represent that one side of the landing will be located on one floor and the other side of the landing will be located on the floor above. Due to the 7.5 in by 9.5 in riser and tread configuration (not including the nose extending the tread space), the diagonal space between steps measured approximately 12 in. Similar stair configuration was used for the 56 in. stair (Stair B). The only difference was the distances from node to node; for instance, instead of a 0.6 m spacing between the centers of landing nodes, there was a 0.7 m spacing input. The number of nodes specified along the width of the stairwell is the buildingEXODUS's method of simulating stair width, and since not more than one person is allowed to occupy the same node, specifying 2 nodes across each stairwell allows for 2-person movement abreast in all three stairwells. NIST is aware of the narrowness of the 44 in. stair (Stair A and C), however, did not find it appropriate to model only 1-person abreast inside the stairwell throughout the entire building. Therefore, two nodes were used across each stair as an assumption made when using the buildingEXODUS model. Stair node connection lengths do not imply areas of the stairs, and therefore density of the space, but rather the distance that occupants travel inside the stair.

For the population, either 19,800 occupants or 25,500 occupants (including visitors) were distributed randomly throughout the building space, depending on the scenario. Similar to the phased evacuation scenario, the following occupant types were used to describe the WTC tower population: 5 percent Males age 17-29, 38 percent Males age 30-50, 21 percent Males age 51-80, 3 percent Females age 17-29, 22 percent Females age 30-50, and 11 percent Females age 51-80. All occupants were able-bodied without mobility impairments.

The minimum evacuation time from the Tower was simulated by choosing an immediate response time and the stair pack option, which predicted that occupants will "pack" inside the stairs during evacuation (however in the simulation each occupant still tries to leave the step ahead of them empty). Also, it was predicted that occupants traveled to the nearest stairwell on each floor. The simulation predicted that occupants from a fully-occupied building without visitors, with a response delay of zero, evacuated the building in approximately 110 minutes. Also, when visitors were added to the simulation, buildingEXODUS predicted an evacuation time of 141 minutes.

Another group of simulations provided the evacuation time from the Tower if the occupants delayed their evacuation by 0 to 10 minutes. All other options chosen for the group of simulations were similar to those described for the non delay simulations. buildingEXODUS predicted that occupants from a fully-occupied building without visitors, with a response delay of 0 to 10 minutes, evacuated the building in approximately 112 minutes. Also, when visitors were added to the simulation, buildingEXODUS predicted an evacuation time of 142 minutes.

EXIT89

The EXIT89 model was also used to simulate Scenarios 2 and 3, a total building evacuation of a fully-occupied tower both with and without the inclusion of visitors. Without visitors, the population totaled 19,800 people and with visitors, the population totaled 25,500 people. The tower was input into the model by describing each of the 11 representative floor plans with a series of nodes and arcs. On the mechanical floors, only the stair nodes and arcs were associated with these floors, and no occupants were

placed on these floors. All usable floor space, including stairs and transfer corridors, was filled with larger-sized nodes ranging from 2 m^2 to 104 m^2 and connected by arcs.

Similar to buildingEXODUS, three stairs were added in their appropriate position on each floor throughout the tower. These stairs were added to the model with the appropriate diagonal length, stair width, and door width into and out of the stairwell.

The stair input for the EXIT89 model was different than that used by the buildingEXODUS model. Instead of the stair consisting of two lanes of nodes, a stairwell in EXIT89 was represented by a horizontal area (m^2), stair width measured where stair nodes meet, and the stair travel distance measured along the diagonal, which included the lengths traveled on the landings. Even though the stair input method varied between buildingEXODUS and EXIT89, stair distances were verified as being similar in both models for the Tower geometry.

Within EXIT89, the transfer corridors were input as horizontal nodes connecting vertical stair nodes at each transfer floor, also part of the geometry input. At each transfer floor, the stairs leading to and leading away from the floor were considered completely different stairwells and named accordingly. However, since EXIT89 could account for only 10 different stairwells, the smallest transfer at floor 42 was considered part of a stairwell.

