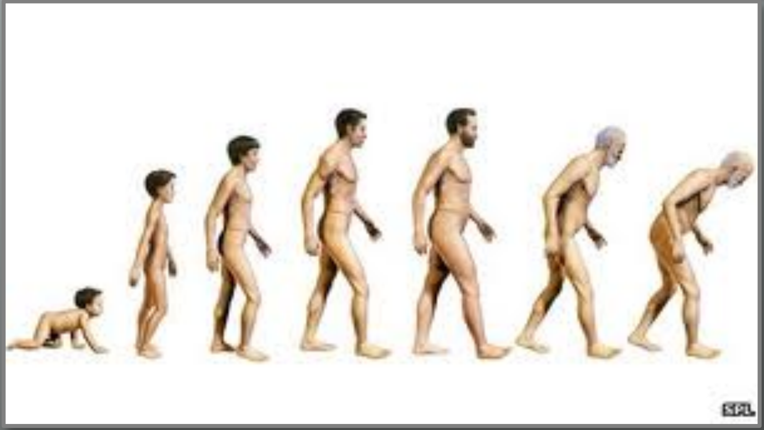
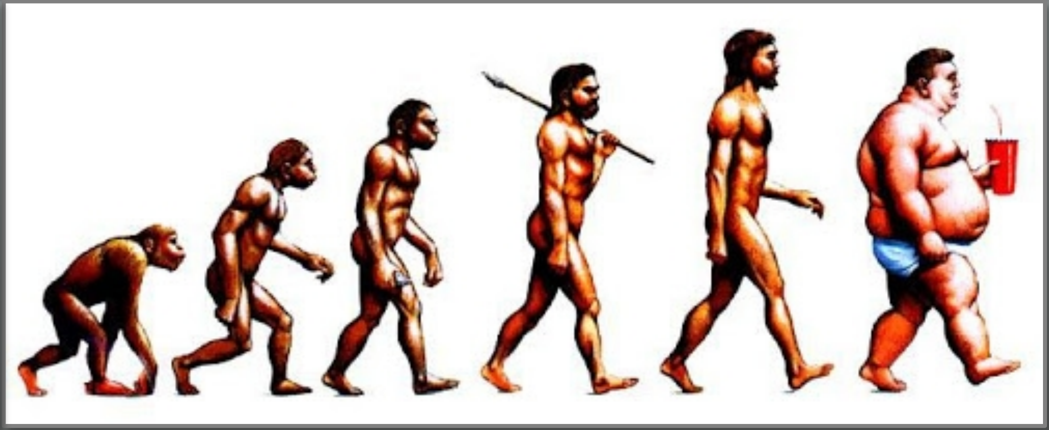
Fire Safety Engineering @
The University of Edinburgh
40th Anniversary Symposium & Celebration, 1974-2014

Symposium theme: ***Where are we, how did we get here, and where are we going?***

Egress & Evacuation models

"are running out of time…"





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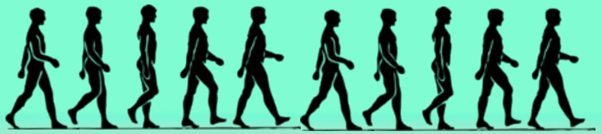
This presentation:



1. Egress & evacuation modelling:
   - The evolution of the maths & analytical approaches
2. The data (movement and flow):
   - Historic data available, R&D and use within regs & design
3. Simulex: developed at Edinburgh University
   - Collecting data and modelling examples
4. Population demographic change
   - Fundamental shifts in age, speed and size: 40 yrs past & future
   - Implications for occupant movement / modelling
5. Why are models 'running out of time'…?
   - What's wrong, how can models & guidance be future-proofed?

40 years past and 40 years forward

1974

- 40 people/21in.(0.53m) flow rate for exits
- No meaningful computer models
- Global populations: shorter, thinner, younger

2014

- 80 people/m/s flow rate for exits (5mm/person)
- Many different computer models: 3D, fire etc
- Global populations: taller, larger, older

2054

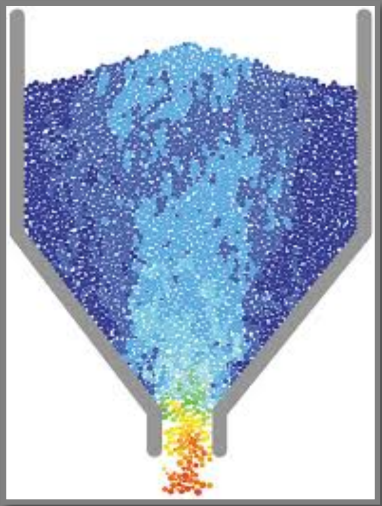
- Different flow rates: ‘obese’, ‘older’, mixed abilities ?
- Sophisticated, predictive computer models ?
- Globally: obesity ‘epidemic’, older (OECD)

OECD: The Organisation for Economic Co-operation and Development (34 country members)

Don’t forget the physics of ‘flow’…

Basic Physics: **Flow = Speed × Density**

- Slower movement = lower flow
- Larger ‘objects’ = lower flow



Modelling the physics of flow <u>should</u> consider…

- Particle (‘body’) dimensions & variations
- Movement (‘walking’) velocity & variations
- The combination of dimensions and velocity

Changing the parameters should change the results…

Timeline: analysis/modelling/data

Decade	Progress	Key elements
1910…	"2.5 min. evac"	Empire Theatre evacuation in Edinburgh: 2.5 minutes evac. time (length of UK national anthem)
1950…	Basic flow rates, UK, US, Japan	UK: "Post war building studies no. 29": 40 p/21in. exit-width (~0.5m) Hankin & Wright published: basic flow rates for commuters UK Japan: Togawa: "Study Of Fire Escapes Basing On The Observation Of Multitude Currents"
1960…	Russian studies	Russia: Predtechenskii & Millinskii: "Planning For Foot Traffic Flow In Buildings": huge set of Russian data sets evaluated in m^2/m^2. Translated in '70s
1970…	US / UK Studies	US: Fruin: "Pedestrian Planning And Design": key ref. text for design. Jake Pauls "effective width" model. UK: "Guide to Safety at Sports Grounds": higher flows for stadia
1980…	Flow models	Computer 'flow' models: BFIRES, EVACNET+, EXITT/EXIT89 Data: Ando (flow, but also walking speed with age)
1990…	Grid & continuous models	Grid Models: Egress, EXODUS, PedGo, Takahashi's Fluid Model Continuous models: Vegas, **Simulex (Edinburgh University)**
2000…	More models	Grid / Continuous models: SimTread, Pathfinder, Legion, FDS Evac, MassMotion

Note: this is NOT an exhaustive list: just a representative one…

Design & peak 'flow' rates

Yr.	Source	Max. design flow (p/m/sec)	Ultimate flow (p/m/sec)	Scope of data / analysis
'58	Hankin & Wright	1.48	1.92	Commuters under normal conditions
'69	Predtechenskii & Milinskii	1.70	2.06	Peak flows at high density for adults in summer dress.
'72	SCICON report	1.37		Data from football crowds
'73	Guide to Safety at Sports Grounds	1.82 (unit exit width method)		Based on Japanese data and derived from 1.0 pers/0.55m/s unit exit width calculation
'71	Fruin	1.37	4.37	Max. flow is ultimate regimented, 'funnelled' soldiers flow under pressure
'83	Polus et al	1.25-1.58	1.56	Data collected in Israel, sidewalks
'85	NFPA 101 (U.S.A)	1.64, now 1.33		Originally 1.64 (unit exit width method) but now same as UK
'88	Ando et al		1.7-1.8	Commuters under normal conditions
'91	Approved Document B1 (UK)	1.33		Standard British code for buildings

Basic maths / flow models

Mathematical (manual design)

- 5 mm per person to size doorways
  - 80 p/m/min., 2.5min. = 200p/m
- Also calc. travel distance/time to safety

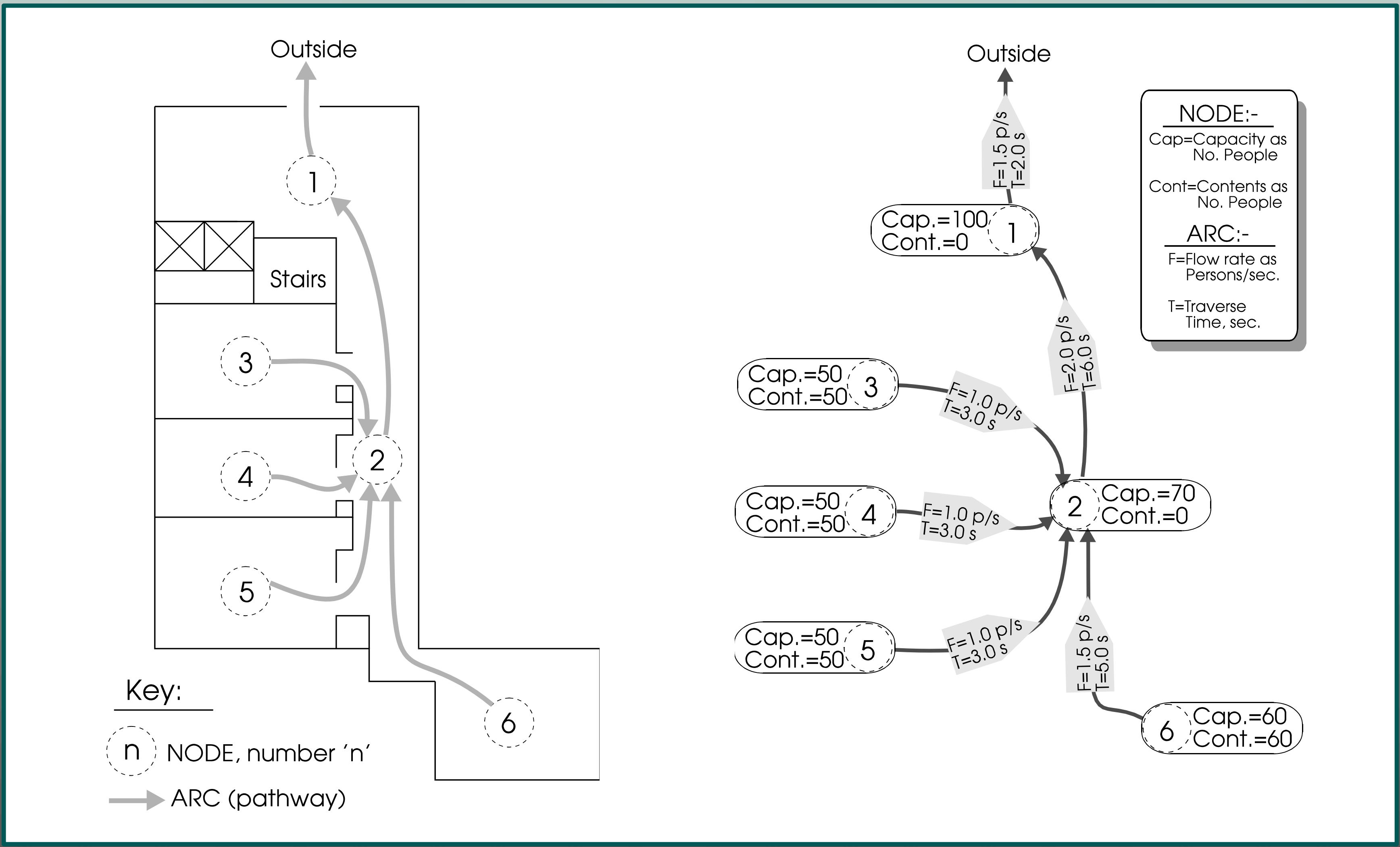
Computing 'flow' (basic & quick to run)

- Network of space nodes, with 'flow' links:
  - set flow rates (1.33 p/m/s)
  - fixed walking speed to traverse arcs
- Egs. BFIRES, EVACNET+, EXITT/EXIT89

