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An Introduction to human behaviour in fire and evacuation

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Outline

- The evacuating crowd
- PBD and evacuation models
- Basic concepts of HBIF
- Predicting behaviour with evacuation models
- Examples of pedestrian evacuation movement models
- Evacuation model results

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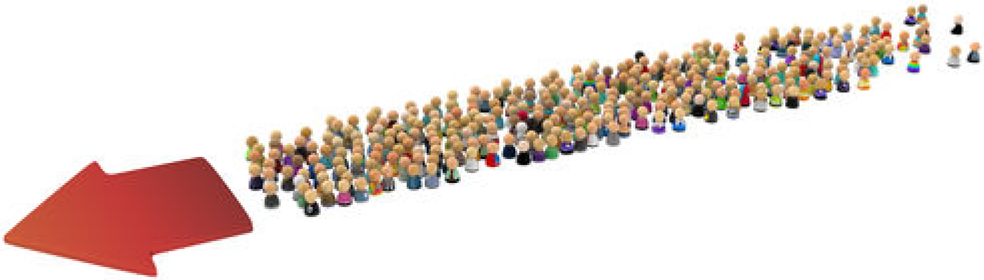
The evacuating crowd

What is a Crowd?



A multitude of individuals walking through the same space at a certain moment in time

The evacuating crowd

- Engineers deal with increasingly large, challenging and complex buildings while trying to minimise costs.

- Larger buildings are associated with potential larger incidents

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The evacuating crowd

QUESTION TIME!

What is the only stadium in the world able to host 70,000+ people that can be evacuated in 5 minutes?

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The evacuating crowd

Calamitas et securitas

- Crowd evacuation disasters known since the Roman Empire
- Colosseum could take up to 73,000 people
- 60 entrances
- It could be evacuated in 5 min

Crowd evacuation disasters still occur!

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PBD and evacuation models

Requirement according to PBD legislations…

Buildings shall be designed so that *satisfactory escape* can take place in the event of fire