The number of occupants intentionally placed on each floor within the input file corresponded to the occupant numbers calculated per zone from both the 14 m^2/person and 11 m^2/person densities, depending upon the scenario. All occupants were assigned the medium body size and both emergency and normal speed options (from multiple simulations as shown by the range of evacuation times in Table D–5).

The simulation predicted that occupants from a fully-occupied building without visitors, with a response delay of zero, evacuated the building in approximately 97 to 117 minutes (emergency to normal speed input conditions). Also, when visitors were added to the simulation, EXIT89 predicted an evacuation time of 114 to 140 minutes.

When a response delay of 0-10 minutes was introduced to EXIT89, the simulation predicted that occupants from a fully-occupied building without visitors evacuated the building in approximately 92 to 113 minutes. Also, when visitors were added to the simulation, EXIT89 predicted an evacuation time of 119 to 139 minutes.

Table D–5. Total Building Evacuation Time (Simulated) for Various Occupant Loads

Evacuation Model	Evacuation Initiation Delay Input	Evacuation Time (min): 8,800 occupants	Evacuation time (min): 19,800 occupants	Evacuation time (min): 25,500 occupants
EXODUS	0 - 10 Minute Delay	55	112	142
	No Delay	52	110	141
EXIT89	0 - 10 Minute Delay	71-74	92-113	119-139
	No Delay	58-78	97[69]-117	114-140

D.4.3 Scenario Four (September 11th Capacity) Inputs and Results

The buildingEXODUS and EXIT89 models were used to perform the total building evacuation analysis of a WTC tower, Scenario 4, with a population similar to that observed on the morning of September 11, 2001. All inputs for the geometry and simulation options in buildingEXODUS and EXIT89 were identical to those used in Scenarios 2 and 3. Also, the inputs for the population options were identical, except for the number of occupants simulated. For scenario four, a total building evacuation was simulated with 8,800 occupants (the capacity estimated for a tower on the morning of September 11, 2001).

buildingEXODUS predicted that occupants from a building holding a September 11, 2001, capacity evacuated the building in approximately 52 minutes with no delay and 55 minutes with a 0 to 10 minute delay time. EXIT89 predicted that occupants from a building holding a September 11, 2001, capacity evacuated the building in approximately 58 to 78 minutes (depending up the speed option chosen, emergency to normal) with no delay and 71 to 74 minutes with a 0 to 10 minute delay time.

D.4.4 Scenarios Five and Six (Full-Capacity with Damage) Inputs and Results

To model how the event would have changed if the buildings were fully occupied, models were run using the calculated fully-occupied number of occupants in each tower, 19,800 occupants (without visitors). Through running these scenarios, NIST hoped to answer the following questions:

- What would have been the consequences if WTC 1 had been fully-occupied on September 11, 2001, the building had been hit by aircraft, and then had collapsed 103 minutes later?
- What would have been the consequences if WTC 2 had been fully-occupied on September 11, 2001, the building had been hit by aircraft 16 minutes after WTC 1 was hit, and then had collapsed 72 minutes after WTC 1 was hit (56 minutes from the time that WTC 2 was hit)?

To model these scenarios, NIST ran a series of calibration simulations for each tower in an attempt to crudely simulate the occupant conditions inside the towers on September 11, 2001 with the capacity of

[69] The underlying theory for people movement in EXIT89 is based upon the work of Predtechenskii and Milinskii. They observed an inverse relationship between density and speed for three different types of movement: emergency, normal, and comfortable. The effect of crowding (density) on overall evacuation speed was greater when no delay time was assumed. A delay time when 19,800 occupants were present, according to EXIT89, spaces the occupants out and increases overall evacuation efficiency. This was not found to be the case for all occupant loads (25,500).

8,800 occupants. Once the calibration simulations approximately achieved the goal of simulating the September 11, 2001 scenario, the fully-occupied population was added to each tower. From the fully-occupied simulations of each tower, possible consequences were predicted, such as the number of occupants who would be trapped inside the tower at the time of collapse and the congestion points (the Mezzanine escalator) that developed with a larger population.