Life-safety modelling aim: RSET < ASET

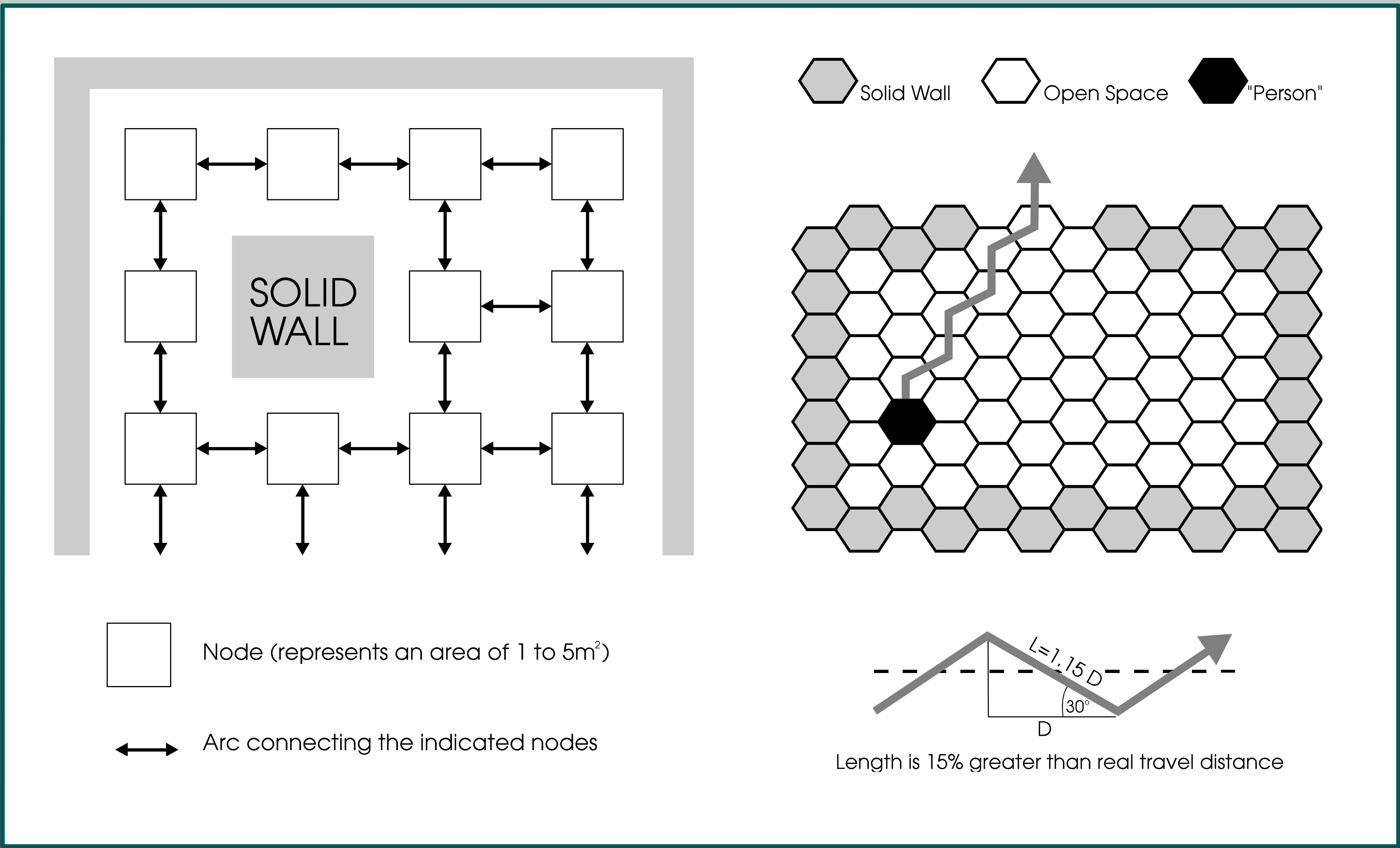
Required Safe Escape Time < Available Safe Escape Time (time to untenability)

Basic flow model analysis



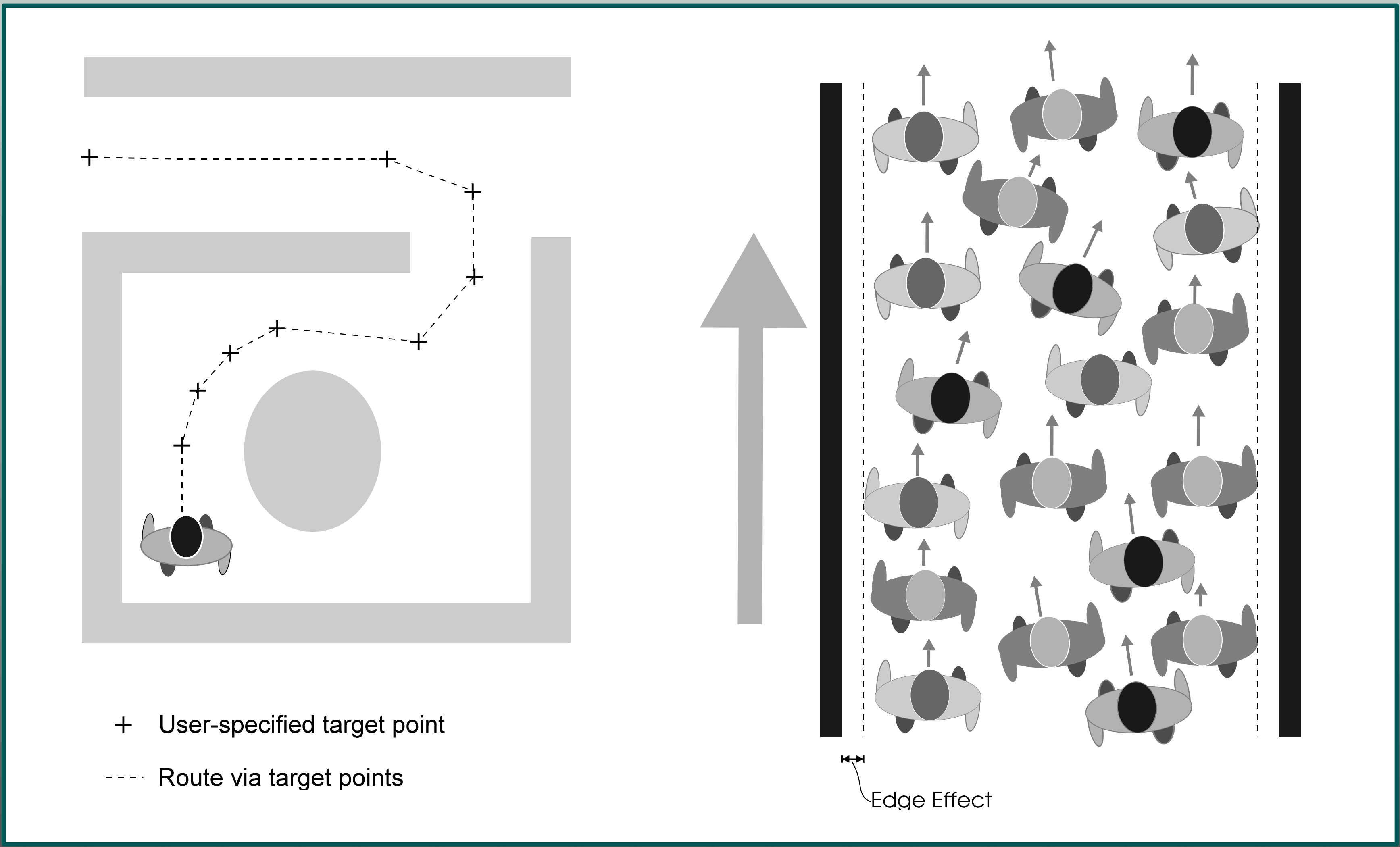
Fixed flow at each 'arc', adjusted for door/passageway width

‘Grid’ model analysis



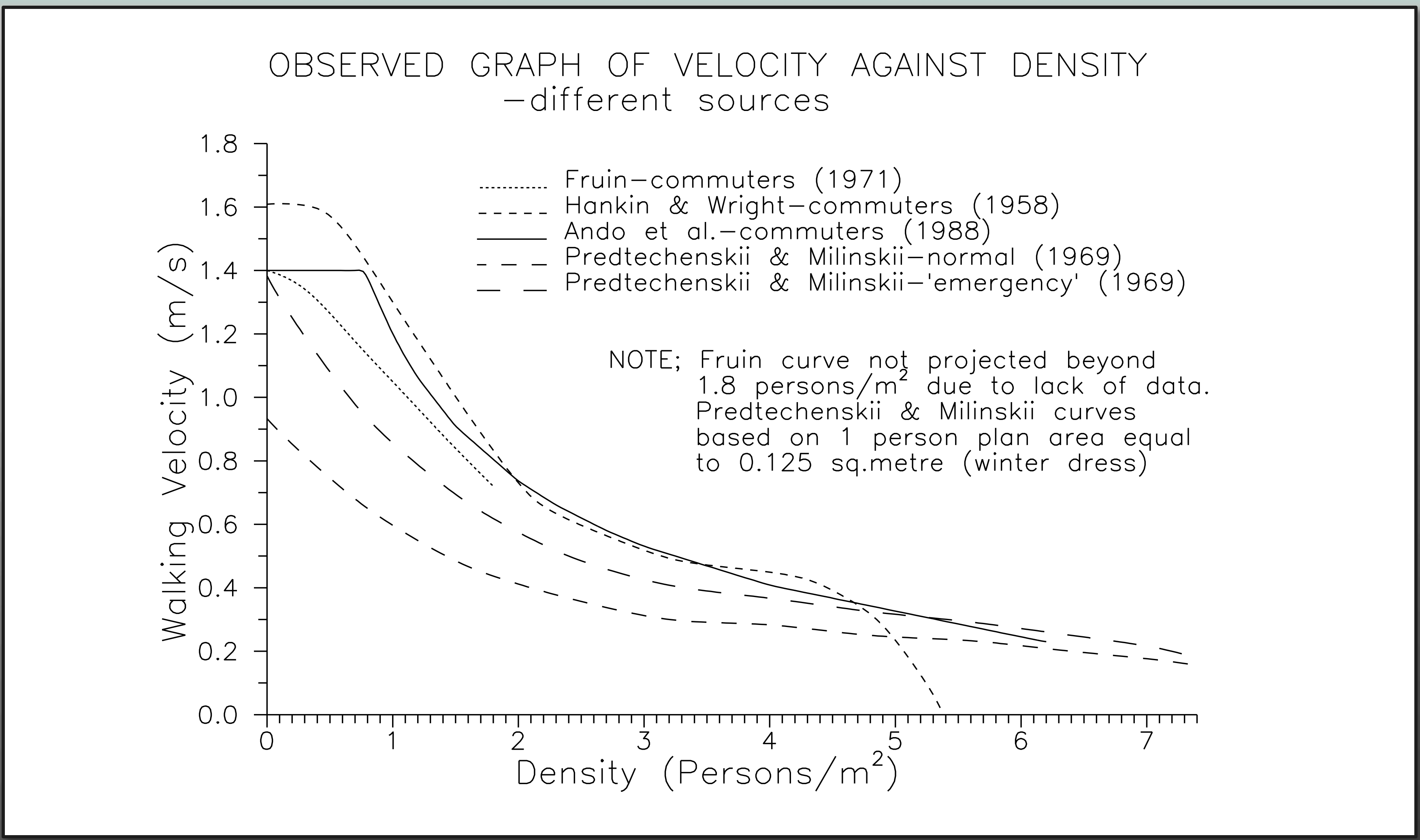
Quick analysis of directions, auto route finding (Dijkstra), restricted movement