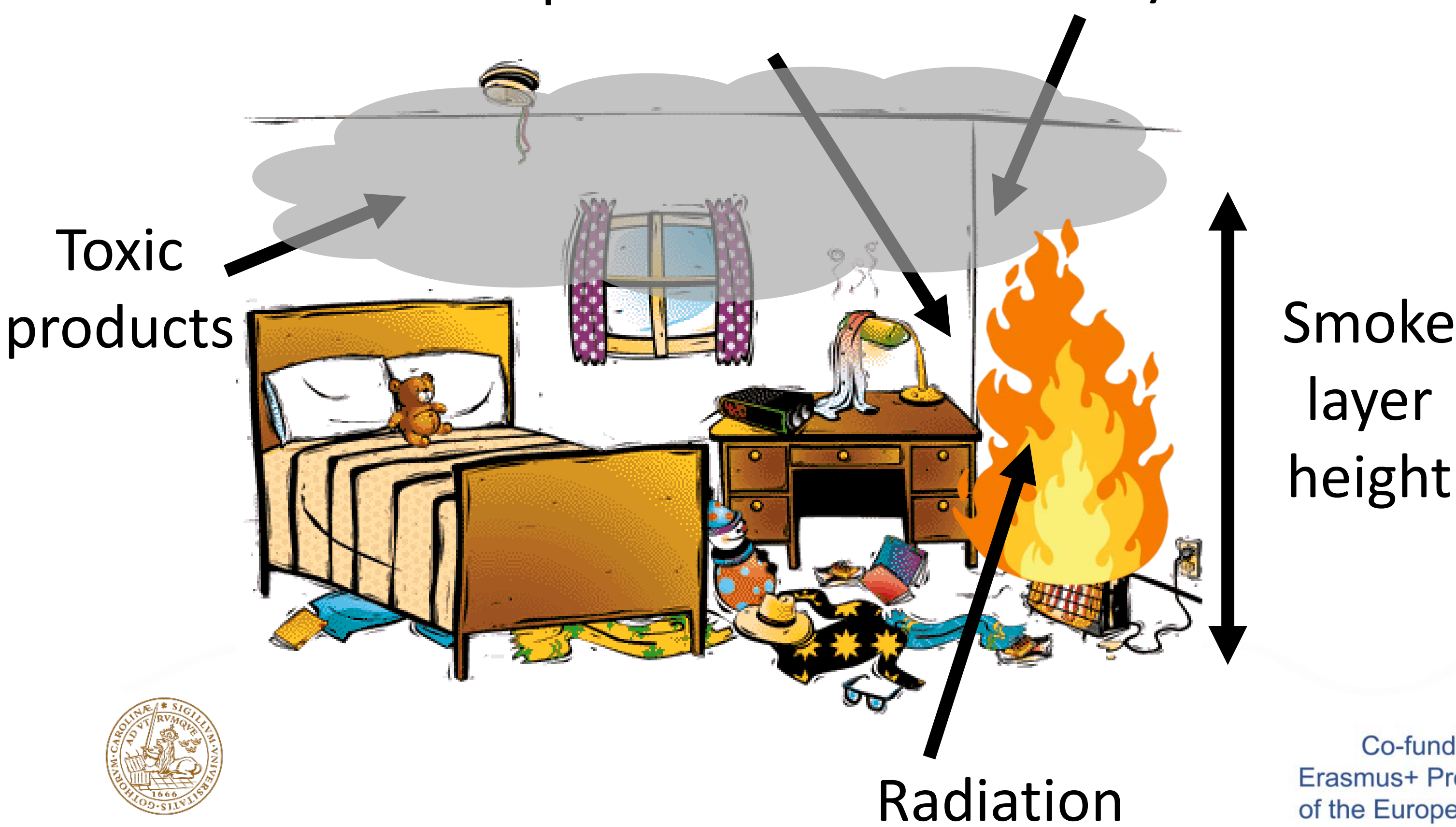
PBD and evacuation models

Is the building safe enough?

Given the threat (e.g. a fire), the conditions in the building shall not become such that <u>*critical conditions*</u> are exceeded during the evacuation process

PBD and evacuation models

How do we know that a building is safe?



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PBD and evacuation models

How do we know that a building is safe?

Required Safe Escape Time (RSET) < Available Safe Escape Time (ASET)

SAFE

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PBD and evacuation models

How do we know that a building is safe?

Required Safe Escape Time (RSET)

We need a way to estimate RSET

Egress models

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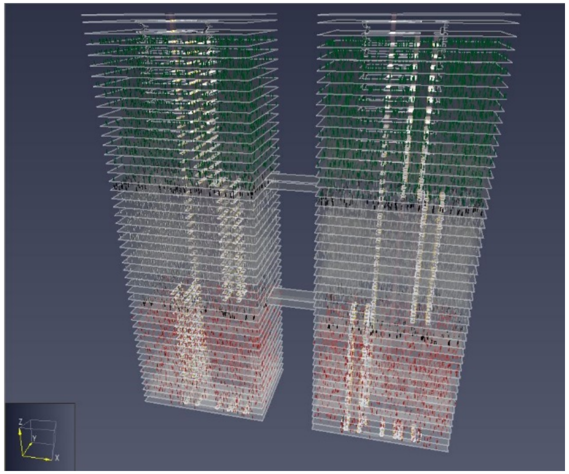
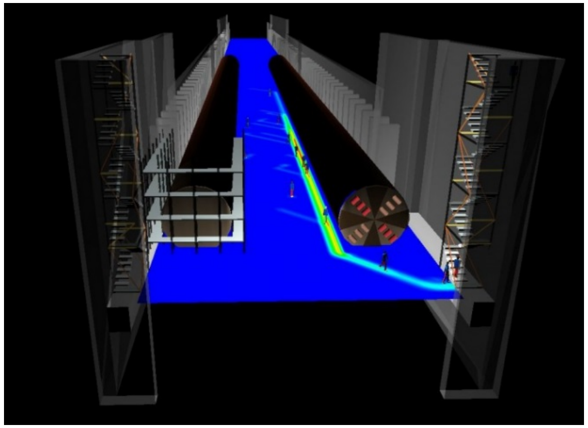
PBD and evacuation models

How do I prove that evacuation design is safe enough?

