RSET

- Calculate the required safe egress time

Historic Fire

- Shanghai Apartment

Time

- Detection and notification
- Reaction
- Pre-evacuation
- Travel time

Effective Width

- Boundary layer

Movement Times

- SFPE equation
  - Pauls, Fruin, Predtechenskii and Milinskii
  - Beyond data collected
  - Not internally consistent
  - Age of data
  - Diversity of population
  - Distribution
  - No data to support k

Observed Flows

Movement Times

$$S = k - a \cdot k \cdot D$$

Where:

- S=speed (ft/min or m/s)
- k=constant (Table 4.2.5)
- a=constant (2.86 when using ft, 0.266 when using m)
- D=density (persons/ft^2 or persons/m^2)

Justification of k-Factors

Element	k (U.S. units)	k (metric)
Corridor, door, ramp	275	1.40
Stairs		
Riser, Tread (in)		
7.5, 10	196	1.00
7.0, 11	212	1.08
6.5, 12	229	1.16
6.5, 13	242	1.23

Movement Times

$$\left(F_{s(in,1)} \cdot W_{e(in,1)}\right) + \cdots + \left(F_{s(in,n)} \cdot W_{e(in,n)}\right) = \left(F_{s(out,1)} \cdot W_{e(out,1)}\right) + \cdots + \left(F_{s(out,1)} \cdot W_{e(out,1)}\right)$$

Where:

F_s= Specific flow (persons/ft-min or persons/m-s)

W_e=Effective width (ft or m)

$_{in,out}$= arriving at, after

Element	Boundary Layer (in)
Stairways	6
Railing, handrails	3.5
Theater chairs	0
Corridor, ramp	8
Obstacles	4
Wide concourses	< 18
Door	6

Movement Times

- Calculations build
  - See example problem on 4-62 to 4-64 in NFPA Handbook
- Consider limiting component

Movement Times

- Speed in reduced visibility

$$W = -0.1364 \cdot \ln \alpha_K + 0.643$$

Where:

Speed can change the visibility

W= movement speed (m/s)

α_K= Extinction coefficient (m^{-1})

You should check your result with S = k- a×k× D,
Because W only give you a lower speed

If W<S, we can use W

Flow

- Specific Flow: $F_s = \left(\frac{\text{Persons}}{\text{min} \cdot \text{ft}}\right)$

→ How to get F_s ?

$\text{Density} = \frac{\text{Person}}{\text{ft}^2}$, $\text{speed} = \frac{\text{ft}}{\text{min}}$

- So $\boxed{F_s = \text{Density} \times \text{speed}}$

→ $\text{speed} = K - aKD$

$F_s = (\underbrace{K - aKD}_{\text{speed}}) \times \underbrace{D}_{\text{Density}}$

↑ We can find maximum F_s because 二次方程

- If give you F_s, let you calculate D, $\boxed{\text{choose the smaller D}}$

二次方程，两个解选最小的那一个

- Calculated Flow

Calculated Flow:Fc=Fs*We

Population Variability

- Age
- Fitness
- Gender
- Fatigue

Accessibility

- Identify the vulnerable populations to consider
- Discuss requirements for accessibility and other special needs

识别弱势群体考虑
讨论无障碍要求和其他特殊需求

Historic Fire

- L’Isle Verte

Mobility Impairments

- Must accommodate everyone
- All occupants not intimate with fire shall be kept safe

IBC Chapter 10

- Four or more floors
  - Elevator
- No exit access stairs
- Stairs 48” between handrails
  - Normal with sprinklers
- Area of refuge

IBC Chapter 11

- Not all areas
  - Work areas where change in elevation is essential
  - No elevators
- Not all routes
  - One
  - Site plan
  - 60 % of entrances
- General circulation

IBC Chapter 11

- Parking spaces
- Hospital sleeping rooms
- Hotel rooms
- Apartments
- Assembly seating areas
- Self-service storage
- Bathrooms
- Check-out aisles
- Recreation facilities