'Continuous' model analysis



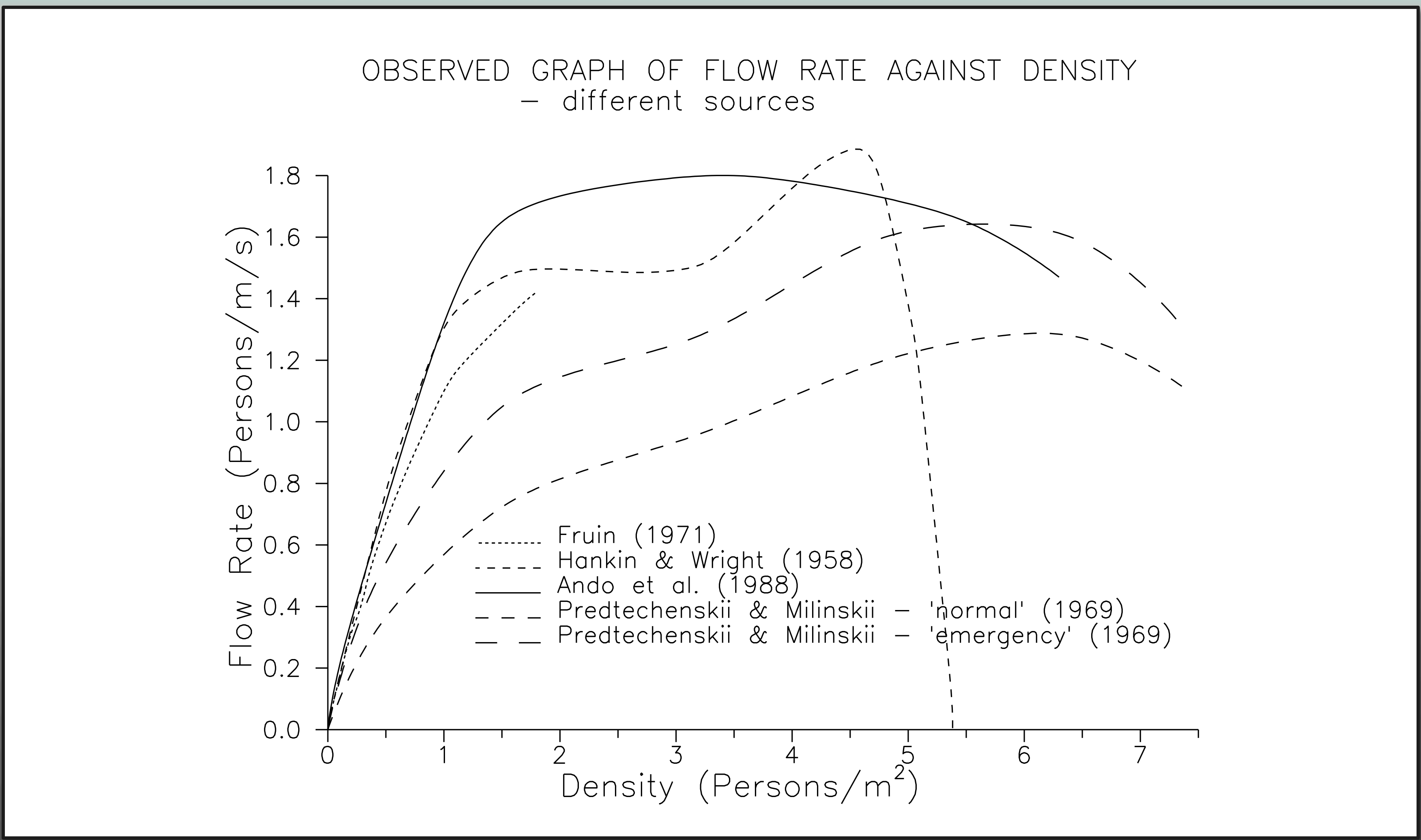
'Continuous' models vary in approach. Complex paths, vector-based movement…

Continuous Models data: *velocity vs density*



Many continuous models use aggregated approaches: small local density ‘tiles’

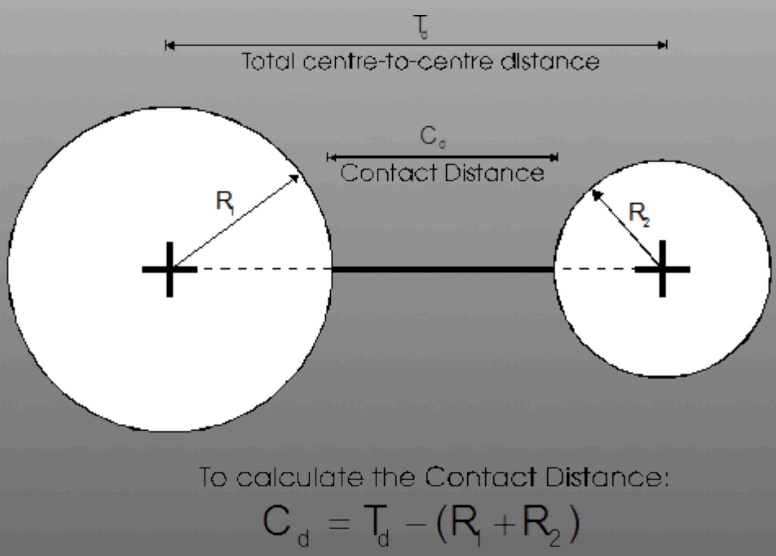
Continuous Models data: *flow vs density*



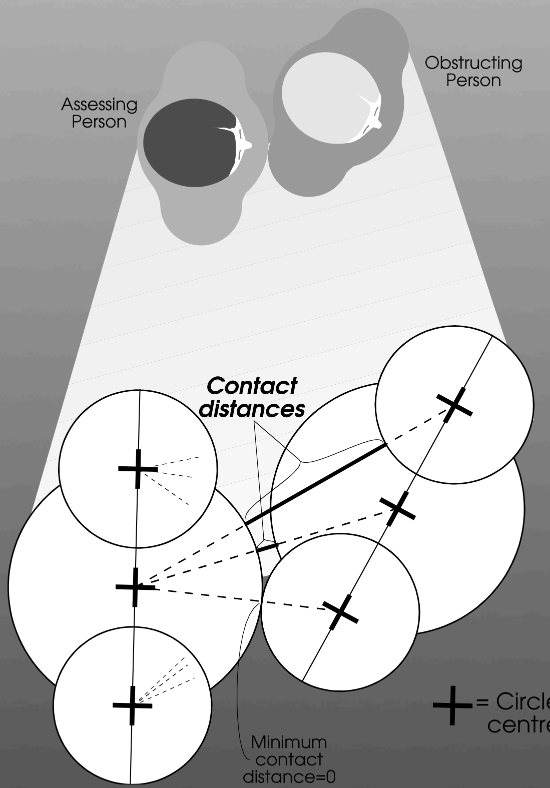
Some 'continuous' models also cap flow, but others use flow curves…

Simulex: distance & ‘contact’

Use simple radial analysis for point-to point ‘contact distance’ analyses…



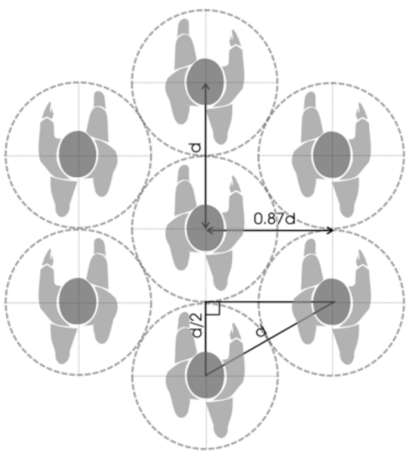
Rotate torso & shoulder circles about angle of orientation…



Simulex (continuous model) uses vector-analysis and contact-distance

Convert distance to speed…

Reduce homogenous ‘flow’ to spatial distances…



Converting circular ‘spacing’ to inter-person distance and pedestrian density…

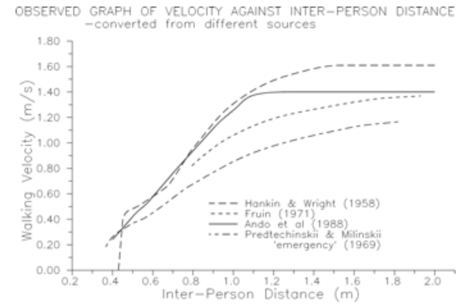
Lateral Spacing $= \sqrt{d^2 - \left(\frac{d}{2}\right)^2} = d^2\sqrt{\frac{3}{4}} = 0.866d$

Area per person $A = d^2\sqrt{\frac{3}{4}} = 0.866d^2$

Density $\rho = \frac{1}{A} = \frac{1}{0.866d^2} = \frac{1.155}{d^2}$

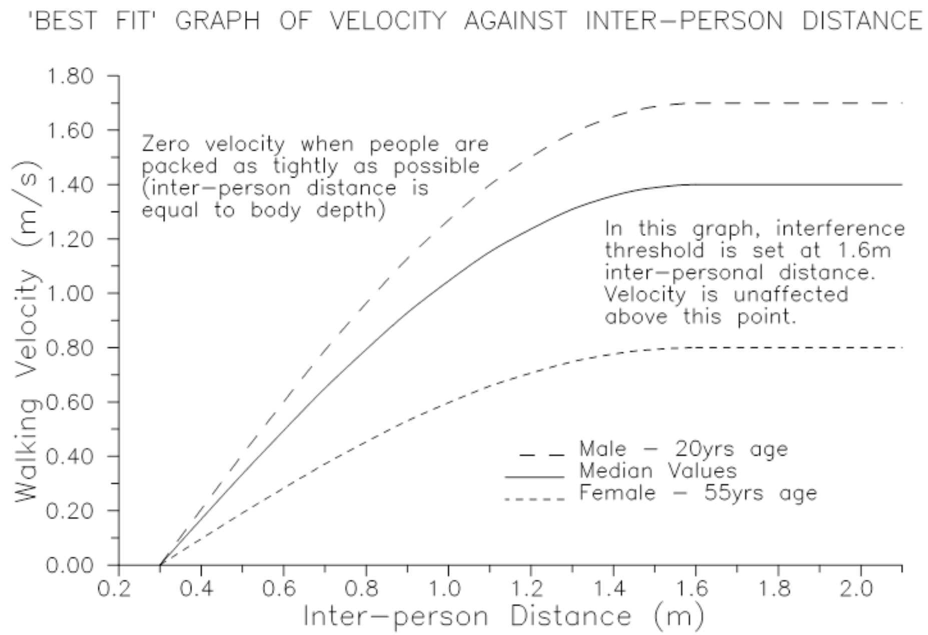
Interperson distance $d = \sqrt{\frac{1.155}{\rho}}$

… and then allow for individual person characteristics (body size, walking speed & gender, related to age etc.)



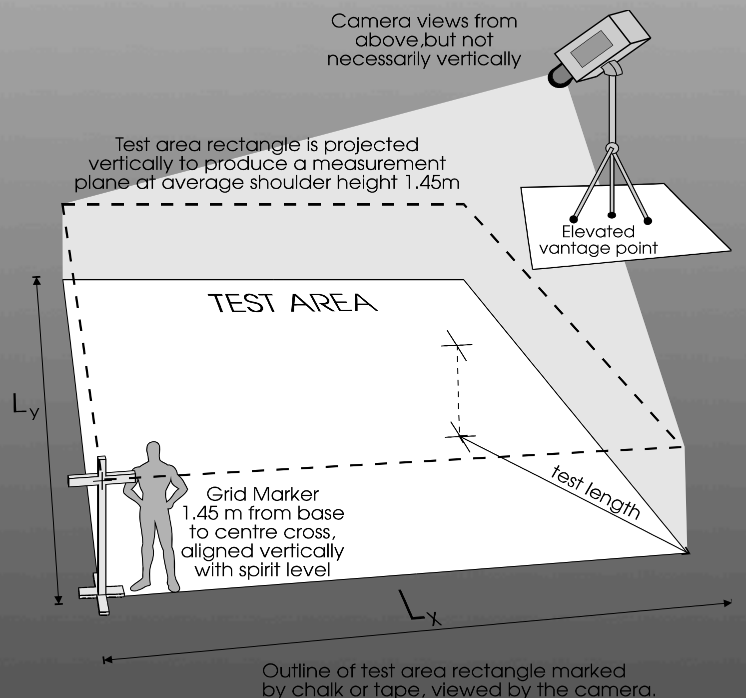
Harvest multiple references to derive best-fit:

Velocity vs distance



Needed to check speed v distance…

- Wrote data collection software
  - *"Perspective Image Analysis Software"*
- Filmed multiple sites in Edinburgh
- Assisted by honours-project students