- Hand calculations (hydraulic model in the SFPE handbook, Predtechinski and Milinski, etc.)
- Evacuation modelling





PBD and evacuation models

Examples

Prescriptive-based design

- Prescribed dimensions of egress components (exits, stairs, etc.)
- Prescribed max distance to an exit, max time to reach an exit, etc.

Performance-based design

- Egress component dimensions is based on the demonstration of a sufficient safety level for evacuation
- Any max distance to/time to reach an exit can be used as long as the building can be evacuated safely

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Basic concepts of human behaviour in fire

- Understanding and predicting human behaviour in fire requires the study of several science fields

- Engineering
- Psychology
- Mathematics/Applied Physics
- Biomechanics

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Basic concepts of human behaviour in fire

Do people behave rationally or do they panic?

http://www.wikihow.com/Evacuate-the-Hotel-You-Are-at-During-a-Fire-Alarm

“Boston on Fire” in The Illustrated Police News, Law- Courts and Weekly Record, 1872.

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Basic concepts of human behaviour in fire

K-FORCE

Do people panic in evacuation?

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Basic concepts of human behaviour in fire

Do people panic in evacuation?

Some definitions of panic

- Panic is an acute fear reaction marked by flight behavior (Quarantelli, 1977)
- Panic is a behavioral response that also involves extravagant and injudicious effort (Bryan, 2002).
- An excessive fear reaction which is persistent and unrealistic in terms of the situation (Sime, 1980)
- Breaking of social order, competition unregulated by social forces (Johnson, 1987)

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Basic concepts of human behaviour in fire

Do people panic in evacuation?

Panic term is used:

- Describing own/other people behaviour referring to stress, anxiety or fear

- Assessing own ability to respond or responses that do not appear the best for the situation (shaking, crying, yelling, running, etc.)

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Basic concepts of human behaviour in fire

Psychology of mass behaviour

- Cooperation and helping behaviour (social vs anti-social)
- Collective resilience (Physical vs Psychological crowds)
- Leadership
- Social Influence / Affiliation
- Lack of trust vs information
- Established and emerging groups

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Basic concepts of human behaviour in fire

K-FORCE

Do people panic in evacuation?

- Competitive behaviours are rare, people behave altruistically
- Panic concept does not match actual behaviour, which in most cases are rational
- Human behaviour in fire models are based on the assumption that people behave rationally

