# Technical Conference on the Federal Building and Fire Safety Investigation of the World Trade Center (WTC) Disaster

**September 13 – 15, 2005** 

Occupant Behavior, Egress, and Emergency
Communications

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## **Purpose and Outcomes**

**Purpose:** To determine the behavior and fate of occupants and responders by collecting and analyzing information on:

- occupant behavior
- human factors
- egress
- emergency communications
- evacuation system

#### **Desired Outcomes**

- Enhanced evacuation systems
- Enhanced safety of occupants



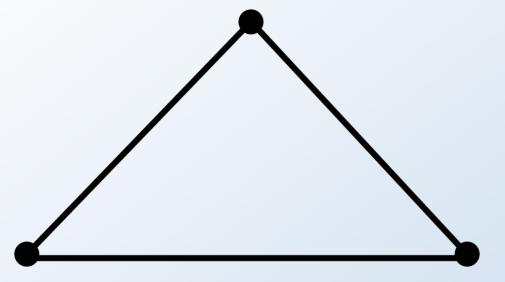
#### **Overview**

- Data Collection
- Egress System
- Chronology of Evacuation
- Causal Modeling
- Egress Modeling
- Principal Findings



#### **Collection of First Person Accounts**

225 Face-to-face Interviews



803 Telephone Interviews

6 Focus Group
Interviews



#### **Other Activities**

- Other Data Collection
  - 9-1-1 Records
  - Published Accounts
  - Written Communications, Protocols, and Procedures
  - Scientific Literature
- Causal Modeling
- Egress Modeling
- Observations Fire, Smoke, and Damage