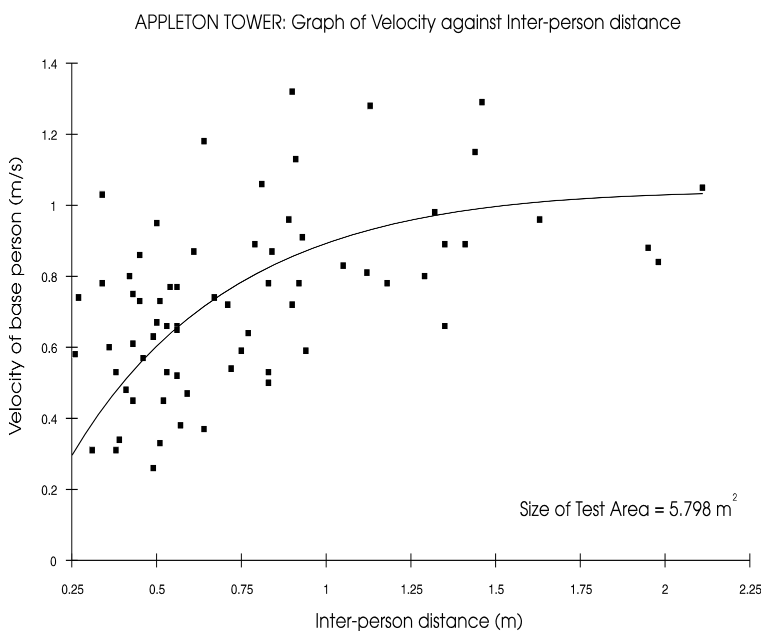


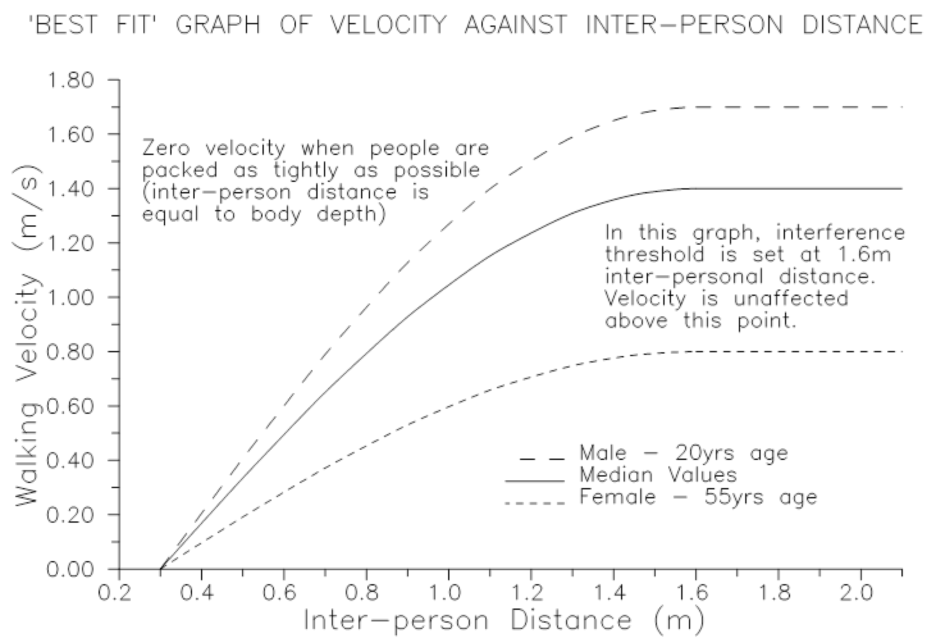
Quantified inter-person marker distances with time…

Collected multiple data sets at 4 key locations, including stadia and uni. buildings

Quantified statistical trends

Large data spread, deconstructed to trend lines



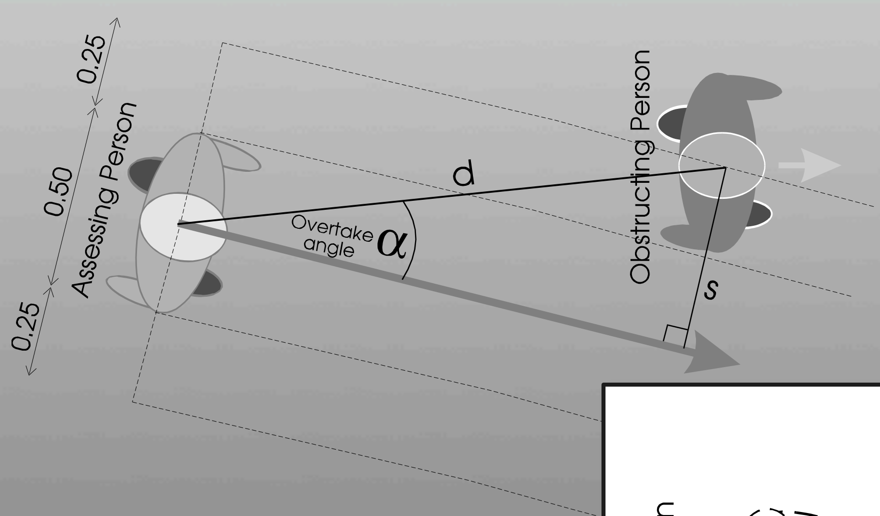


Also quantified:

- Acceleration ~10%/0.1sec
- Rotational twist: 10 degrees/0.1sec

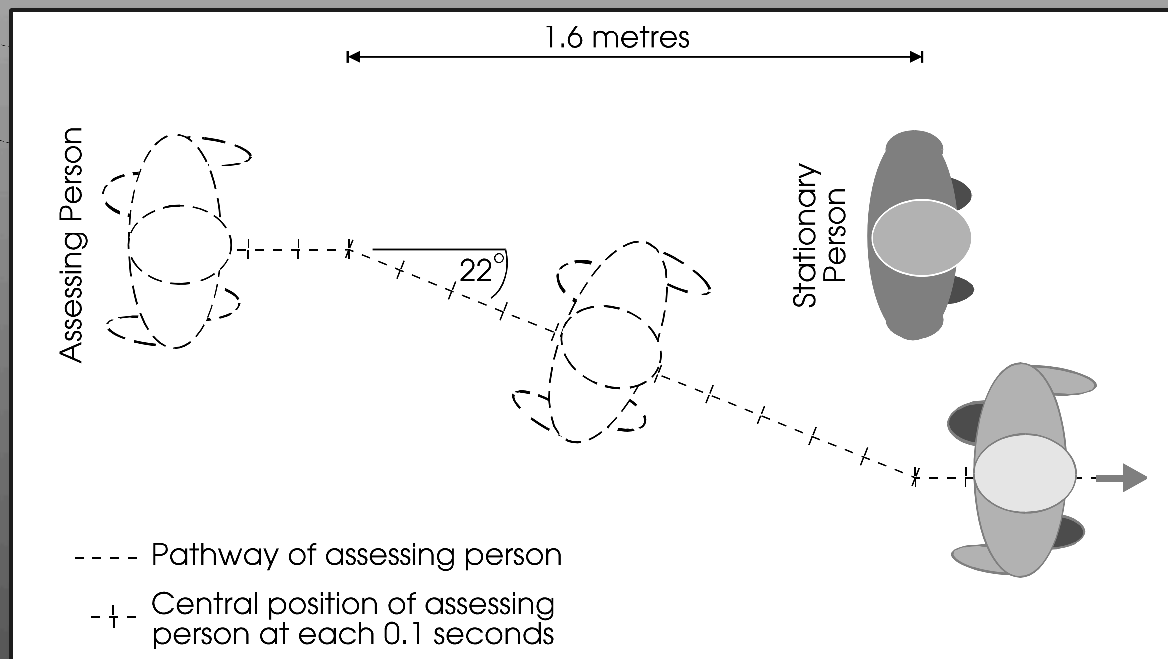
Wide spread of data, reduced to best fit curves…

Overtaking, obstructions etc…



Use body size, position, speed to assess overtaking vectors…

‘A.I.’ algorithms make decisions about response, overtaking, shuffling, turning.

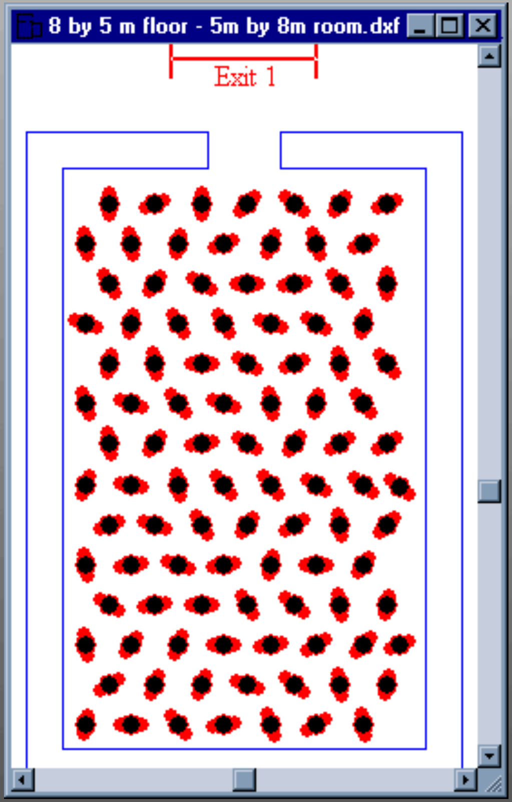


Vector-based movement reassessed every 0.1 seconds: shuffling, overtaking etc.

Simulation ‘unit’ testing

Testing model on simple, stock geometries to recreate flows & compare with multiple results…

Flow rates on floors:

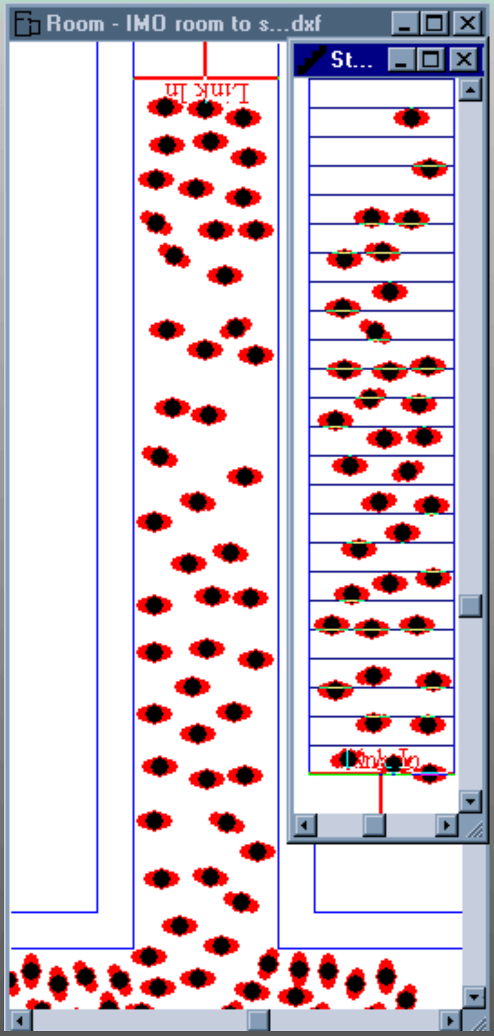


Standard office population:
Flow rate ≈ 80 P/m/min
(people/metre-exit-width/minute)

Same as UK regs & NFPA101

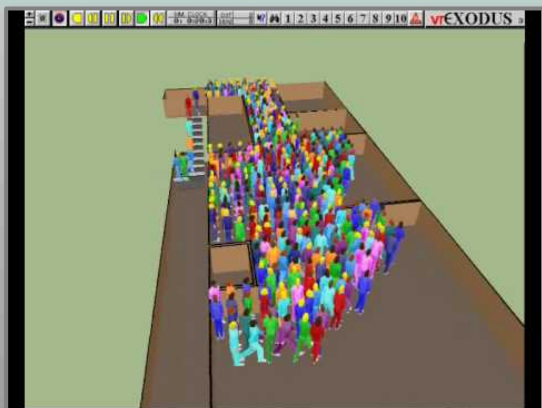
Shows Windows version, developed collaboratively with Lund University, funded by Brandforsk (Sweden)

Flow rates on stairs:

