CERN

DGS/SEE Seminar on Fire Protection for Physics Research Facilities

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CERN

A simplified approach to evacuation modelling in research facilities at CERN

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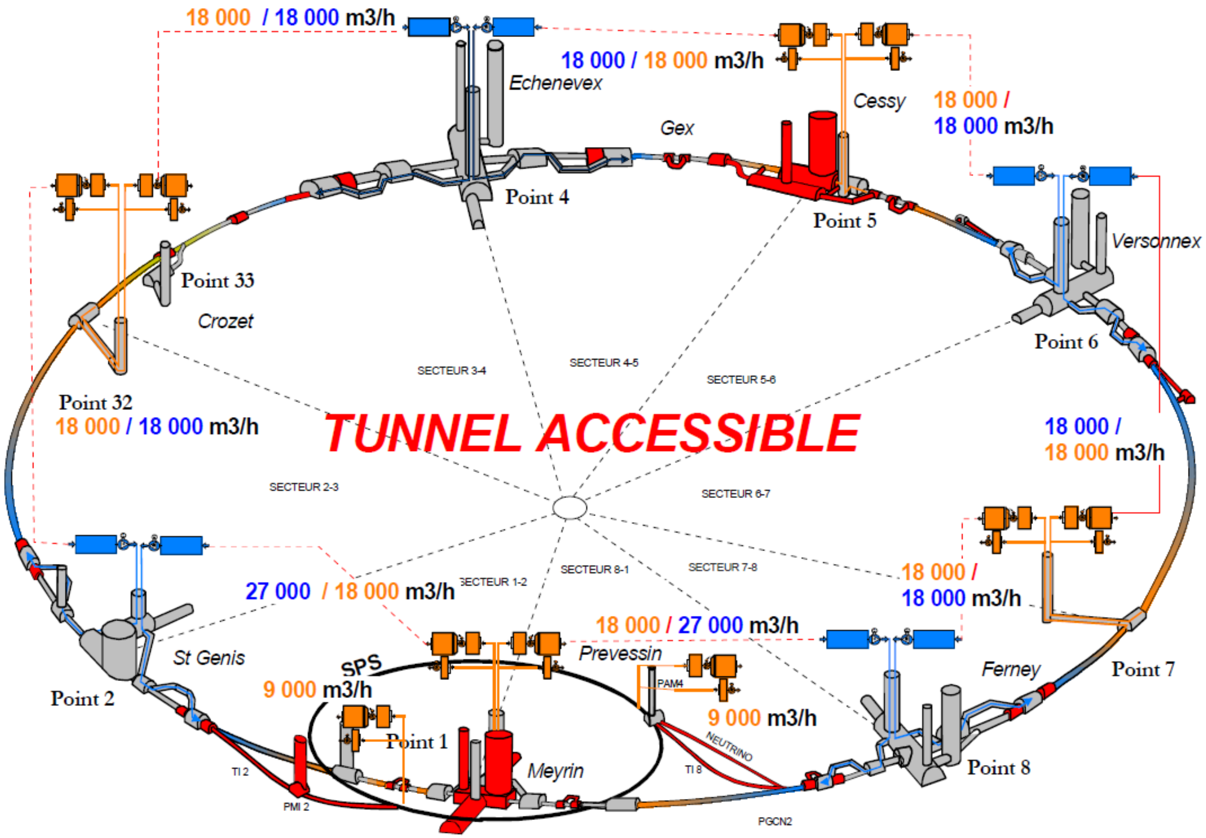
LS1 and definition of maximum occupancy

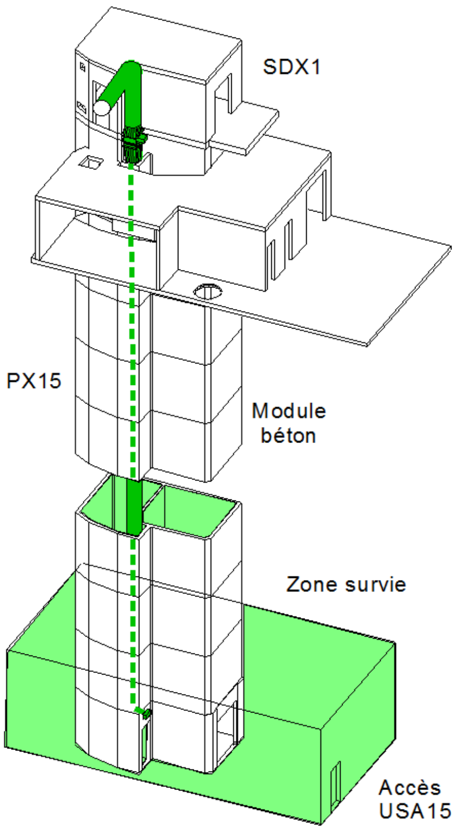
- The first long shutdown of LHC (LS1) had a very busy schedule to carry out a large number of works keeping the downtime as short as possible.
- Maximum number of occupants allowed in the different LHC zones had to be defined.
- Existing approach, dating back to 2002, was revised for this occasion.