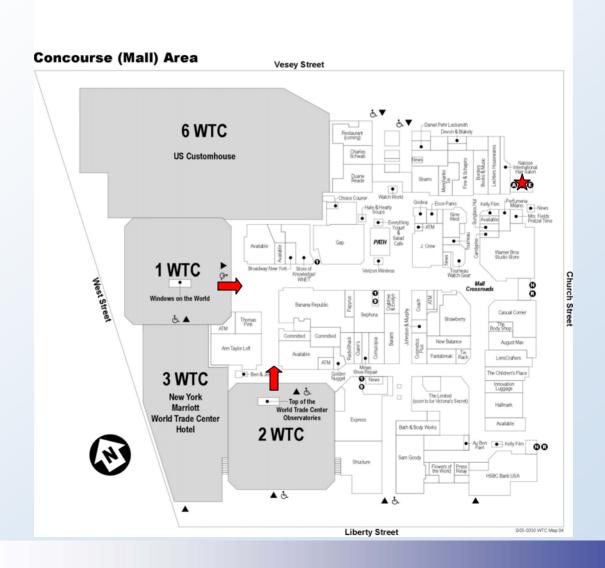


#### WTC Site Plan - Plaza Level



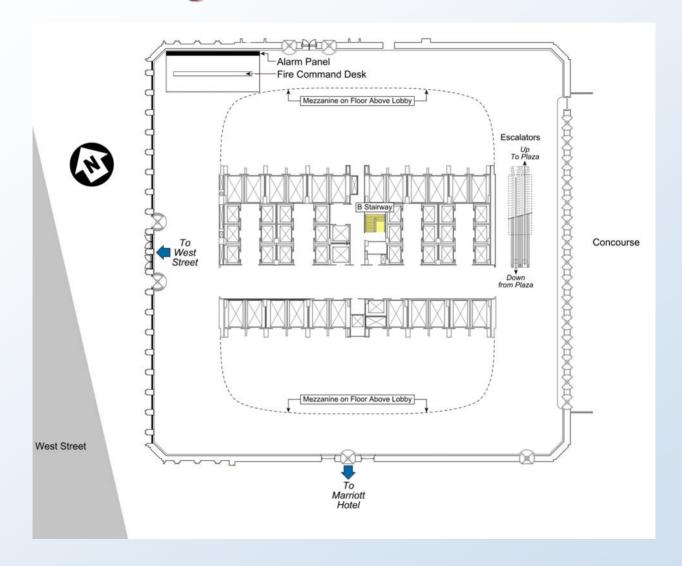


## **WTC Site Plane – Concourse Level**



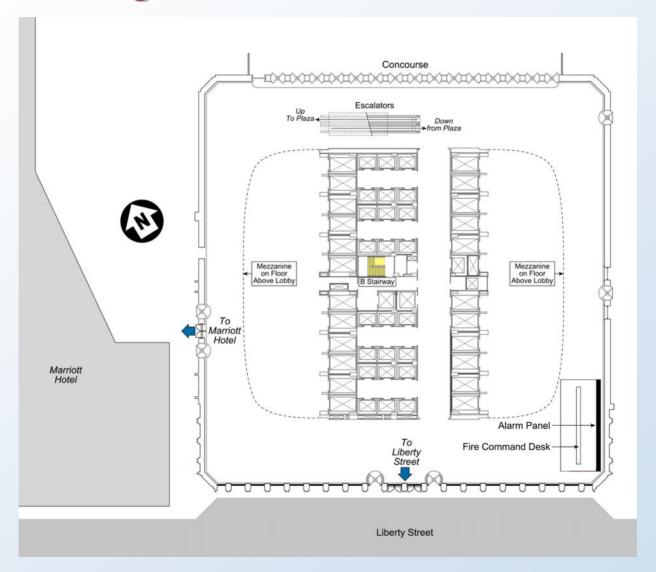


## WTC 1 Building Plan – Concourse Level





## WTC 2 Building Plan – Concourse Level

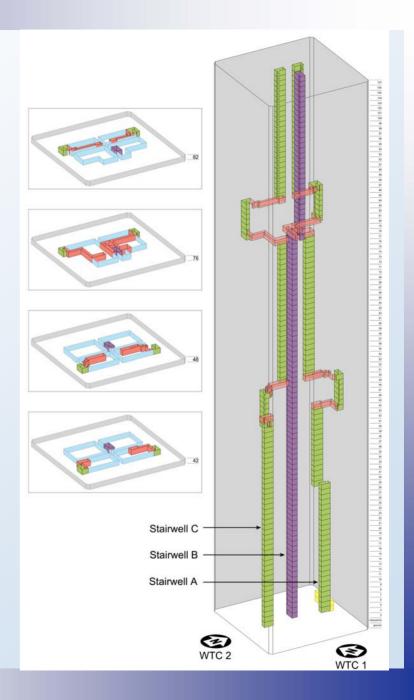




## **Stairwells**

- 3 Stairwells
  - (2) 44 in. Stairwells
  - (1) 56 in. Stairwell

**Transfer Hallways** 

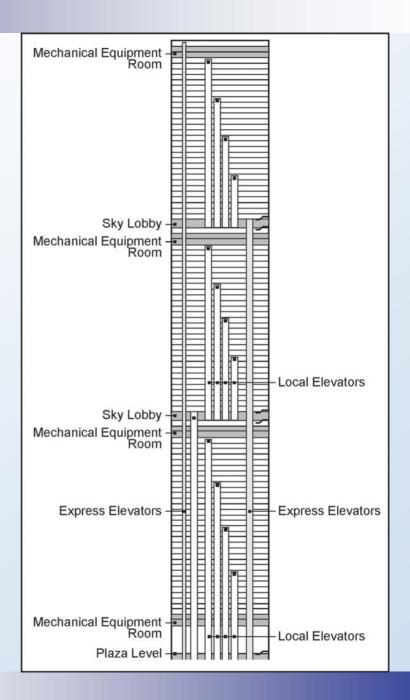




## **Elevators**

106 Elevators in Each Tower

Innovative Skylobby Configuration





# September 11, 2001 Moments Before 8:46 a.m.



## **Building Population**

	WTC1	WTC2	Total	
Estimated Total Population of Survivors*	7,500**	7,900	15,400	
Statistical Precision Calculations				
Sample n	427	376	803	
Standard Error (p)	1.90%	1.92%	1.36%	
Standard Error (Total)	750	900	1200	
Number of Decedents				
Decedents	1,434***	599***	2,033*** - 2,189****	
Total Building Population				
Total	8,900	8,500	17,400	

<sup>\*</sup> Includes only occupants with badges

<sup>\*\*\*\*</sup> Calculated as 2,749 – 403 first responders – 157 airplane passengers



<sup>\*\*</sup> includes only occupants below floor 92.