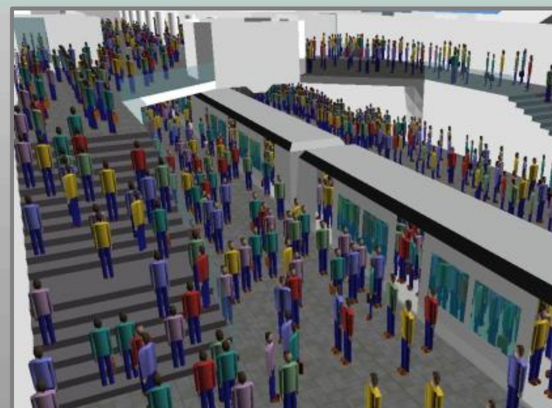


Using curve-analysis (distance v speed) from experiments = realistic flow rates

Sample (modern) model images

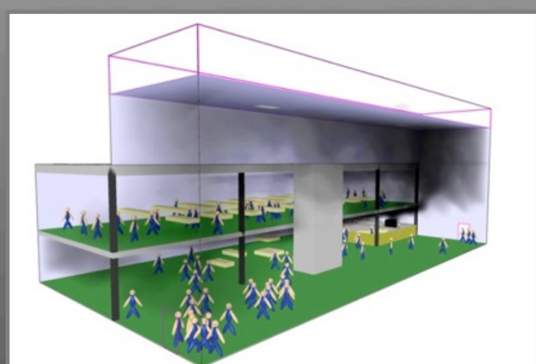


BuildingEXODUS (FSEG)



STEPS (MottMac)

MassMotion (OASys)



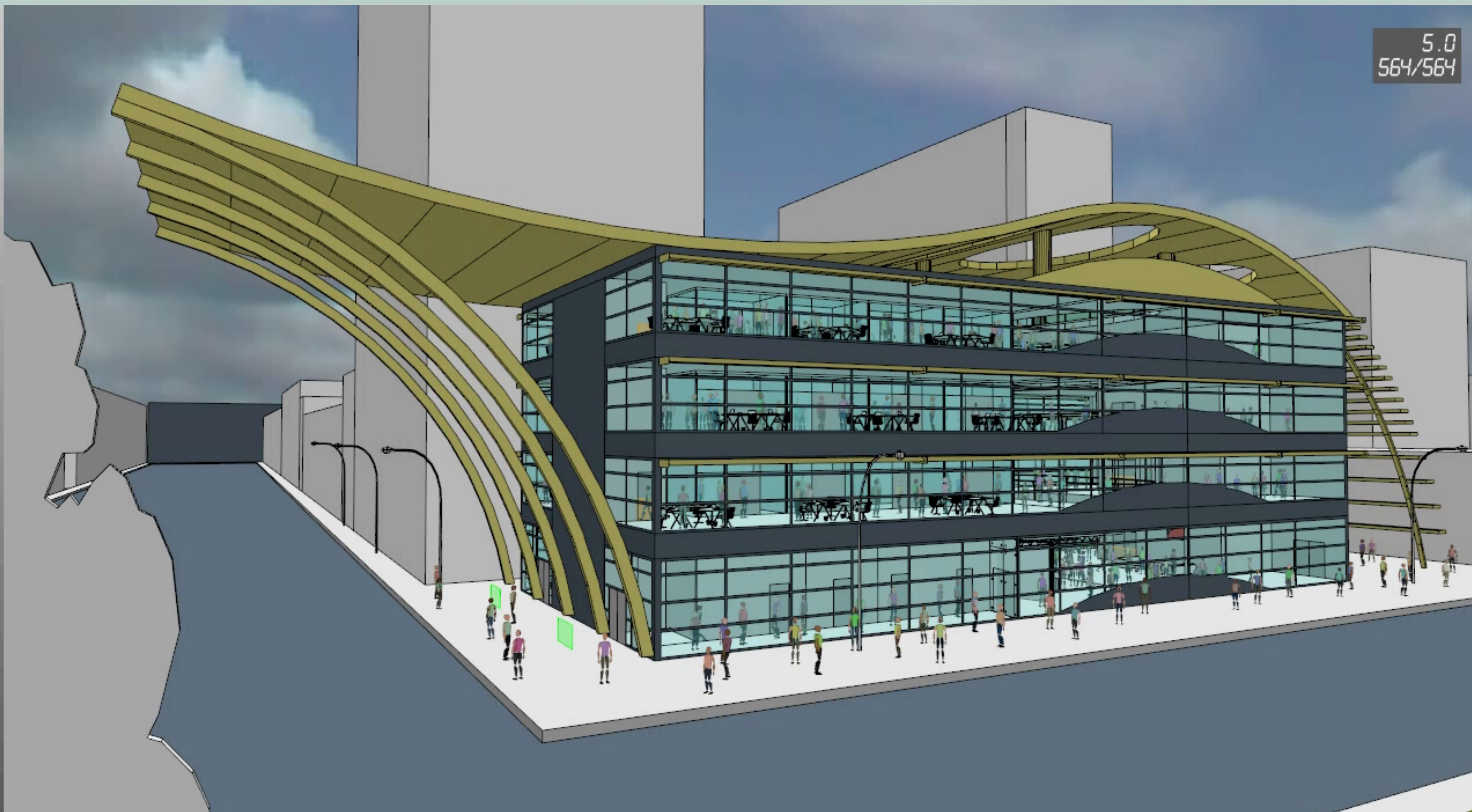
FDS + Evac (OpenSource)

PathFinder (Thunderhead)

Simulex (IES)

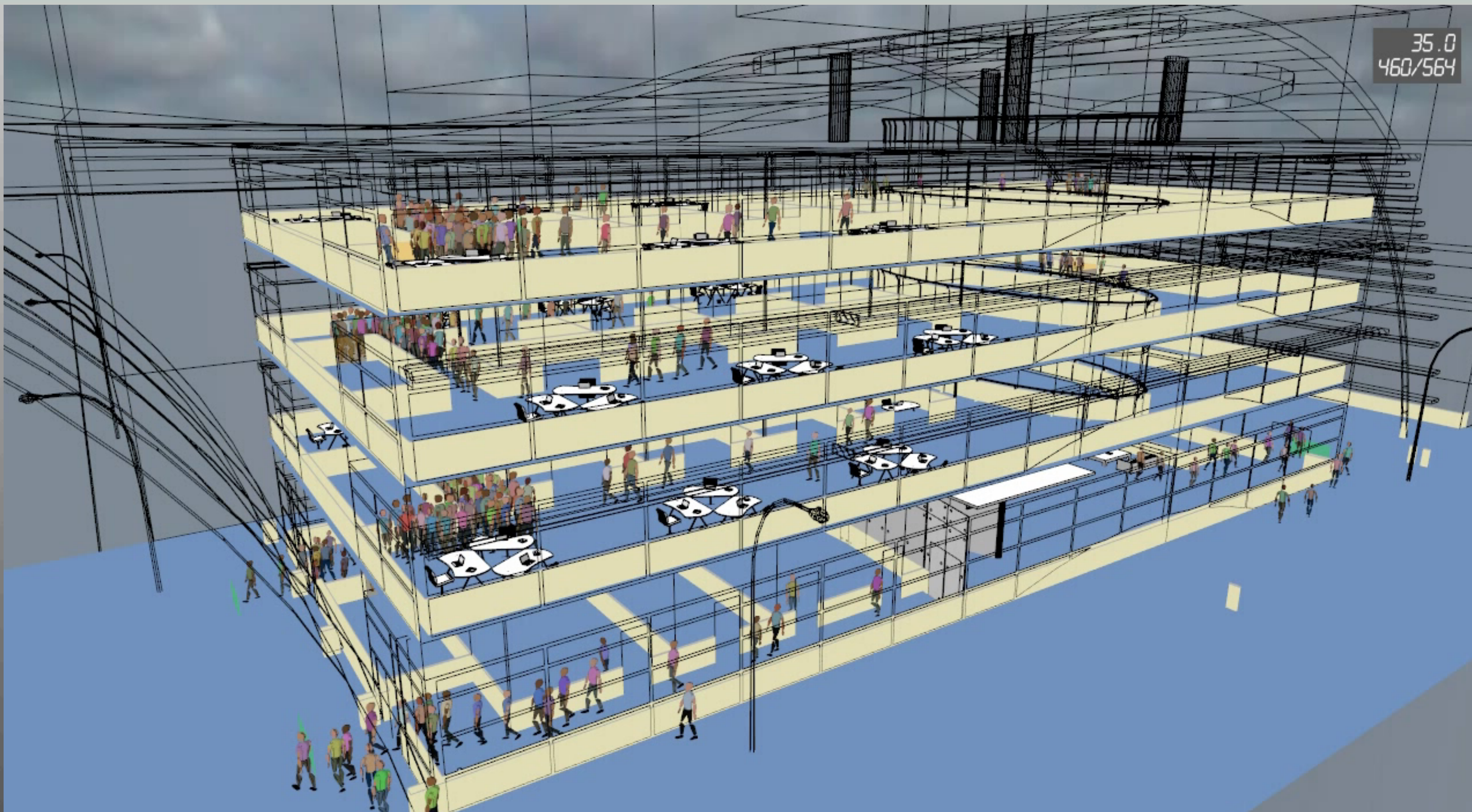
The 3D viewers give the impression of highly sophisticated modelling…

The seduction of animation



Simulex 3D viewer, showing egress from North American demo building (from Revit)

Multi-level analysis



Cut-away mode, showing movement around obstacles, and 'decking' view…

The models look great. What's wrong?

Remember when most data was collected (1950-1980)

☒ WE HAVE AN AGEING SOCIETY

- The 'baby boom' generation got older
- People are also living longer (medical science, diet)
  - Older people walk more slowly

    - Slower people = reduced flows

☒ PEOPLE HAVE LARGER BODIES

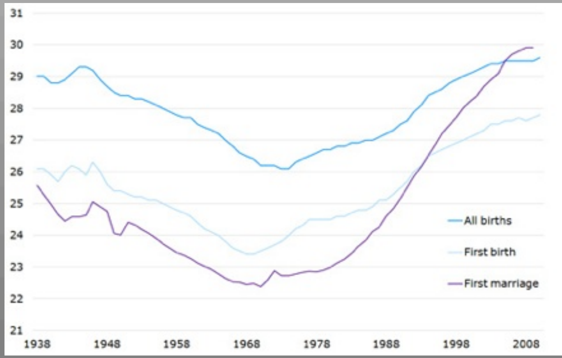
- Higher calorific intake: taller, larger people
- Rapidly increasing obesity rates
  - Larger bodies = density reduction (same speed)

    - Larger/obese people = reduced flows

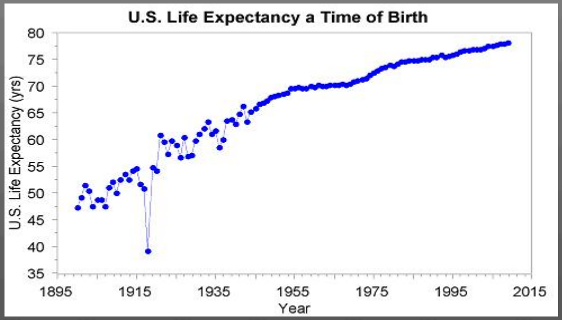
The 'ageing' society: root causes…

- Declining birth rate
  - (USA birth rate halved in last 100 yrs)

- Mothers are having children in later life
  - (3-4 yrs later than 1974, UK)