For the calibration simulations, there were some difficult aspects of the evacuation that needed to be accounted for in the evacuation, such as pre-evacuation activities, occupants changing stairs for various reasons and the activities that they perform on the floor during evacuation, occupants resting in the stairs, occupants being delayed by helping behaviors, occupants giving way to injured persons (superflow), and firefighters counterflow. Although it was recognized that the models cannot accurately simulate all of these activities as of yet, an attempt was made to account for time lost to perform such activities in the calibration simulations. The buildingEXODUS model was the primary model used for this set of scenarios. Due to the way that the stairs are created in the model (lanes of occupants instead of an occupied space), it was difficult to model actual firefighters walking throughout the building and achieve the same kind of occupant response and effect that were seen on September 11, 2001. It was also difficult to simulate the effect of a larger bodied individual on the rest of the occupants in the stair, due to the method of simulating stair movement used in the buildingEXODUS model (2-lane stairways).

The successful calibration simulation used for the WTC involved a method (to be referred to as) the "stop and go" method. The stop and go method involved the creation of "doors" inside the stair that would open and close throughout the simulation. This method attempted to account for evacuation interruptions and the "stop and go" reports from survivors during the evacuation at different points throughout the stair, such as leaving/changing stairs (sometimes occupants did this multiple times) for various reasons, resting on the stairs, helping, waiting behind larger or disabled occupants, superflow, firefighter counterflow, etc. Evacuation delays were distributed uniformly throughout the building, depending upon the Tower, to account for pre-evacuation delays and any actions that occupants took when leaving the stairs, such as short activities like moving directly to the next stairs, and longer activities such as seeking information, making phone calls, looking for staff/coworkers, and looking out windows. In each building, a minimum evacuation delay of 6 minutes was assigned to the population because even if the occupant left their floor immediately, they were still faced with other challenges/actions taken while outside of the stairs. Although the evacuation delay distribution on September 11, 2001, was not uniform, this assumption was made for the model.

One must remember that the "stop and go" method was only an estimate of the reported "stop and go" activities observed in the WTC towers. This "stop and go" method alleviated a large crowd surrounding the escalator, which was a result in the simulations run for Scenarios 2-4, but was not overwhelmingly reported by survivors of September 11, 2001.

D.4.5 WTC 1 Calibration Simulation

The inputs for the calibration simulation of WTC 1 were the following:

- 7,200 occupants distributed from floors 90-ground floor

- "Stop and go doors" located inside the stairwells at floor 76 (early in the evacuation) to simulate the locked doors in the transfer, floor 5 (late in the evacuation), and floors 15 and 48 during the evacuation
- 6-30 minute delay uniformly distributed over the entire population
- Distribution of gender and age used in Scenarios 2-4
- Stair packing and local potential

In the calibration simulation, 7,200 occupants were distributed from floor 90 to the ground floor. The "stopping" points occurred (door closed) at every 5 minute interval for 2 minutes at floors 15 and 48 starting after 10 minutes. Then, at floor 76, the "door closed" only three times for 2 minutes each, to simulate the locked doors on floor 76 in Stair A at the beginning of the simulation. Lastly, on floor 5, the door closed 5 times for 2 minutes each at the ending time of the evacuation. Also, a 6 - 30 minute delay was uniformly distributed to the entire population of the building.

The simulation was judged to be "successful" at predicting a September 11, 2001, scenario if the following criteria set for the WTC 1 calibration simulation were met:

- Evacuated more than 90 percent but less than 100 percent of the occupants from the tower before WTC 2 collapse (72 min)
- Alleviated significant crowding at the entrance to the Mezzanine escalator

For the calibration simulation, when 7,200 occupants in WTC 1 were given a 6-30 minute time delay with stoppage points, no significant queue developed at the escalator. Also, 7,200 occupants (under a uniform delay) evacuated the building in approximately 71 minutes. This is a good estimate for WTC 1, because 90 percent of the occupants reported leaving the WTC complex before WTC 2 collapsed. Therefore, this geometry and scenario set up was used to simulate a fully-occupied WTC 1, which contained 16,000 occupants below floor 92 (19,800 occupants minus those trapped above floor 91). Of the remaining 10 percent who were trying to evacuate, however, some were located inside the towers at the very base of the building (which the model falls a bit short of predicting), and some were located in the Concourse area trying to evacuate the complex at this time. Further, this simulation did not account for those who waited until WTC 2 collapsed to initiate their evacuation, (e.g., occupants on floor 64, and some very high in the building trapped by significant floor damage).