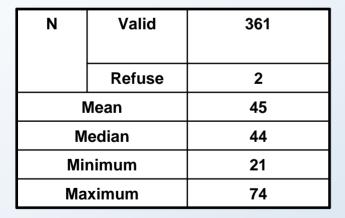
<sup>\*\*\*</sup> Calculated from Cauchon as 1,434 + 599

## Occupant Characteristics

## Age

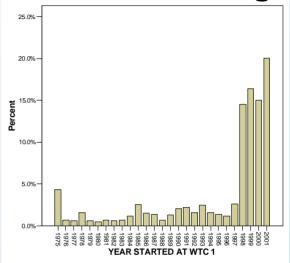
N	Valid	439
	Refuse	1
Mean		45
Median		46
Minimum		22
Maximum		73

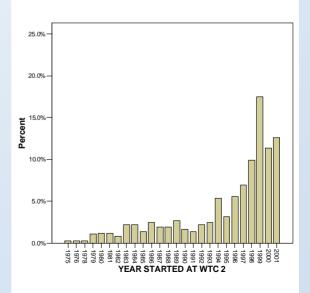
WTC 1



**WTC 2** 

## **Years in Building**







## **World Trade Center Occupant Preparedness**

 During the year from Sep. 11, 2000 to Sep. 11, 2001, how many fire drills did you take part in at the World Trade Center?

At least one: 66%

None: 17%;

Don't know: 17%

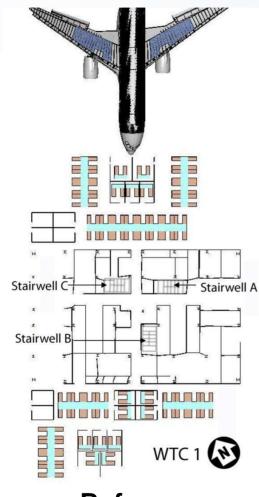
- 93% of fire drill participants were shown closest stairwell.
- Approximately half (51%) of WTC occupants had never used a stairwell at the World Trade Center prior to September 11<sup>th</sup>.



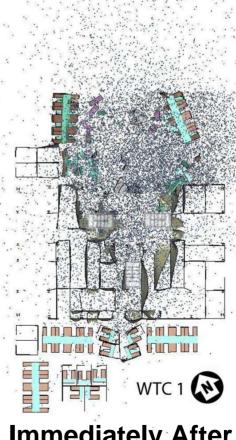
September 11, 2001 8:46 a.m.



## **WTC 1 Impact**



**Before** 



**Immediately After** 



"I saw the plane halfway in the building." (Floor in the 90's)

"The door blew open from the closet, causing my chair to hit the desk." (Floor in the 50's)

"We felt the entire building shake and saw some people who were sitting in chairs slide across the floor." (Floor 10's)

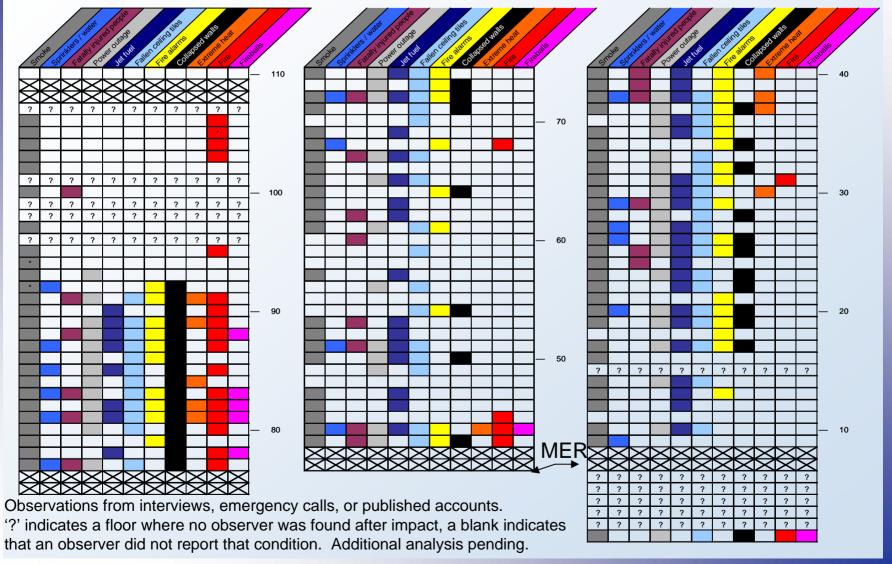
"I was walking through the mall towards tower one to get to the elevator. The lights flickered. I stopped in my tracks and looked around....At this point, the revolving doors exploded. They seemed to vaporize." (Concourse)