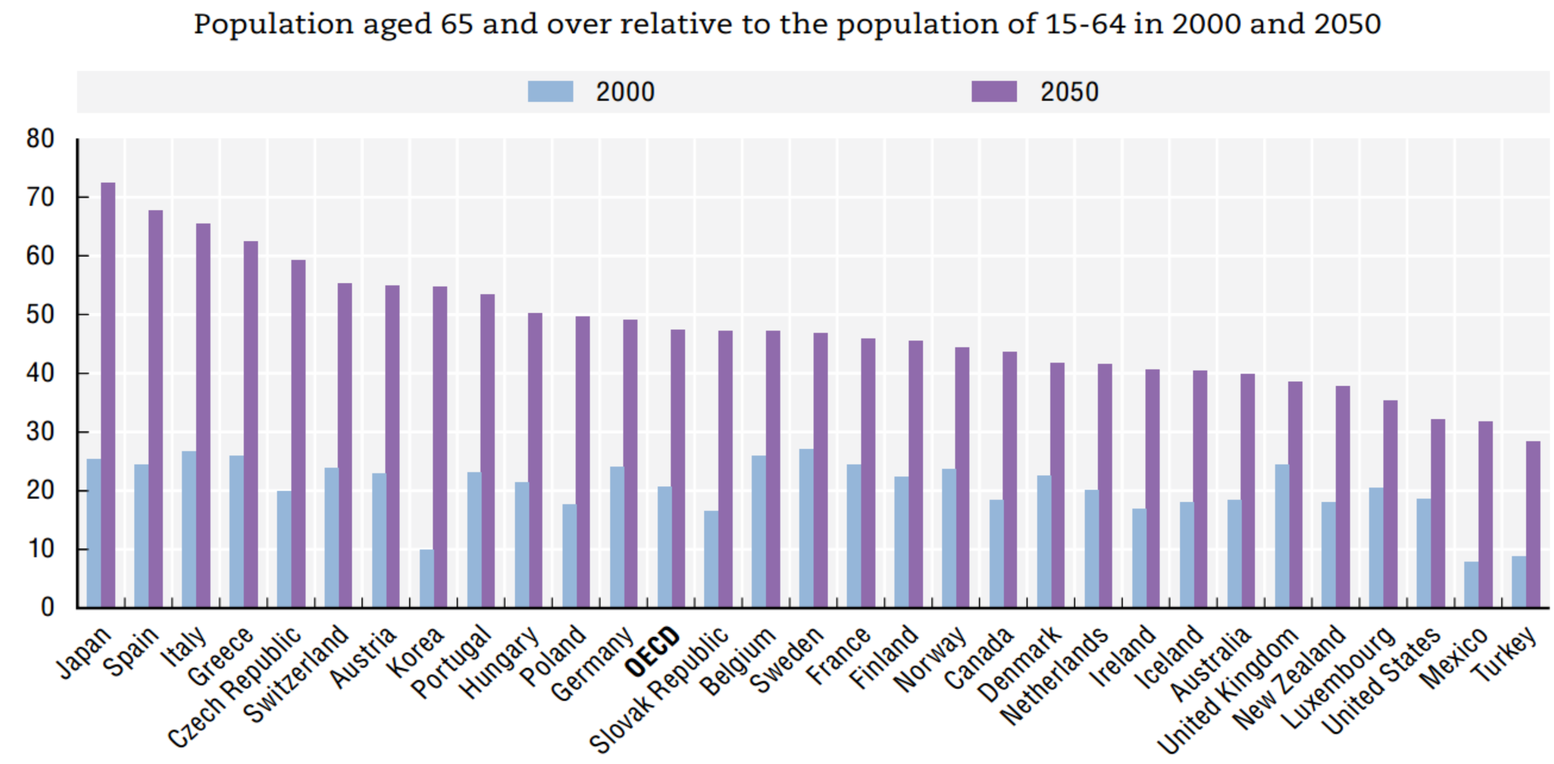


- Rising life expectancy
  - Average rose from 70-80 since '74



The 'ageing' society: over 65s doubling

The average OECD country will have ≈ 50% of the adult population > 65, by 2050



StatLink http://dx.doi.org/10.1787/403710262251

Source: OECD (2006), *Society at a Glance*.

Older people walk more slowly

'Elderly' (age > 65) walk approximately 20 – 25% slower than adults (age 18 - 40)

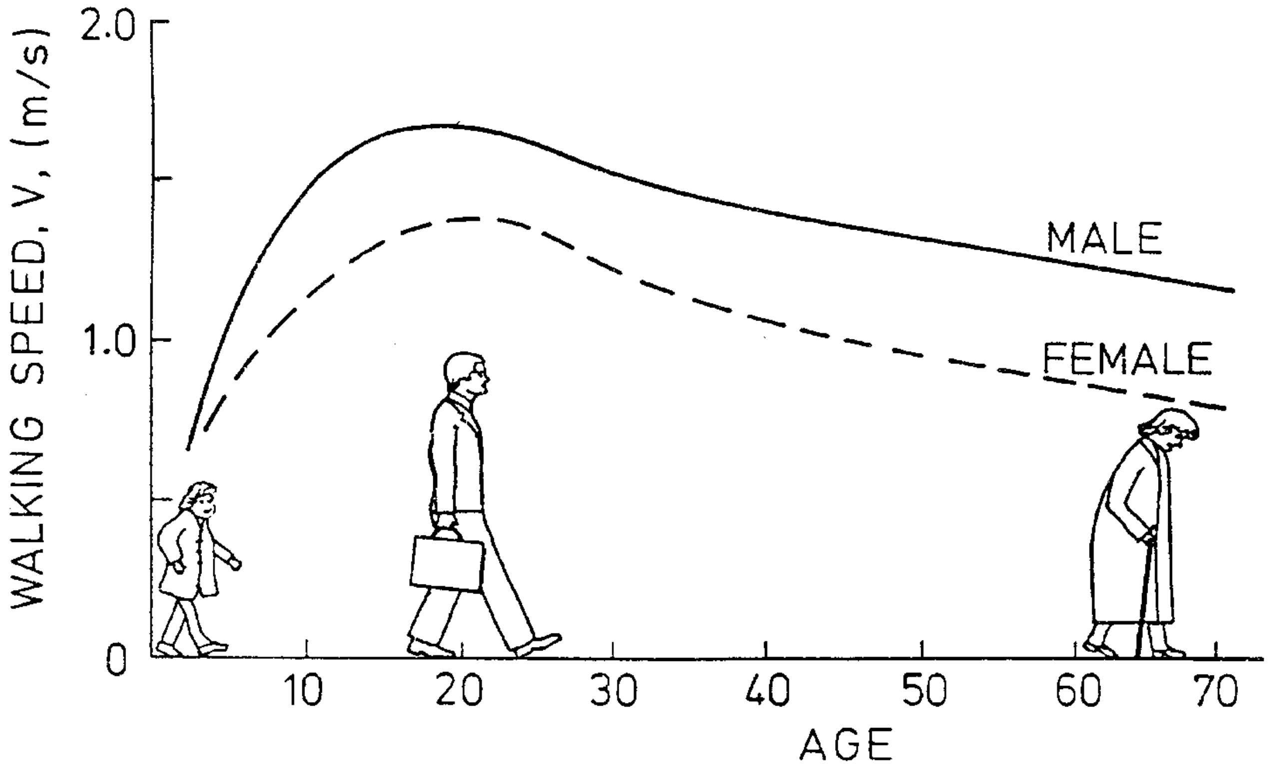
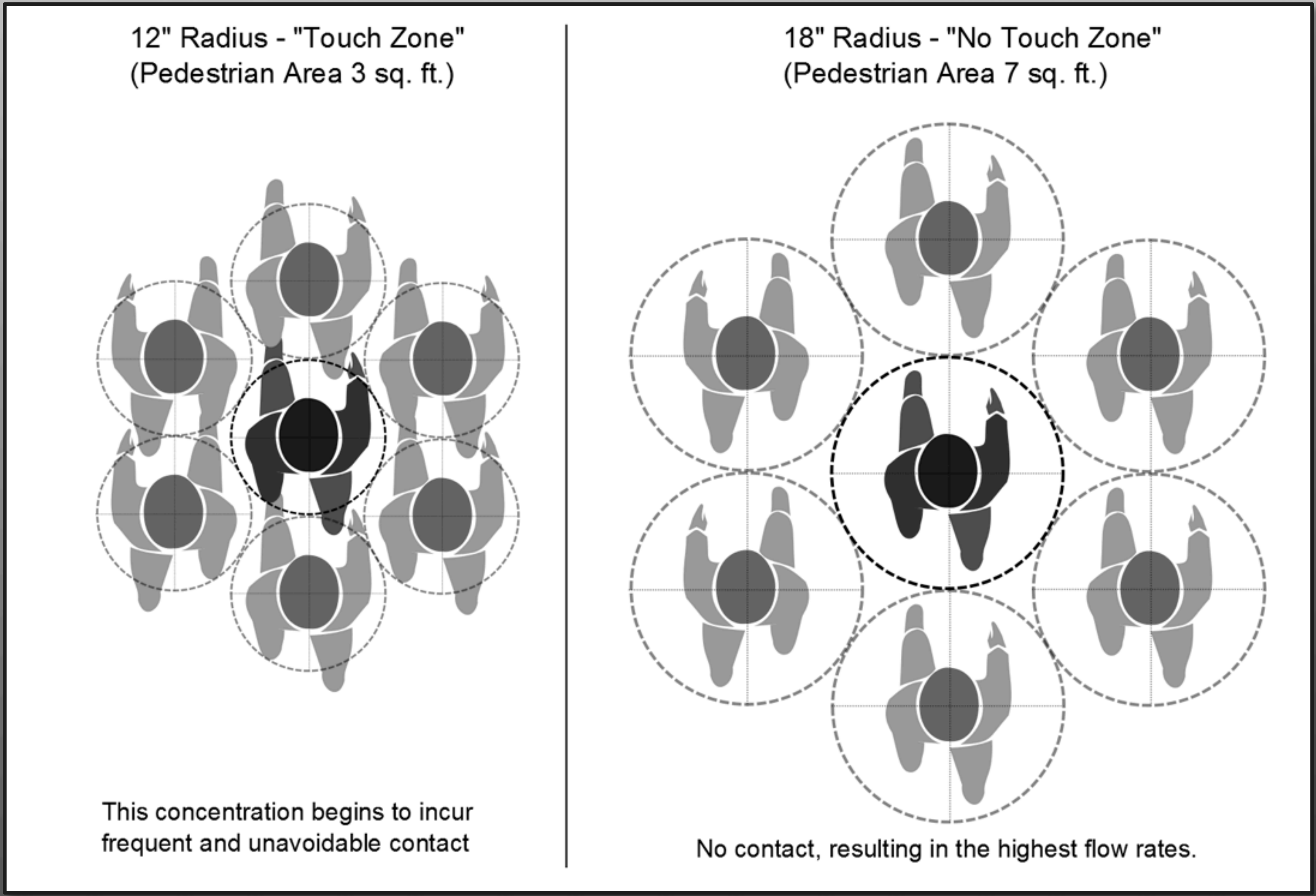


Chart from Ando et al, 1988

Slower people will dictate flow rates

Overtaking is not possible at the sustained design flow densities.



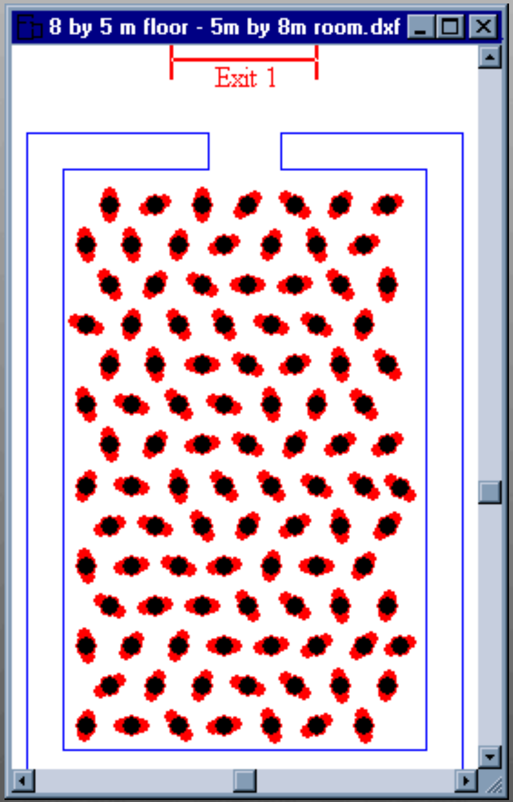
Derived from Fruin (1971)

At significant % proportions, the slower (and larger) occupants dictate flow

Simulex sims. - different populations

Benchmark tests International Maritime Organisation

- IMO Reg. Misc 1038: Specifies different population types



IMO Population Group(s)	Peak flow (people/s) 10 sec sample	Sustained flow (people/m/s)
Commuter	1.4	1.36
IMO Crew	1.6	1.58
Elderly Passengers	1.0	0.88
SFV Adults	1.4	1.28
SFV Adults (+life jacket)	1.2	1.12

Demographics – controlled flow

IMO ‘Elderly / mixed-ability’ passengers = 34% lower flow rates (than standard)