International Codes

- https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/441786/BR_PDF_AD_M2_2015.pdf

Vulnerable Populations 弱势群体

- Movement impaired
- Visually impaired
- Hearing impaired
- Cognitive disability
- Elderly
- Children
- Large groups
- Isolation
- Unfamiliar
- Asleep
- Intoxicated
- Non-Native speakers
- Committed to task
- Situationally disabled
- Compounded effects

Code Requirements

- Combination horn/strobe
- 520 Hz smoke alarms
- Voice alarms?
- Area of refuge
- Occupant evacuation elevators
- Assistive listening systems
- Stair markings?
- Signage

Future

- Increased occupant evacuation elevators
- Stairway descent devices
- Multi sensorial wayfinding
- Personalized emergency messaging
- ?

Human Behavior

- Explain how people actually respond compared to the myths of human response
- Describe the decision making process
- Explain what pre-evacuation time is and why it is important

Historic Fire

- Hamlet Chicken Processing Plant

Myths 神话

- Panic
- Disaster shock
- Immediate
- To exits
- Flocking
- Fluid
- Ignore own senses
  - Will travel through smoke

Awareness

- Environment
  - Fire cues
  - People
- Systems
  - T-3
  - Flashing lights
  - Voice alarm
  - Other
- Latane and Darley

Notification

- Not all people receive message
  - Background noise/images
  - Hard of hearing
  - Limited vision
  - Dedicated to task
- Not all people comprehend message
  - Recognition of alarm
  - Do not speak/read language

Non-Adaptive Behaviors and Interactions 非适应性行为与互动

- Non-Adaptive Behaviors
  - Notification
  - Re-entry
  - Firefighting
  - Crowd crush
- Interactions
  - Milling
  - Convergence clusters
  - Platoons
  - Groups

碾磨
聚合簇
排
组

Decision Making Process

Response

- Actions
  - Waking up
  - Gathering more information
  - Dedicated to task
  - Notifying others
  - Preparing
  - Fighting fire

Pre-Evacuation Time 撤离前时间

- Amount of time can be great
- Introduces uncertainty
  - Densities
  - Exposures
- Messaging is critical
  - Attention
  - Source
  - Event
  - Location
  - Action
  - Time

Expected Times 预期时间

So how much evacuation time should you account for ?

- There is no single number 没有单一的数字
- There are no general engineering guidelines
  - No rules of thumb
  - No table values
- Need to use engineering judgment
  - Informed

Pathfinder

- Select an egress model to meet the needs of the project
- Use Pathfinder to predict egress times

Historic Fire

- Brown’s Ferry

Pathfinder

- http://www.thunderheadeng.com/pathfinder/download/
- 60F5 8ED5 5895 7390 6048 94
- Read: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=906951

Pathfinder

- Draw Room

Pathfinder

- Add new floors

Pathfinder

- 3 m between floors

Pathfinder

- Copy room to other floors

Pathfinder

- Four new rooms needed

Pathfinder

- Rotate view to see all floors

Pathfinder

- Add room for stairs

Pathfinder

- Copy and move to other levels

Pathfinder

- Add stairs

Pathfinder

- Stairs connecting all floors

Pathfinder

- Add exit door

Pathfinder

- Stair doors on other floors

Pathfinder

- Add exterior door

Pathfinder

- Add occupants

Pathfinder

- Business

Pathfinder

- Put occupants on all floors

Pathfinder

- Run simulation

Pathfinder

- After following prompts, simulation runs and movie pops up
- Can rotate view

Pathfinder

- Can manipulate image

Pathfinder

- Can manipulate image

Pathfinder

- View Summary file

Pathfinder

- Summary File

Pathfinder

- Create hole by adding new room inside old room
- Copy to floor above
- Delete new rooms

Pathfinder

- Add stair

Pathfinder

- Create triangular room
    - 5 m base and height

Pathfinder

- Add in three occupants
- Make one slow moving
- Apply to selected occupants on each floor