WTC 1 - First Awareness		
Felt something (building moving, impact, shaking, swaying)	63 %	
Heard something (boom, crash, explosion, rumbling)	30 %	
Saw airplane	2 %	
Other	5 %	

Only small number witnessed fire and smoke at first awareness



## **Observations of Building Damage, WTC 1**





WTC 2 – First Awareness		
Felt or heard a boom, explosion, or rumble*	61%	
Saw smoke, flames, airplane, or debris*	19%	
Warned by someone else	12%	
By phone, public address announcement, television or radio	2%	
Other means	6%	

\*Primarily from Tower 1

Observations vary by floor (height).

Many observations of fire(ball),
debris

"I saw the plane crash into [WTC 1]" (Floor in the 100's)

"I noticed it was getting dark and I saw massive bright orange flames wrapping themselves around the building." (Floor in the 90's)

"My boss came in and told us to evacuate." (Floor in the 30's)

"I heard a loud roaring sound." (Floor in the 10's)



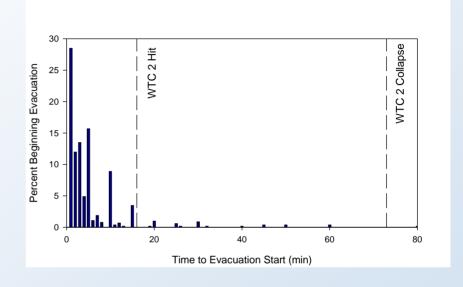
September 11, 2001 8:47 a.m. – 9:02 a.m.



"In the hallway...there were no walls left...and the bathroom seemed to be missing. There was a hole in the wall near the elevator (in the hall) and fire was coming up onto our floor through that hole. (Floor in the 90's)

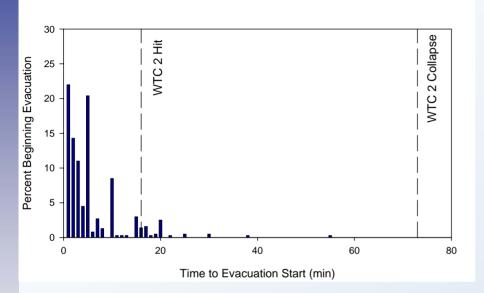
"To me everything seemed normal, all the ceilings were fine, the electricity was fine..." (Floor in the 70's)

"I was close to the windows. The windows were broken and I saw things from the office were going out the window." (Floor in the 20's)



- 92% of survivors began evacuation before WTC 2 was hit; 29% within 1 minute.
- 21% exited WTC 1 before WTC 2 was hit.





- 91% began evacuating before Tower 2 was hit; 22% within one minute.
- 41% of the survivors exited the building before WTC 2 was hit.

"We were instructed to go back to our offices and that the building was secure. So, I started back to my office. As I exited the fire escape and met my supervisor, I was told that he wanted me to leave the building and not follow the instruction to stay." (Floor in the 90's)

"Heard the building was secure by announcement...Kept moving down the stairs to exit the building. Came to a uniformed person holding the door open in the 44th floor sky lobby. We were asked to exit the stairwell area and to use the elevators to go back up, [but we] kept on going to exit the building." (Floor in the 80's)



Life in Danger?	Others	Self
Initial Awareness	48%	41%
Interim Period	63%	52%

- "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." (Floor in the 70's)
- "I felt that my life was threatened. I also thought of 1993 bombing and I know what some of my friends went through." (Floor in the 70's)
- "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." (Floor in the 60's)

Activities Before Evacuation			
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 %		



#### Used elevator for entire evacuation

 "The decision to use the elevators was based on the fact that there was no fire in our building." (Floor in the 100's)

#### Used stairs and elevators

"I was raised in Los Angeles; I was taught that in case of emergency situations and disasters to avoid elevators" (Floor in the 100's) – Decision was made to use stairs until the PA announcement, when respondent used an elevator to evacuate.