Older, slower people = lower flow rates

‘Elderly’ speeds approx. 20% slower (Ando)

- Flow = speed x density
- Therefore, basic maths, flow ≈ 20% lower

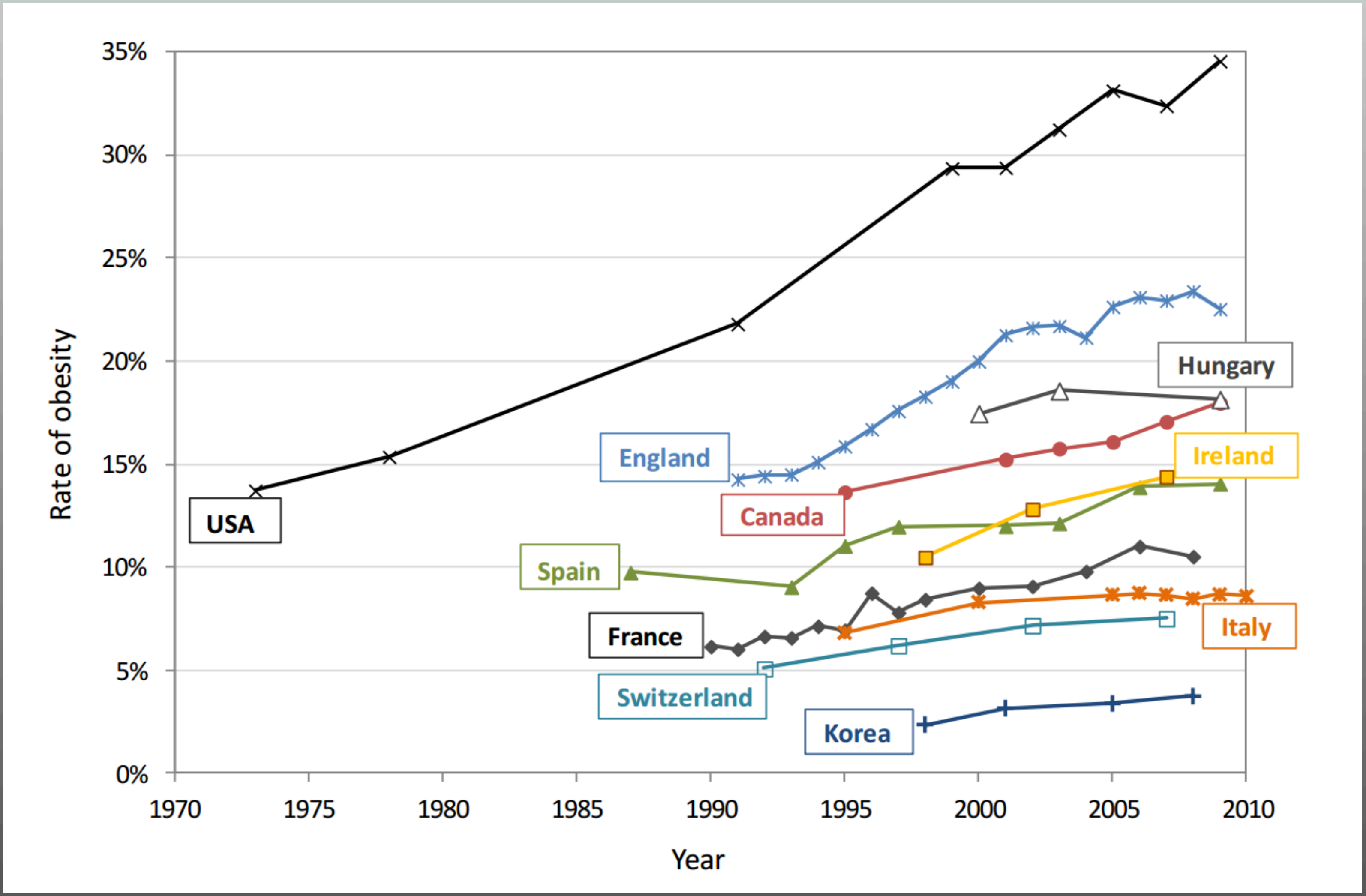
Computer simulation of ‘elderly’/mixed ability

- Well-defined demographic speeds
    - (IMO Misc 1038 population)
- Simulations showed IMO ‘elderly’ flows = 34% less

Also note, the reverse effect: higher flows observed for very fit, healthy adults (army tests) much higher than average.

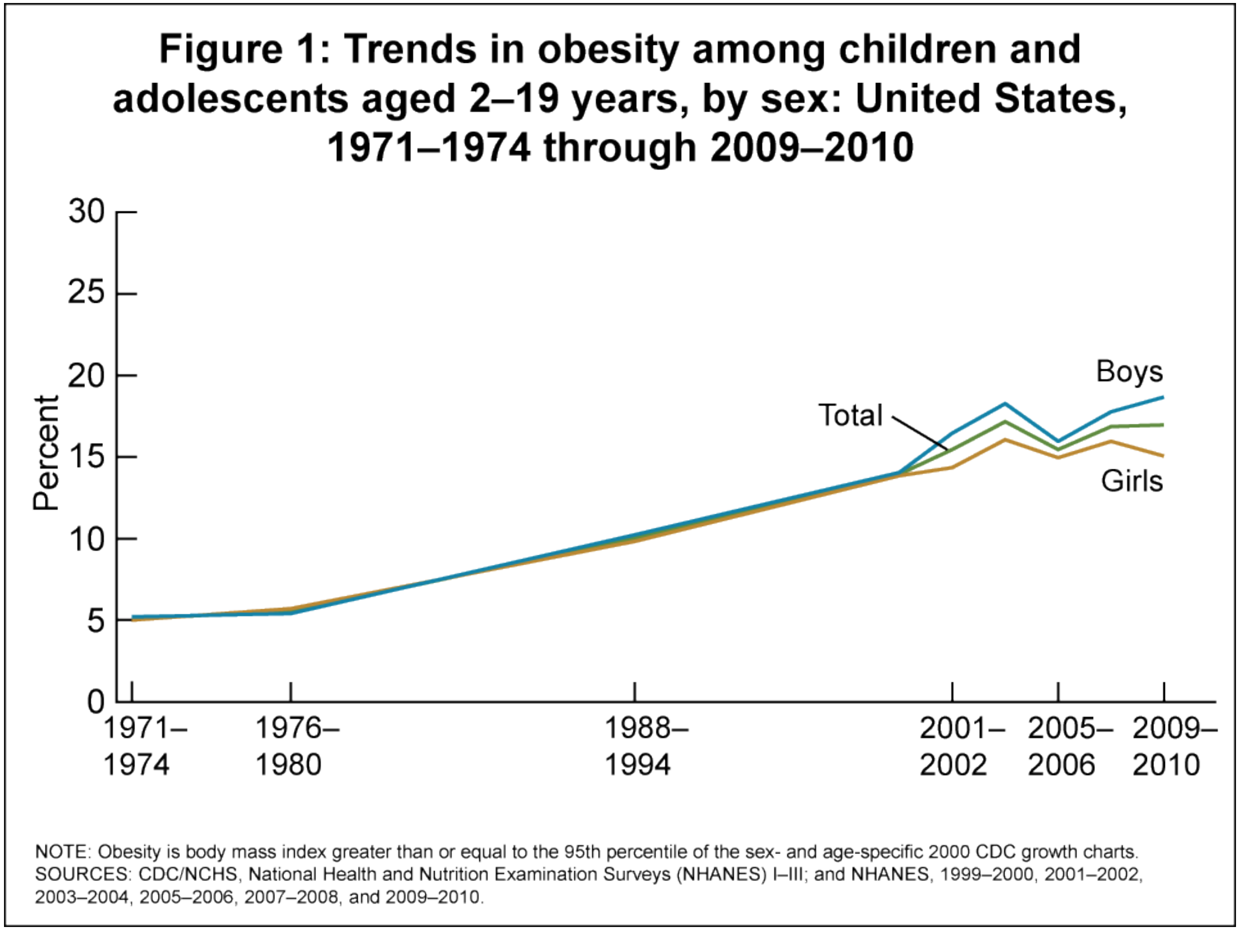
Mathematically: estimate ‘elderly’ flows 20 – 34% lower

Bigger waistlines and obesity: so far…



Adult obesity rates have risen in all countries. *OECD 2012

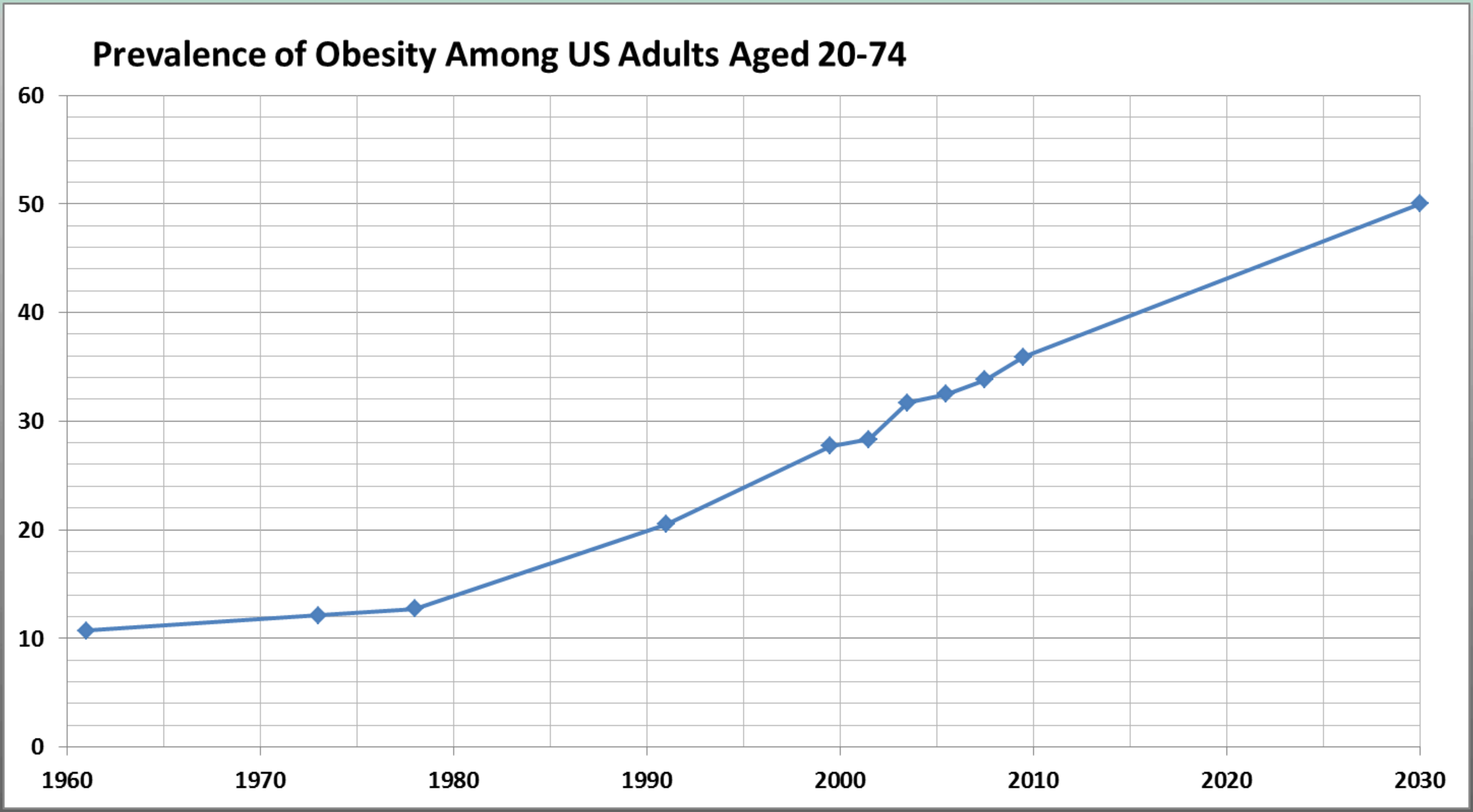
Obesity among US children so far…



Child obesity rate has more than trebled over forty years

Source: US Centre for Disease Control and Prevention (Sept. 2012)