D.4.6 WTC 1 Full-Capacity with Damage Simulation

When 16,000 occupants were simulated using the calibrated input assumptions, buildingEXODUS calculated that there were still 2,400 occupants left inside WTC 1 as the building began to collapse. There were larger queues simulated at the escalator in a full-capacity scenario when compared to the September 11, 2001, calibration simulation. It is understood that with a larger population, occupants would have encountered even more stoppages in the stairs than occupants did on September 11, 2001; however, this is not quantifiable and only the delay times and stoppages used in the calibration simulation were used in this scenario. Stoppage points in the full-capacity simulation continued until 10 minutes after the collapse of WTC 2.

D.4.7 WTC 2 Calibration Simulation

The inputs for the calibration simulation of WTC 2 were the following:

- 7,400 occupants distributed from floors 107-ground floor (after subtracting elevator users).
- "Stop and go doors" located inside the stairwells at floor 5 (late in the evacuation), and floor 15 and 48 during the evacuation, beginning after 20 minutes
- "Door" closed inside stairs at floor 78 after 16 minutes
- 2-17 minute delay uniformly distributed over population from floors 107-78; 6-30 minute delay uniformly distributed over the population from floors 77 - ground
- Distribution of gender and age used in Scenarios 2-4
- Stair packing and local potential

A total of 7,400 occupants (84 percent of 8,800) were specifically placed throughout each of the three building sections, depending upon the percentage of occupants reporting elevator usage within that section. Stoppage points were placed low in the building to simulate stopping for fire officials, superflow, helping behaviors, etc. on floors 15 and 48 (throughout the evacuation beginning at 20 minutes) and floor 5 (toward the end of the simulation). The reason that the stoppages began after 20 minutes is because the fire department and others did not respond to WTC 2 until the building was hit.

This simulation modeled evacuation from the entire building until WTC 2 was attacked. After 16 minutes, it was assumed that everyone above the impact floor, 78, would not be able to evacuate past the impact point, even though it is known that 18 occupants escaped from this area. The reason for assigning a difference in delay times to occupants above and below the impact zone was because the time delay was used to account for both pre-evacuation activities and activities performed during the evacuation, such as waiting on a floor. Since occupants above the impact zone were not able to complete their evacuation, a lower delay range was assigned to them.

The simulation was judged to be "successful" at predicting a September 11, 2001, scenario if the following criteria set for the WTC 2 calibration simulation were met:

- All occupants below the 78th floor evacuated before T2 collapses (72 min)
- A loss of approximately 600-700 occupants was predicted above 78 when WTC 2 collapsed
- Alleviated significant crowding at the entrance to the Mezzanine escalator

The WTC 2 calibration simulation predicted that all occupants evacuate from below floor 78 and that 645 occupants remained above floor 78 when WTC 2 collapsed. Also, there was no significant queuing predicted at the entrance to the Mezzanine escalator. These modeling assumptions were then used to simulate the full-capacity tower containing 17,260 occupants, which accounted for occupants who used elevators, as described below.

Elevators

For WTC 2, a fully occupied building on September 11, 2001 was assumed to contain 19,800 occupants. It was necessary to estimate the number of occupants who would have been able to use the elevators within the first 16 minutes on September 11, 2001, when WTC 2 was fully occupied. Calculations were performed using the ELVAC model (Klote 1993). From the estimations made by the face-to-face interview respondents using the shuttle elevators (NIST 2004), the peak speed of the shuttle elevators was approximately 4.8 m/s (close to 78 floors in 60 seconds). The ELVAC model was used to calculate how many occupants could have evacuated to the ground floor of WTC 2 in less than 16 minutes using 80 percent of the shuttle elevators available on floors 44 and 78. Only 80 percent of the elevators were modeled, under the assumption that some elevators would be out of service. Under the assumptions that the peak elevator speed was 4.8 m/s and had an acceleration of 1.5 m/s^2, 20 percent of the occupants (1,337) from the high section of the building (floors 78-110), 25 percent of the occupants (1,661) from the middle section of the building (floors 44-77), and 6 percent of the occupants (388) from the lower section of the building would have been able to evacuate via elevators before their tower was hit.