Initial Evacuation Mode		
Stairwell A	18%	
Stairwell B	18%	
Stairwell C	14%	
Stairwell A or C	10%	
Used elevator	18%	
Don't Know [Stair]	23%	

Did not consider elevator use

•"I knew one shouldn't take an elevator in an emergency situation" (Floor in the 30's)

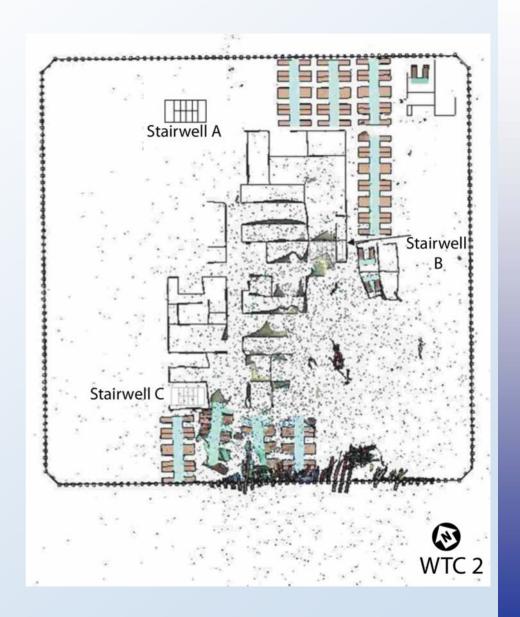


September 11, 2001 9:03 a.m.



## **WTC 2 Impact**

Stairwell A was passable for a period of time after WTC 2 was attacked. NIST identified 18 individuals who used this path, although one died from 9/11 related injuries. At least two people from below the impact region went up to help and did not successfully evacuate.





- •"It was clear that something hit the building...the stairwell swayed and it was as if the building was doing the 'twist'." (Floor in the 90's)
- •"I felt an explosion and saw fire and smoke coming from the corridor. The whole building was shaking and breaking glass was cascading down the building. The smoke was a light grayish and the flames leapt out of the corridor from the pressure."

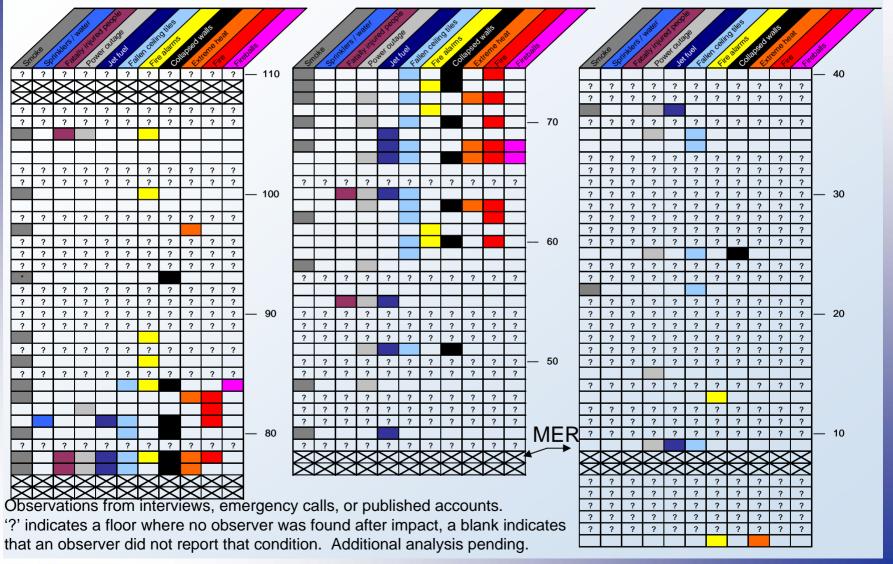
  (Floor in the 70's)
- •"I heard a loud noise, felt the building shake, and the temperature in the air went up." (Floor in the 60's)

## Observations of Survivors Still on Floor at 9:03

Power outage/flick	37%
Fallen Ceiling tiles	29%
Jet Fuel	20%
Smoke	18%
Collapsed walls	18%
Fire or flames	12%
Fire alarm sounding	12%
Fatally injured	
people	10%
Extreme heat	10%
Sprinklers	2%



## **Observations of Building Damage, WTC 2**





Some noticed minor disturbances when WTC 2 was hit; many never mentioned anything related to Tower 2 being hit.