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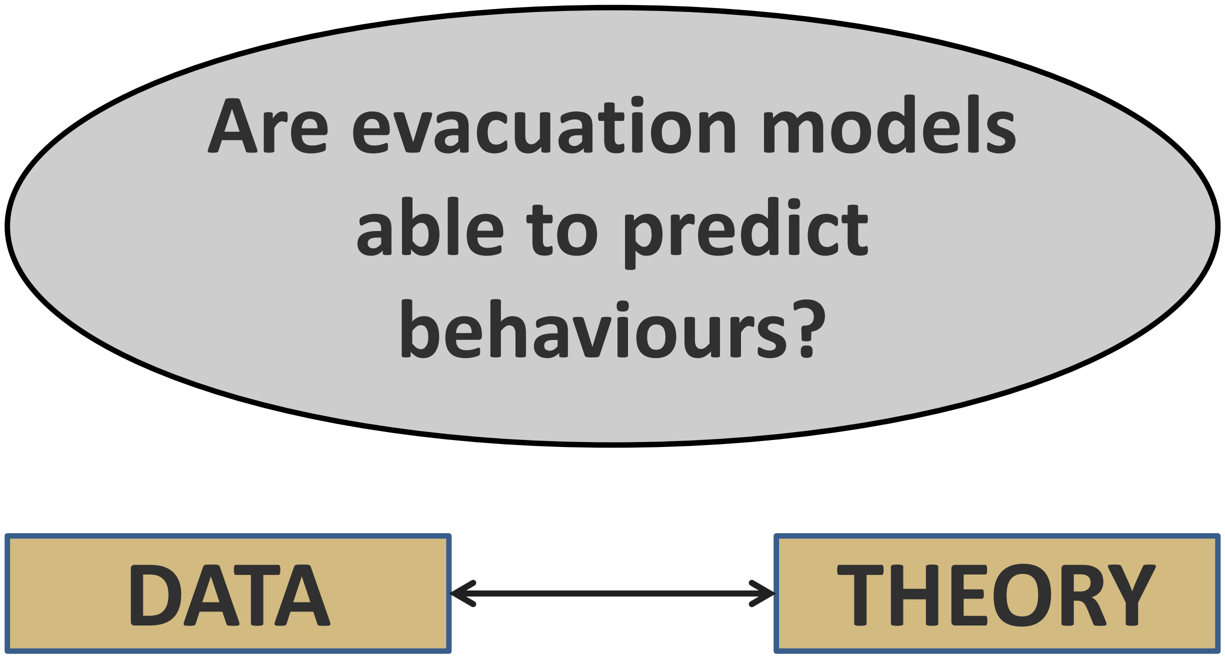
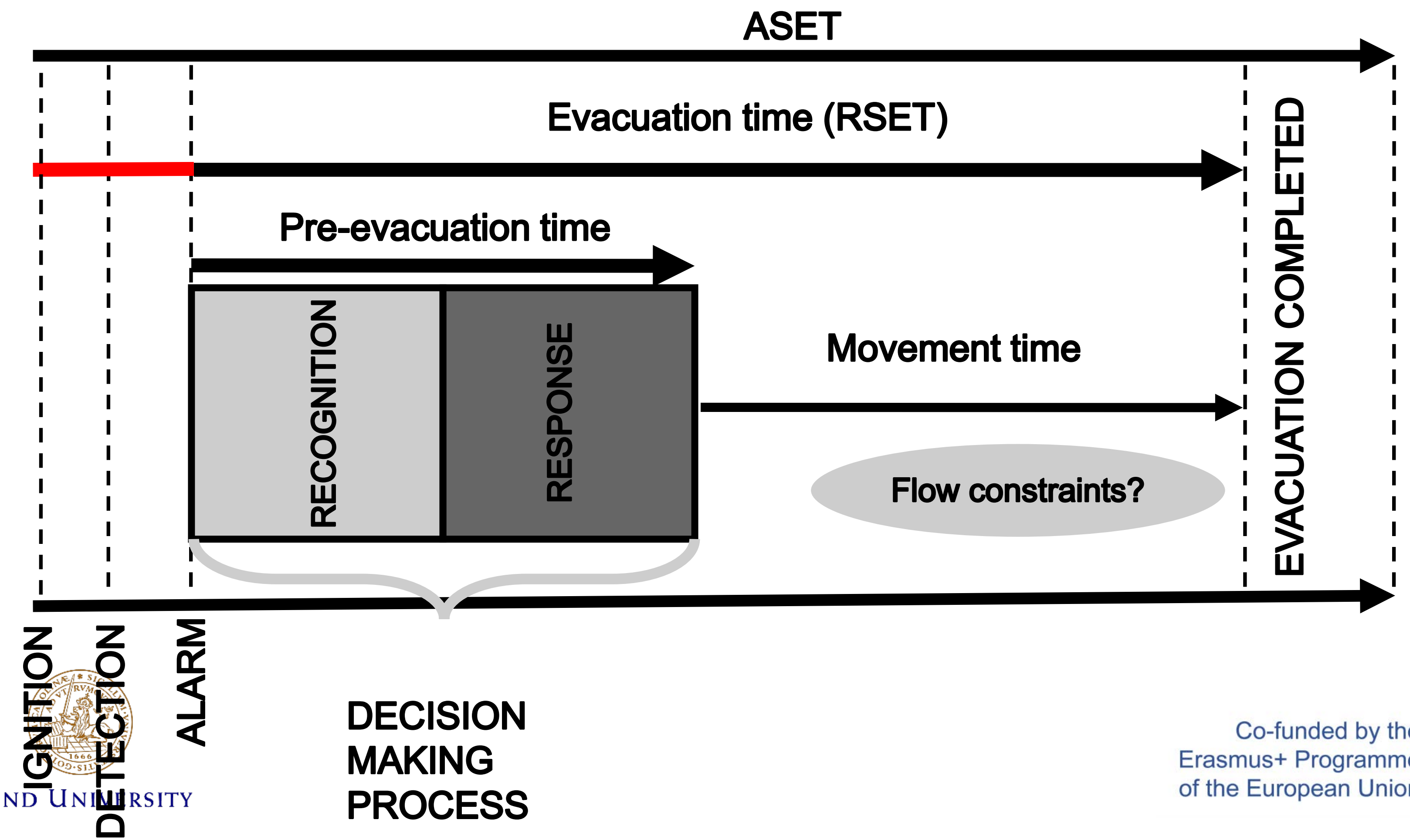
Basic concepts of human behaviour in fire