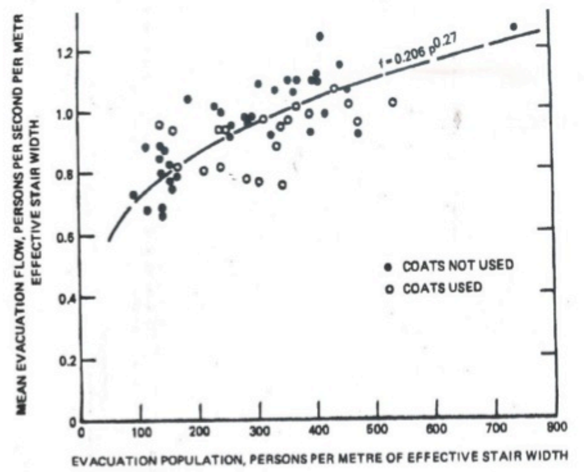
Obesity among US adults 1960 - 2030



Half of US adults are predicted to be ‘obese’ by 2030…

Source: Robert Wood Johnson Foundation and the Trust for America's Health “F as in Fat”

Bigger bodies = lower 'people' flows



(Pauls Fig 3-13.4, SFPE Handbook)

SFPE Handbook – Jake Pauls

Evacuation flow is affected by clothing…

~ 10 - 30% lower flow with coats on (p/m/s)

Also ref. Simulex SFV 'lifejacket' simulations (larger torso only) produced 12.5% lower flow

Predtechenskii & Millinskii (1969)

'Flow' = m^2(occupied space)/m^2(total space)
Flow is therefore related to body size.
Adult (summer)= $0.1m^2$, (winter)= $0.125m^2$
… = 25% lower flow in winter clothing (p/m/s)
… and higher flow for children

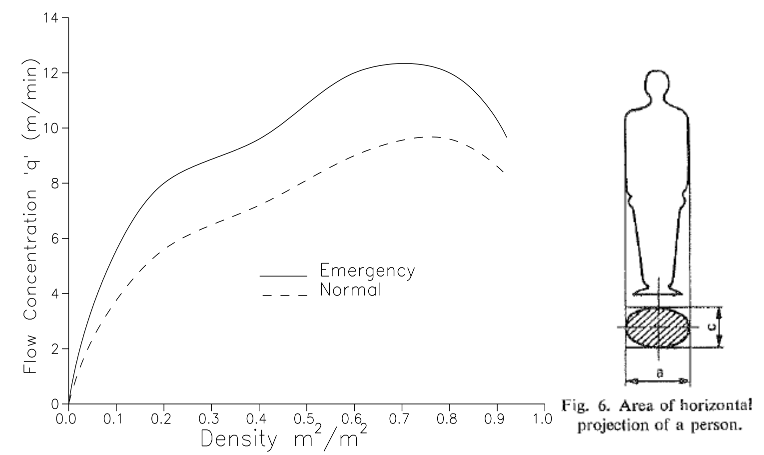
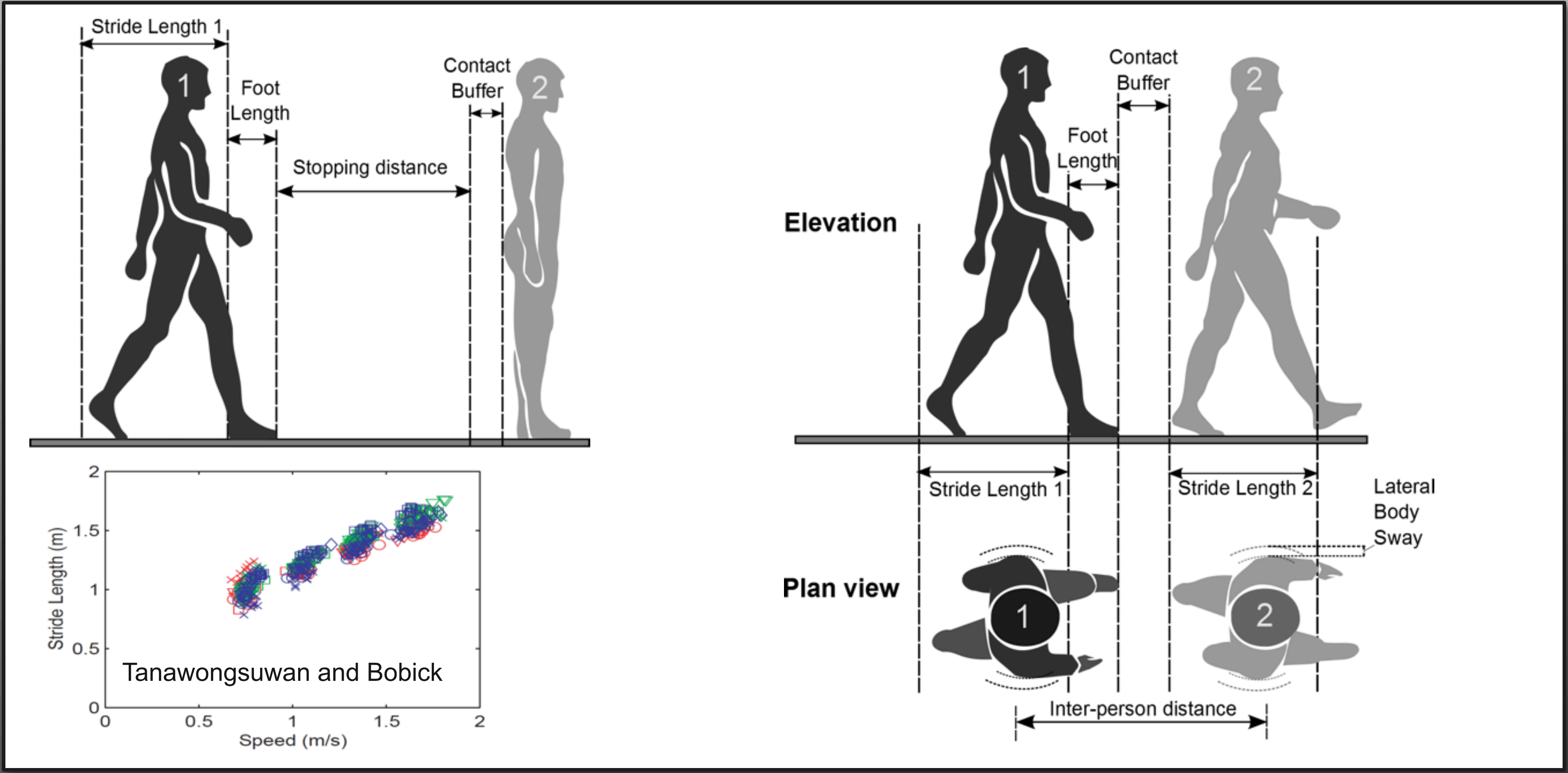


Fig. 6. Area of horizontal projection of a person.

Mathematically: estimate 'obese' flows 25% lower

Speed, step-length, biomechanics

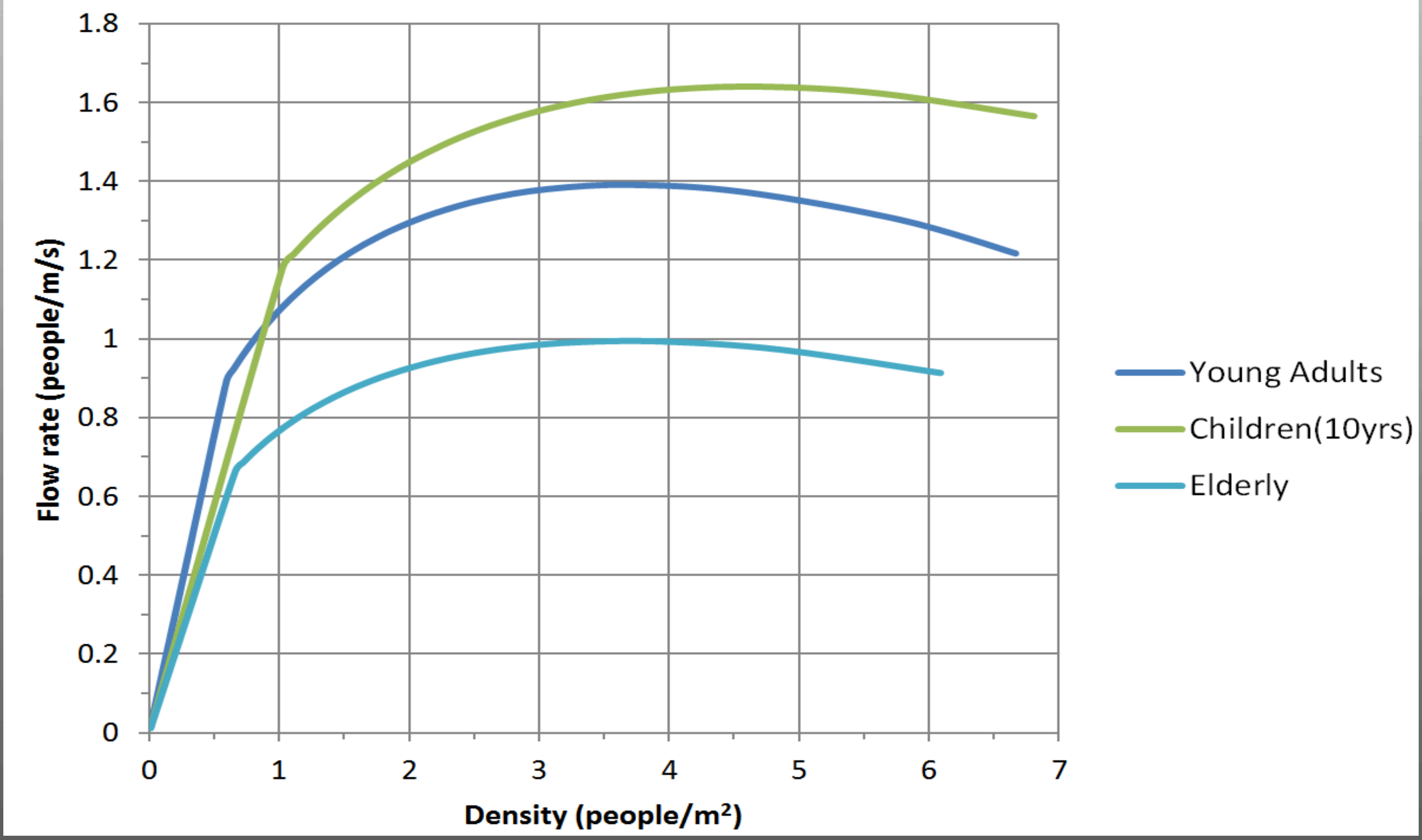
- Developing new theory of biomechanics for crowd flow
- Can be used to predict safety implications for demographic change



✓ Collaboration (Universities): Lund, Ulster, Dublin (University College) Institute for Sport and Health

Relating biomechanics to flow

Using step-length, walking speed, response time, etc…



From first principles: elderly characteristics = lower flow

What about the smoke?

The Fractional Effective Dose Model (Purser)
How is it affected by demographics ?
Unclear, but elderly & infirm likely to be more heavily affected

Also consider pre-movement time, response to alarm & smoke etc…

… so how does this affect design?

Population trends

Elderly: we might estimate >= 20% lower flow rates
Obesity: trends to 2050… estimate 25% lower flow.
(not yet an exact science)

Implications for flow

Standard models / maths:

- Compare to base flow: 0.8 x 0.75 = 0.60
- The compound effect could be **40% lower flows**

Computer model:

- Simulex = **34% lower flows (**elderly), 12.5% lower for larger torso.

In populations which are ageing/obesity-dominated, flows could be 30 - 40% less, so calculations should be adjusted…

Summary (-40yrs / Now / +40yrs)

1974: Data & Hand-calcs:

Bulk of data collected for modern analyses

Hand-calcs for general design

2014: Advanced computing + population bigger, older

Highly sophisticated 3D visualisation of models

Data & algorithms not in-step with population trends

Indications: we need new data & **bigger doors soon**

2054: Cloud computing + bigger, older population

Increasing computing power, waistlines & age

Computer models need:

- Better algorithms, demographics data

Questions

- Thank you… Questions ?