"I answered the [cellular] phone and my wife was telling me that another plane had struck Tower 2 and she said, 'Get out of the building as fast as you can; it is a terrorist attack." (Floor in the 40's) "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)." (Floor in the 60's)

"The building shook. Not anything like the first time [but] it rocked. We stopped briefly on the 31st floor." (Floor in the 60's)

"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. Later [there was] a report of the second plane hitting." (Floor in the 50's)



September 11, 2001 After 9:03 a.m.

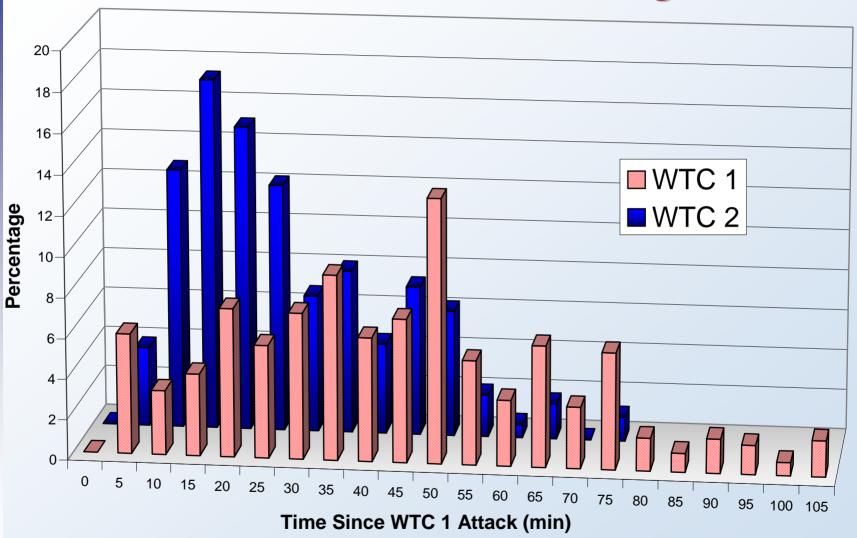


## Reported Aids & Constraints to Evacuation

WTC 1	Evacuation Aids	WTC 2	WTC 1	Evacuation Constraints	WTC 2
66%	Support from others	60%	73%	Crowded stairwells	69%
44%	Firefighters/Police	30%	51%	Firefighters/Police	27%
32%	Exit signs	35%	24%	Lack of clear instructions	29%
18%	Photoluminescent paint	11%	16%	Locked doors	7%
10%	Floor Warden	13%	11%	Poor lighting	4%
			5%	Bad/missing signage	5%

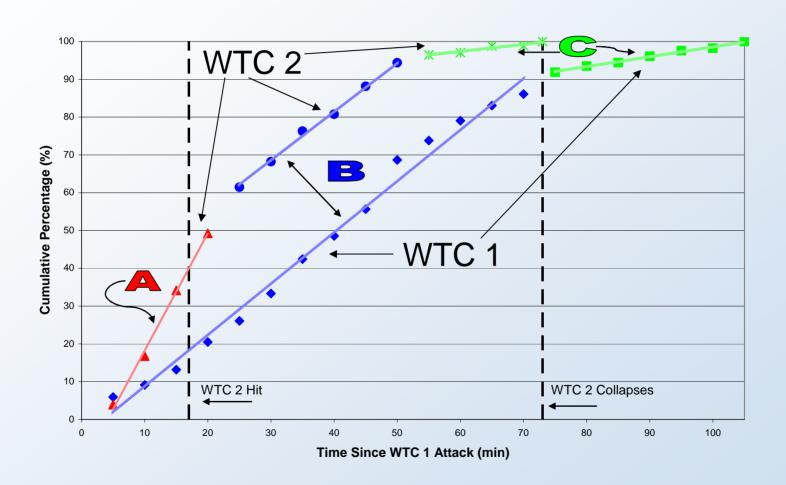


## **Time Until Out of Building**





## September 11, 2001 WTC Evacuation Rate





## **Decedent Analysis**

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.