The maximum number of occupants who would have been able to use the shuttle elevators, which had a capacity of 50 occupants each, to evacuate the building in under 14 minutes was estimated to be 3,386 occupants. However, since it was discovered from face-to-face interviews (NIST 2004) that some elevators traveled to the ground floor without full capacity, it was assumed that only 75 percent of the maximum number of occupants who could use elevators (0.75 x 3,386 = 2,540) evacuated using the elevators. Therefore, approximately 17,260 occupants used the stairs in this simulation (19,800 – 2,540 = 17,260).

D.4.8 WTC 2 Full-Capacity with Damage Simulation

When 17,260 occupants were placed within the calibration simulation, buildingEXODUS predicted that there were still over 8,000 occupants left inside WTC 2 after 72 minutes. Occupants were distributed throughout the building, above and below the floors of impact, according to predicted elevator use, and assigned an appropriate response delay. As was found with the WTC 1 full-capacity simulation, a larger amount of queuing was predicted by the buildingEXODUS model, especially at the entrance to the Mezzanine escalator.

Table D–6 shows the results for the calibration and fully-occupied scenarios with building damage for both WTC 1 and WTC 2.

Table D–6. WTC 1 and WTC 2 full capacity evacuation simulation results.

Simulation Title	Geometry; Population	Simulation	# occupants evacuated before tower collapses
WTC 1 Calibration 9/11	Floors 90-ground; 7,200 occupants	Response time = 6-30 min, stoppage points throughout the stairs to simulate stopping of occupants for approx. 2 minute intervals	7,200 evacuate from below impact region within 71 minutes
WTC 1 fully-occupied building on 9/11	Floor 90-ground; 16,000 occupants	Response time = 6-30 min, stoppage points throughout the stairs to simulate stopping of occupants for approx. 2 minute intervals	13,600 occupants evacuated before WTC 1 collapsed; 85 % evacuated from below impact zone
WTC 2 Calibration 9/11	Floors 107-ground; 7,400 occupants when removing occupants using elevators	Response time 2-17 minutes above 78; 6-30 minutes all other places; stoppage points throughout the stairs that begin after 20 minutes, "door" closes inside stair at 78 after 16 minutes	6,755 occupants evacuated before WTC 2 collapsed; 645 remained above floor 78
WTC 2 fully-occupied building on 9/11	Floors 107-ground; 17,260 occupants when removing occupants using elevators	Response time = 6-30 min, stoppage points throughout the stairs to simulate stopping of occupants for approx. 2 minute intervals	8,883 occupants evacuate before WTC 2 collapsed; 3,900 remained above floor 78; 58 % evacuated the WTC 2

Differences were found between the results of the full-capacity with damage simulations for WTC 1 and WTC 2. The reasons for the differences in results are the following:

- In WTC 1, all "stop and go" points within each stairwell were ceased 10 minutes after the collapse of WTC 2. This allowed "free flow" from 82 minutes to 103 minutes in WTC 1. In WTC 2, the firefighters had no prior warning to stop counterflow measures and begin to evacuate. Therefore, the "stop and go" points continued until the collapse of WTC 2.

- Occupants in WTC 1 had a total of 103 minutes before their building collapsed, whereas occupants in WTC 2 had only 72 minutes.

- In WTC 2, with a much higher population, there were a greater number of congestion points throughout the building, in addition to the "stop and go" points added to the building. Additionally, some occupants higher in the building were given a longer evacuation time delay to account for activities performed during evacuation, causing them to take longer than the allotted 72 minutes to reach the ground floor. These congestion points were located at the transfer floors.

- Only 58 percent of the occupants in the fully-occupied building evacuated WTC 2, via the use of stairs or elevators. 2,540 were removed from the evacuation because they used elevators and 8,883 occupants evacuated via the stairs from WTC 2, for a total of 11,423 out of 19,800 occupants.