Use of a simplified engineering time-line model

Basic concepts of human behaviour in fire

Simplified engineering time-line model



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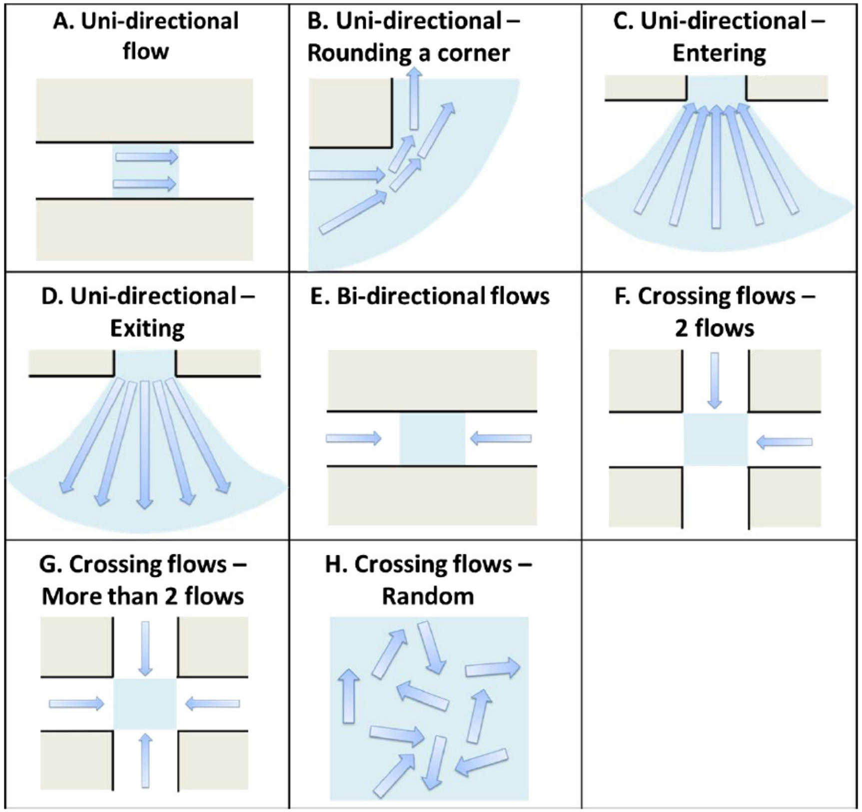
Predicting behaviour with Evacuation models

Simulated crowd behaviour

- Range of pedestrian movement behaviours
- Emerging behaviour such as group behaviours, collision avoidance, crowd pressure