NIST Interviews with occupants and family members

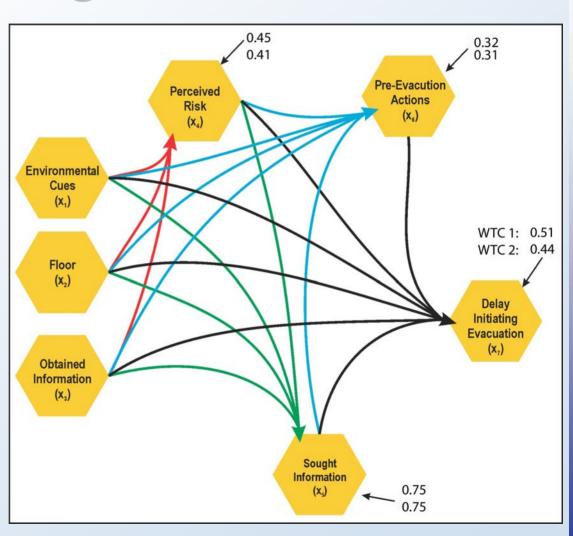
\* Where possible, eyewitness accounts were used to place individuals. Where no specific accounts existed, employer and floor information was used to place individuals.

Likely Location at Time of Impact*	Modified April 5, 2005
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
First 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



## Causal Modeling: WTC 1

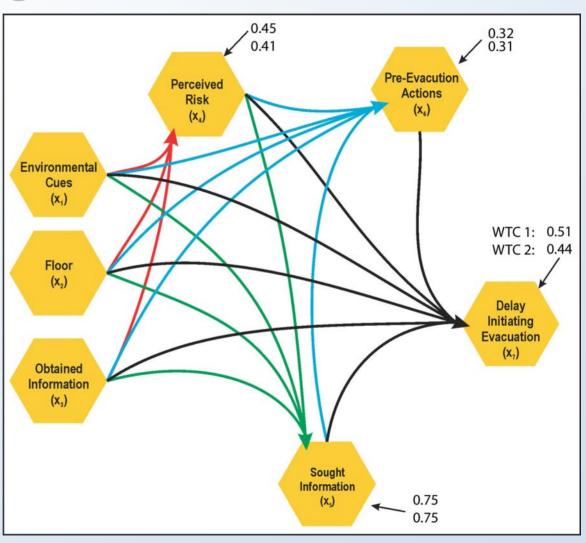
The main process that led to evacuation delay: **Environmental** cues and initial floor led people to seek additional information and take actions which delayed the start of evacuation.





## Causal Modeling: WTC 2

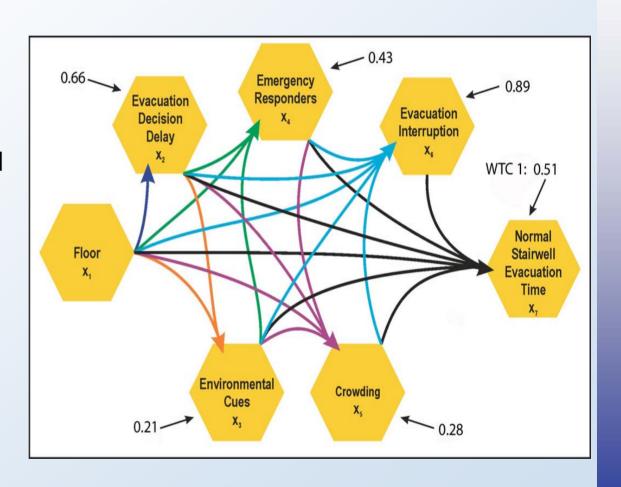
The main process that led to evacuation delay: **Environmental cues** and initial floor led people to perceive risk and these three factors led people to seek additional information and take actions which delayed the start of evacuation.





## Causal Modeling: Normalized Stairwell Evacuation Time (WTC 1)

Floor increased the odds of encountering environmental cues, which had a large and direct effect upon increasing the time people spent in the stairs. Additionally, interrupting evacuation increased stairwell residence time.