D.5 CONCLUSIONS AND FINDINGS

As shown in Table D–7, four different scenarios were run using three evacuation models, with and without a 0-10 minute delay time randomly distributed among the occupants. The first column of results shows the times for phased evacuation (with and without a delay time of 0-10 minutes) and the last three columns show full evacuations of occupants with different building populations. On average, the phased evacuation time (with initiation delays) for three floors to evacuate to three floors below the fire floor was 11 minutes. However, for a fully-occupied building (19,800 occupants), evacuation times were calculated as 8 to 10 times larger for a total evacuation when compared to phased evacuation for this building. These scenarios assume a 0 to 10 minute delay time and do not account for other types of behavior that may delay evacuation and increase total evacuation time.

Table D–7. Summary of egress simulation results.

Evacuation Model	Evacuation Initiation Delay Input	Phased Evacuation: 600 occupants	Evacuation Time (min): 8,800 occupants	Evacuation time (min): 19,800 occupants	Evacuation time (min): 25,500 occupants
EXODUS	0-10 Minute Delay	11	55	112	142
	No Delay	4	52	110	141
EXIT89	0-10 Minute Delay	11.5	71-74	92-113	119-139
	No Delay	3.5	58-78	97[70]-117	114-140
Simulex	0-10 Minute Delay	11.5			
	No Delay	4			

Some mid-rise buildings that plan for phased evacuation can completely evacuate their building, at full capacity, in less than 20 minutes. However, a building such as a World Trade Center tower produces full evacuation times of over 100 minutes, which is a large difference in comparison to the phased evacuation time of 11 minutes. With buildingEXODUS, adding a 0-10 minute delay did not significantly affect the evacuation times from the building, adding only two additional minutes. The movement inside and from the base of the stairwell was the limiting factor and controlled the evacuation time. When the starting population roughly doubled, the evacuation time roughly doubled. As this simulation did not account for behavioral aspects of the evacuation (such as leaving the stairs and resting), the full impact may be underestimated somewhat by these evacuation model simulations.

Scenarios 2 – 4 estimated the total evacuation time for a fully-occupied building on September 11, 2001. Figure D–4 shows that the evacuation with 25,585 occupants took approximately 2.5 times longer to evacuate than the 8,800 occupant population. Therefore, to estimate the total evacuation time from a fully-occupied building under the conditions observed on September 11, 2001, multiply by 2.5 the observed time required to evacuate WTC 1 on September 11 (approximately 100 minutes). This estimate is subject to the assumption that upon adding additional occupants, the emergency evacuation time scales

[70] The underlying theory for people movement in EXIT89 is based upon the work of Predtechenskii and Milinskii. They observed an inverse relationship between density and speed for three different types of movement: emergency, normal, and comfortable. The effect of crowding (density) on overall evacuation speed was greater when no delay time was assumed. A delay time when 19,800 occupants were present, according to EXIT89, spaces the occupants out and increases overall evacuation efficiency. This was not found to be the case for all occupant loads (25,500).

linearly, as was observed with the modeled evacuation time. A fully occupied building with visitors, but without elevator usage, would have required approximately four hours (2.5 x 100 minutes ≈ 4 hours) to evacuate the building. Using the same method, if WTC 1 was occupied with approximately 20,000 occupants (without visitors), the evacuation would have required roughly twice as long to evacuate than the 8,800 occupant simulation. Therefore, a fully occupied building without visitors and without the use of elevators would have required over three hours (2 x 100 minutes ≈ 3 hours) to evacuate the building. Note that in 2005, PANYNJ estimated that the maximum population of WTC 1 or WTC 2 would not likely have exceeded 20,000.[71]