Duives et al, 2013

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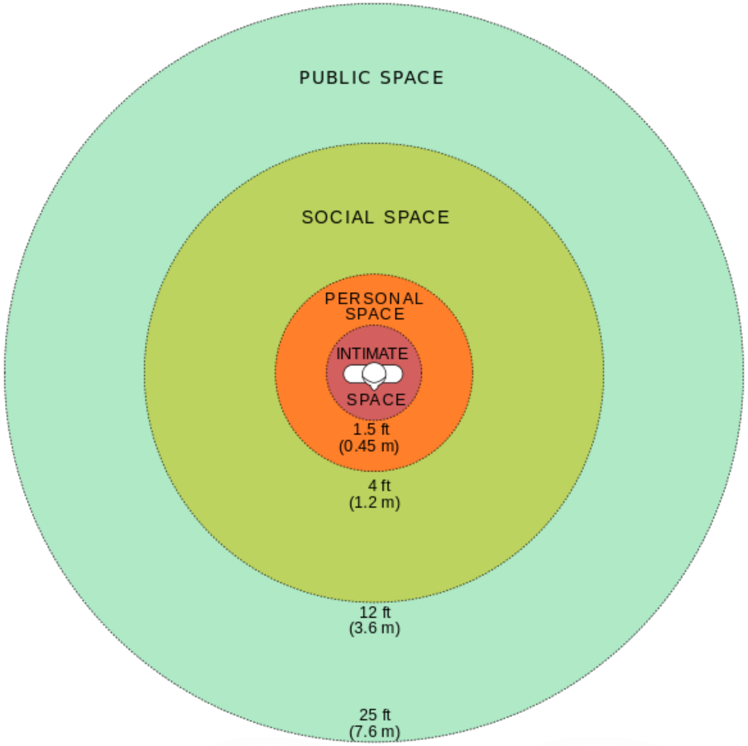
Predicting behaviour with Evacuation models

How much space do evacuating crowds need?

- Personal space preferences (depending on body width, sway and collision avoidance)
- Needed to understand comfort and safety requirements
- Different among cultures



Based on E. T. Hall

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Predicting behaviour with Evacuation models

Level of Service

- LoS concept introduced by Fruin (1987)
- Speed and density to define guidelines for comfort and safety during evacuation
- These area include space around the person: this is called the body ellipse.
- LoS assumes an elliptical body size for personal space

Table 2.1 Body sizes from around the world

Population	*Breadth (cm)*	*Depth (cm)*	*Area (m^2)*
British males	51.00	32.50	0.26
British females	43.50	30.50	0.21
Polish males	47.50	27.50	0.21
Polish females	41.00	28.50	0.18
Japanese males	41.00	28.50	0.18
Japanese females	42.50	23.50	0.16
Hong Kong males	47.00	23.50	0.17
Hong Kong females	43.50	27.00	0.18
The USA males	51.50	29.00	0.23
The USA females	44.00	30.00	0.21
French males	51.50	28.00	0.23
French females	47.00	29.50	0.22
Swedish males	51.00	25.50	0.20
Swedish females	42.50	30.00	0.20
Swiss males	47.50	29.50	0.22
Swiss females	45.50	32.50	0.23
Indian males	45.50	23.50	0.17
Indian females	39.00	25.50	0.16
Average	46.06	28.18	0.20
Maximum	51.50	32.50	0.26