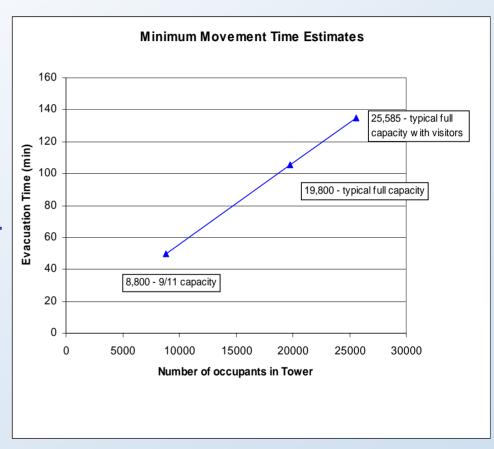


## **Egress Modeling: Minimum Time**

Preliminary results from buildingEXODUS

Full Tower evacuation with the following assumptions:

- All able-bodied occupants
- Response delay = 0 sec.
- No damage simulated
- No elevator use
- Continual stair movement (no resting in stairway)





## **Egress Modeling: Calibrated Model**

## 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 %		



## **Occupant Preparedness**

 Occupants were often unprepared for the physical challenge of full building evacuation. Numerous occupants required one or more periods of rest during stairwell descent or turned to elevators after finding the stairwells strenuous.

 Occupants were often unprepared to encounter transfer hallways during the stairwell descent. Groups of evacuees occasionally hesitated or debated a course of action upon encountering a transfer hallway.



## **Mobility Impaired Occupants**

- 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.
- Mobility Impaired occupants were not universally accounted for.
- As the emergency responders started evacuating WTC 1 after the collapse of WTC 2, they found mobility impaired occupants still in the staircases going down.



## **Mobility Impaired Occupants, cont'd**

- FDNY and PAPD personnel found 40 to 60 mobility impaired occupants on the 12<sup>th</sup> floor of WTC 1 as they went down and attempted to clear each floor on their way out. These impaired individuals had been placed on a floor somewhere between 12 and 20 in WTC 1 in an attempt to clear the stairways.
- Emergency responders were assisting approximately 20 of these mobility impaired people down the staircase just prior to the collapse of WTC 1. It is unknown how many fatalities occurred with this group.
- No mobility impaired rest station was reported in WTC 2



## **Emergency Communications**

- Occupants called 9-1-1 and Port Authority seeking assistance and advice.
  - Opportunities to improve occupants situational awareness were often lost. Specific knowledge about location of fires and impact damage was only occasionally communicated to occupants who requested the information and was without apparent coordination.
  - Some operators advised sheltering (e.g., many at 9-1-1), while others advised evacuation (e.g., many at PA Police Desk); some permitted window breaking while others instructed occupants not to break windows.
    - The "right" advice with respect to a particular action, however, is highly sensitive to the caller's particular situation and may be clear only in hindsight.



#### WTC 1

Many announcement attempts were made from the Fire Command Station in the lobby, initially to selected floors and then, within approximately ten minutes, to the entire building. However, only two face-to-face interviewees in WTC 1 reported hearing any announcements, and the source is unclear.

#### **Conclusion:**

Damage to the 22<sup>nd</sup> floor communication closet likely disabled building-wide announcement capability.



WTC 2, Prior to 9:03 a.m.

~ 9:00 a.m. - There is a fire condition in WTC 1. WTC 2 is secure. Please return to your offices.

9:02 a.m. – "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."



WTC 2, After 9:03 a.m.

9:12 a.m. – (Fire Command Station in WTC 2 over Radio Channel 22) "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 2003)



#### WTC 2, After 9:03 a.m., cont'd

~9:20 a.m. – Announcement made updating occupants on the condition of the building and progress of the evacuation.

Prior to approximately 9:40 a.m. – Building-wide announcement instructing occupants to go down the stairs.

#### **Conclusion:**

Announcements in WTC 2 were heard by occupants building-wide before 9:03 a.m. and were heard in at least the upper regions (including above the impact area) of WTC 2 after 9:03 a.m.



## **Evacuation (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.
- 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.



## **Evacuation (WTC 2)**

- 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.
- Self-evacuation and use of elevators for 16 minutes in WTC 2 saved roughly 3,000 lives.
- 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.



# Recommendations, Group 5: Improved Building Evacuation

Building evacuation systems should be improved to include:

- system designs that facilitate safe and rapid egress,
- methods for ensuring clear and timely emergency communications to occupants,
- better occupant preparedness for evacuation during emergencies, and
- incorporation of appropriate egress technology.