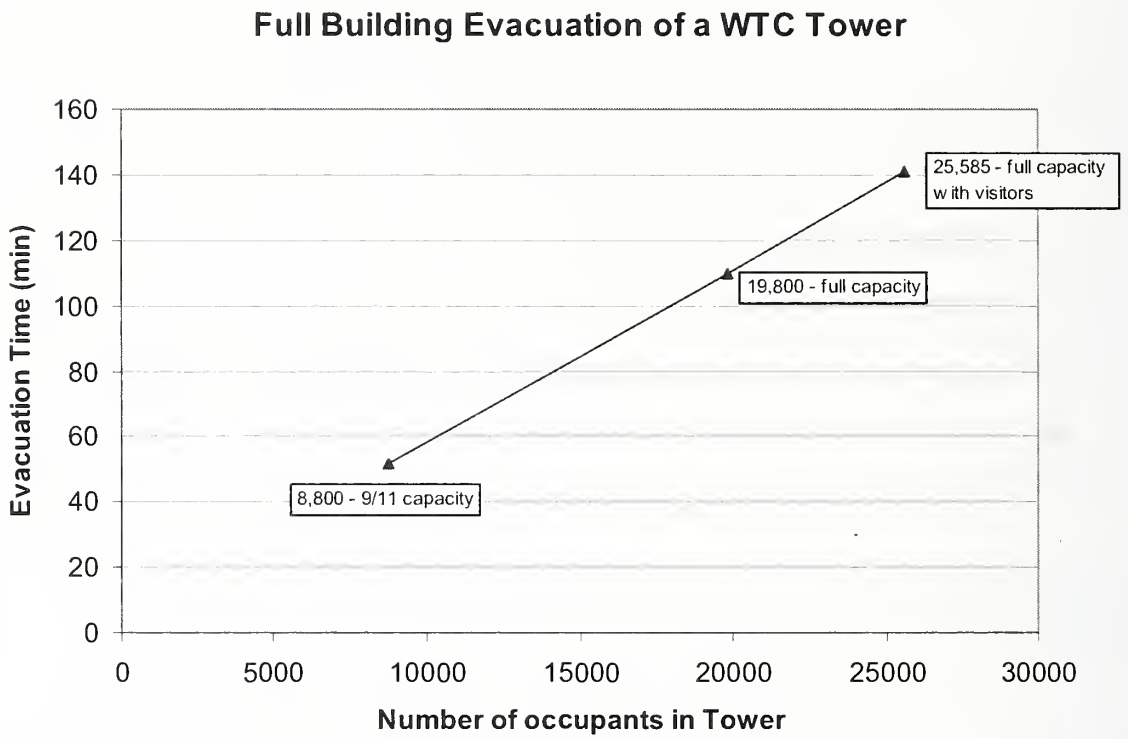


Figure D–4. Full building evacuation simulation results with differing building populations.

Scenarios 5-6 were modeled to estimate the consequences of a fully-occupied building on September 11, 2001 by estimating the number of lives lost at each building collapse. As the results show, more people would have lost their lives, particularly in WTC 2 due to its earlier collapse. Table D–8 shows the simulated number of occupants (by starting location) who successfully evacuated WTC 1 and WTC 2 for a fully-occupied building subject to the conditions observed on September 11, 2001. .

- WTC 1 – 69 percent of all occupants (13,600 occupants out of 19,800) would have successfully evacuated the Tower, which breaks down to 0 percent (0 out of 3,800) from above the impact zone and 85 percent (13,600 out of 16,000) from below the impact zone in 103 minutes.

[71] Bhol, Saroj. PANYNJ (September 21, 2005). Email from S. Bhol to S. Sunder in response to NIST question.

- WTC 2 – 58 percent of all occupants (8,883 by stairs and 2,540 by elevators) would have successfully evacuated the tower with the use of stairs and elevators in 72 minutes, which breaks down to 44 percent from above the impact zone and 75 percent from below the impact zone in 72 minutes.

Table D–8. Simulated evacuation results for fully-occupied WTC 1 and WTC 2 on September 11, 2001.

Building	Total Number of Occupants at t = 0.0	Potential Number of Evacuees	Occupants Remaining in Building at Collapse	Occupants Trapped Above Floors of Impact	Percentage of Occupants Who Successfully Evacuated Relative to Where They Started		
					Total	Below Impact	Above Impact
WTC 1	19,800	16,000	6,200	3,800	69 %	85 %	0 %
WTC 2	19,800	17,260	8,377	3,900	58 %	75 %	44 %
Total	39,600	33,260	14,577	7,700	63 %		

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