Pathfinder

- Modifying occupants
  - Double click on profiles
- Individual occupants
  - Select one occupant
- Exit choice and pre-evacuation time
  - Double click on behaviors

Population Characteristics

- Identify factors that can influence a person's ability to evacuate
- Explain the impact of different population characteristics

Historic Fire

- Arundel Park

Occupant Characteristics

- Not all people are the same
  - Designs based off of “expected” population
  - Homogeneous?
  - Not always obvious which occupants are most at risk
- Number of people
  - Occupant load factors?
  - Crowded conditions more problematic
- Locations of people

基于“预期”人口的设计

Factors

- Alertness
  - Sleep
  - Drugs/alcohol/medication
- Physical and cognitive ability
  - Poor understanding
  - Temporary condition
  - Permanent condition
  - Different impact of effluent
  - Notification
  - Movement

Factors

- Social affiliation
  - Seek out others
  - Move at speed of slowest member
  - Impact flow
- Role and responsibility
  - Staff
  - Activities other than evacuation
- Previous experience

Factors

- Commitment
  - Inattentional blindness/deafness
  - Refusal to leave task
- Focal point
  - Inattentional blindness/deafness
  - Beneficial use

Factors

- Gender
  - Actions
  - Movement speeds
- Culture
  - Societal
  - Individual
- Age
  - Movement speeds
  - Sensory skills
  - Decision making
  - Impact of effluent

Factors

- Familiarity
- External
  - Weather
  - Egress systems
  - Light
  - Noise

Personal Characteristics

- Age
- Gender
- Pre-evacuation
- Body size
- Perception
- Knowledge
- Experience
- Notification

Mobility 流动性

- Disabilities
- Encumbrances
- Clothing
- Fatigue
- Groups

Position Factors

- Density
- Exit lanes

Interactions

- Merging
- Passing
- Counterflow
- Congestion

合并
经过
逆流
拥塞

Cultural Significance

- Explain how building design should change based on the expected occupants
- Identify code requirements that are culturally dependent

Historic Fire

- Notre Dame

Underlying Assumptions

- Data primarily from relatively few locations
- Significant variation

Underlying Assumptions

- Density drives flow
- At lowest levels people free to choose own speed
- Spacing is culturally dependent

Building Codes

- Use factors
  - Determined based on observations of actual buildings
  - Change with time
- Spiral stairs
  - NFPA 5000: Spiral stairs shall turn such that descending users have the outer handrail on their right side

Societal Norms

- Gender
  - Some studies found differences in movement speeds, others have not
    - Potential correlation to clothing
  - Interpersonal spacing
- Passing and merging
  - Deference behavior
- Exit choice

Fire Experience

- Project BeSeCu
  - Library evacuations from multiple European countries
  - Statistically different results

Fire Experience

- Differences in fire safety training in schools- sometimes within country
- Differences in pre-evacuation time
- Differences in actions taken
- Difference in perceived severity

Impact

- Building design
  - Refuge floors
  - Vestibules
  - Numbers in codes
- Speeds
  - Clothing
  - Density
  - Fitness
- Interactions
  - Merging
  - Deference
- Response
  - Pre-evacuation
  - Training
  - Behavioral norms
- Exit choice
  - Exits designated for others
  - Familiarity

Culturally Significant Buildings

- Concerns beyond life safety
- Building more than just a building
- May not be obvious what the significance is to outsiders

Methodologies

- Explain how means of egress rules have been developed
- Identify other methods of determining people movement
- Explain the limitations of existing methodologies

Historic Fire

- Daegu Subway

Origins of Egress Requirements

- Stair width
  - First building code (1905): 20 in
  - NFPA committee (1913): 44 in, handrails protrude 3.5 in
    - Based on people standing in stair (28 per floor)
    - 22 in per person on every other tread (from soldiers standing in line)
    - “Sufficient” to prevent three people from forming arch and blocking traffic
  - Why stairs are based on single floor at a time