Pheasant, 1998

Predicting behaviour with Evacuation models

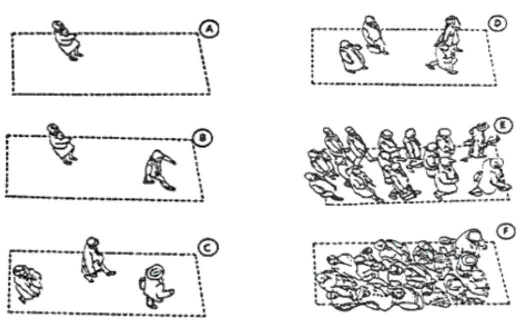
Simulated LoS

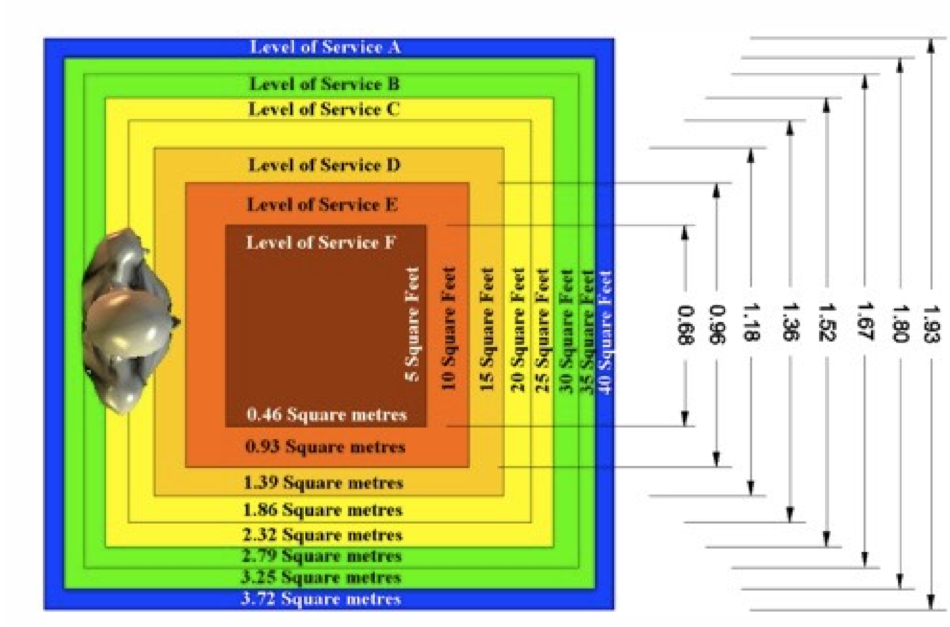
Level of Service (LoS)

LoSA - free circulation

...

LoSF – complete congestion





Fruin, J. J. (1987). *Pedestrian Planning and Design*. Elevator World, Inc, Mobile, AL.

Ongoing discussion on the exact relationship between densities, speeds and flows

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Predicting behaviour with Evacuation models

Shockwaves

At 6+ people per square metre, there is no space between individuals and push forces are transmitted through the crowd → crowd turbulence

Dangerous → prevent shockwaves to occur

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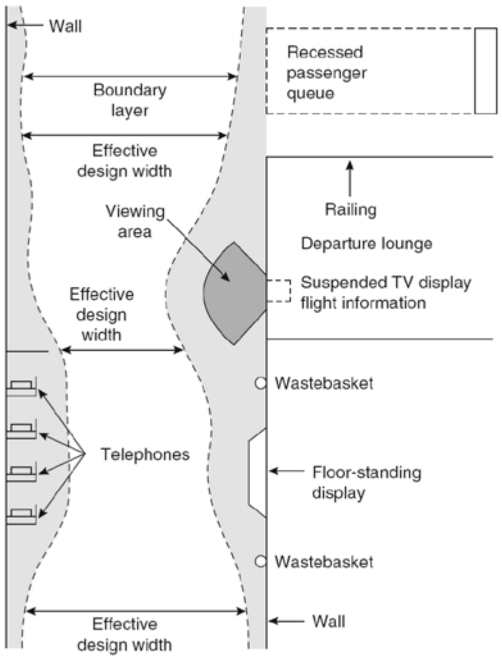
Examples of pedestrian evacuation movement models

Hydraulic model (Gwynne and Rosenbaum, 2016)

Movement equations based on effective width concept

- If the population density is less than approx.0.54 pers/m2, people move at their own pace, independent of the speed of others.
- If the population density exceeds approx. 3.8 pers/m2, no movement will take place until enough of the crowd has passed



Gwynne and Rosenbaum, 2016

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Examples of pedestrian evacuation movement models

Social Force Model (Helbing and Molnar, 1995)

Acceleration term

$$\mathbf{f}_i(t) = m_i \frac{d\mathbf{v}_i}{dt} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW}$$

Desired velocity at the desired direction

Actual velocity

Interaction with walls

Interaction with other pedestrians

Relaxation time: strength of the motive force

Repulsive (private sphere)
Or
Attractive (e.g. family, friends, etc.)

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Evacuation model results

- Total evacuation times
- Occupant-evacuation time curves
- Prediction of congestion levels and other emergent behaviours
- Toxicity assessment in case of fire-people interaction (Purser's FED model)

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References

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Questions for students

- Explain how you can define panic from a scientific point of view and the misconception about its occurrence in evacuation scenarios
- Explain the difference between prescriptive-based and performance-based design from an evacuation design perspective
- What is the Required Safe Escape Time (RSET)?
- Do evacuation models assume the occurrence of irrational behaviours?
- Explain the concept of Level of Service

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