Flow Method

- Based on number of people per minute per exit lane
  - Level 60 persons/min
  - Stairs 45 persons/min
  - Stairs later found to be closer to 27 persons/min
- Still used in NFPA 130
- Time based
  - 4 min for platform
  - 6 min to point of safety
- Level
  - 2.08 persons/in-min
  - 124 ft/min
- Stairs
  - 1.41 persons/in-min
  - 48 ft/min (vertical)

Level of Service

- Concept from transportation
  - Pathfinder allows you to view
- Ability of people to freely choose their own speed
  - A: Free to choose own speed and pass
  - B: Free to choose own speed and pass, minor conflicts
  - C: Speed and passing restricted, major conflicts
  - D: Cannot pass
  - E: Intermittent stoppages
  - F: Movement to shuffle, not suited for design

Level of Service

Behavior

Behavior

Behavior

- Stairs
  - Preference

Model Selection

- Determine the appropriate type of model to use for a given project
- Explain validation and verification of a model
- Identify appropriate information to include in the documentation of the results of a model

Historic Fire

- General Slocum

Model Selection

- Essential to choose a model that meets the needs of the project
- Models are approximations
  - Each best suited for different applications
- Multiple considerations
  - Skill/knowledge of user
  - Cost
  - Time
  - Desired output

Algebraic Equations vs. Simulation Models

Algebraic Equations

- Simplistic (component) analysis
- Single actions
- Homogeneous population
- Limited knowledge of building
- Less time and funding
- Simplistic output

Simulation Models

- Complicated (system) analysis
- Multiple actions
- Variations within population
- Detailed knowledge of building
- More time and funding
- More advanced output

Level of Service

- Concept from transportation
  - Pathfinder allows you to view
- Ability of people to freely choose their own speed
  - A: Free to choose own speed and pass
  - B: Free to choose own speed and pass, minor conflicts
  - C: Speed and passing restricted, major conflicts
  - D: Cannot pass
  - E: Intermittent stoppages
  - F: Movement to shuffle, not suited for design

Level of Service

Types of Models

- Movement
- Partial Behavioral
- Behavioral

- Special applications
  - Vessels
  - Low-rise buildings
  - Stadiums
  - Transportation stations
- Special Features
  - Fire effects
  - Elevator use

Verification and Validation

- Verification
- Validation

both a way to see it's a model working correctly

Default Values

- Immediate use
- Underlying assumptions

Output

- Text files
- 2-D graphs
- 3-D animations

文本文件
二维图形
三维动画

- Individual level
- Aggregate level
- Scenario level

个人层面
聚合层面
场景层面

Documentation

- Explain why model was selected
  - Capabilities of model
  - Validity
- Explain selected scenarios
  - Sensitivity
  - Bounding
  - Values used
- Explain results
  - Verification
  - Meaning
  - Values

Emerging Issues

- Identify areas where more information is needed

Historic Fire

- Oakland Hills Fire

Human Behavior (Details)

Data	Technology	Design Tools	Risk/Probabilistic Approaches

• **Demographics**
  ○ **Vulnerable populations**
  ○ **Anthropometry**
  ○ **Cultural differences**
• Basis for numbers in codes
• Response to notification
	• **Smart egress systems**
	  ○ **Cameras**
	  ○ **Cell phones**
	  ○ **Exit usage**
	  ○ **Other**
	• LED strobes
	• Occupant evacuation elevators
		• **Design egress scenarios**
		• Behavior based models
		  ○ Cultural
		  ○ Pre-evacuation time
		  ○ Actions other than evacuating
		• Combined fire and evacuation models
			• **Residential buildings**
			• Large populations
			• Community level
			• High challenge environments
			• Quantify level of “life safety” in a building
			• Effects of fire
			  ○ Visibility
			  ○ Gases
			• Impact of public education on fire risk