LHC air management

In the LHC, fresh air is injected in even points while vitiated air is extracted at odd points.

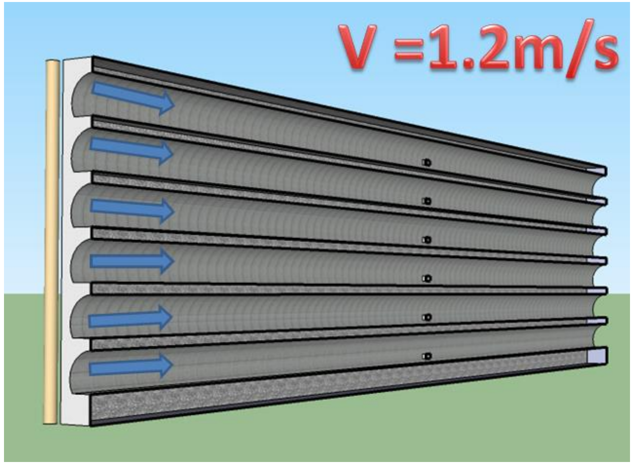
Pressurized safe zones are located at the bottom of the shafts. Staircases are pressurised as well.

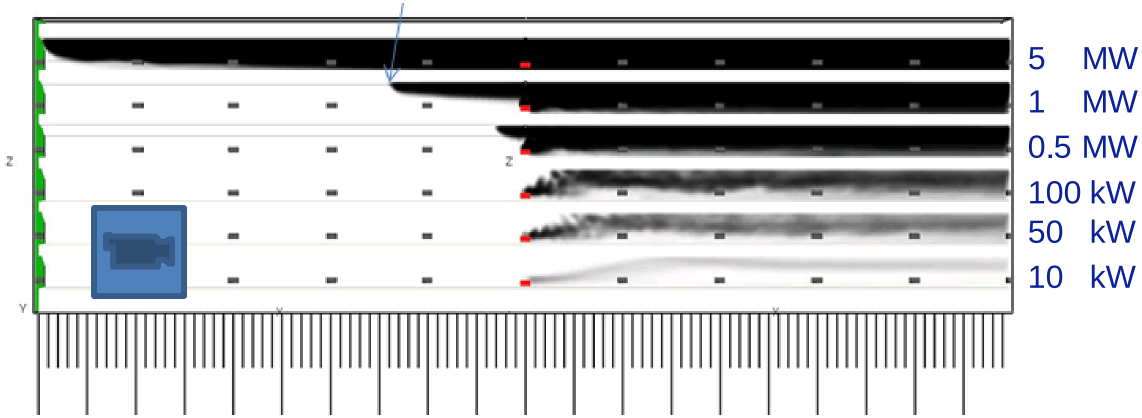




In the LHC, the evacuation takes place through the lifts

Characterization of fire hazard in tunnels

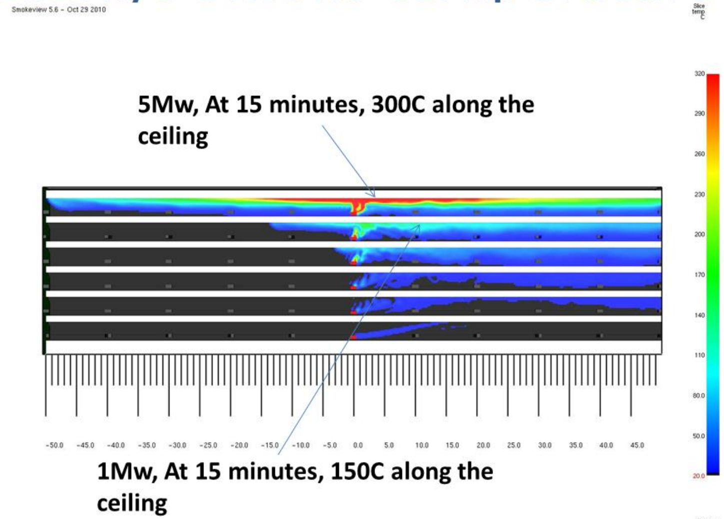




Main results

- Back layering reaches an equilibrium distance;
- Stratification downstream is lost very early;
- Air velocity downstream slows down to ventilation speed ;
- Gas temperature reaches a maximum of almost 300 °C (5 MW fire), but after 200 m it goes down to ≈ 50 °C;
- Decrease of visibility to almost zero in smokes;
- O_2 concentration down to 16.5 % and CO_2 up to 3.2% (5 MW fire).

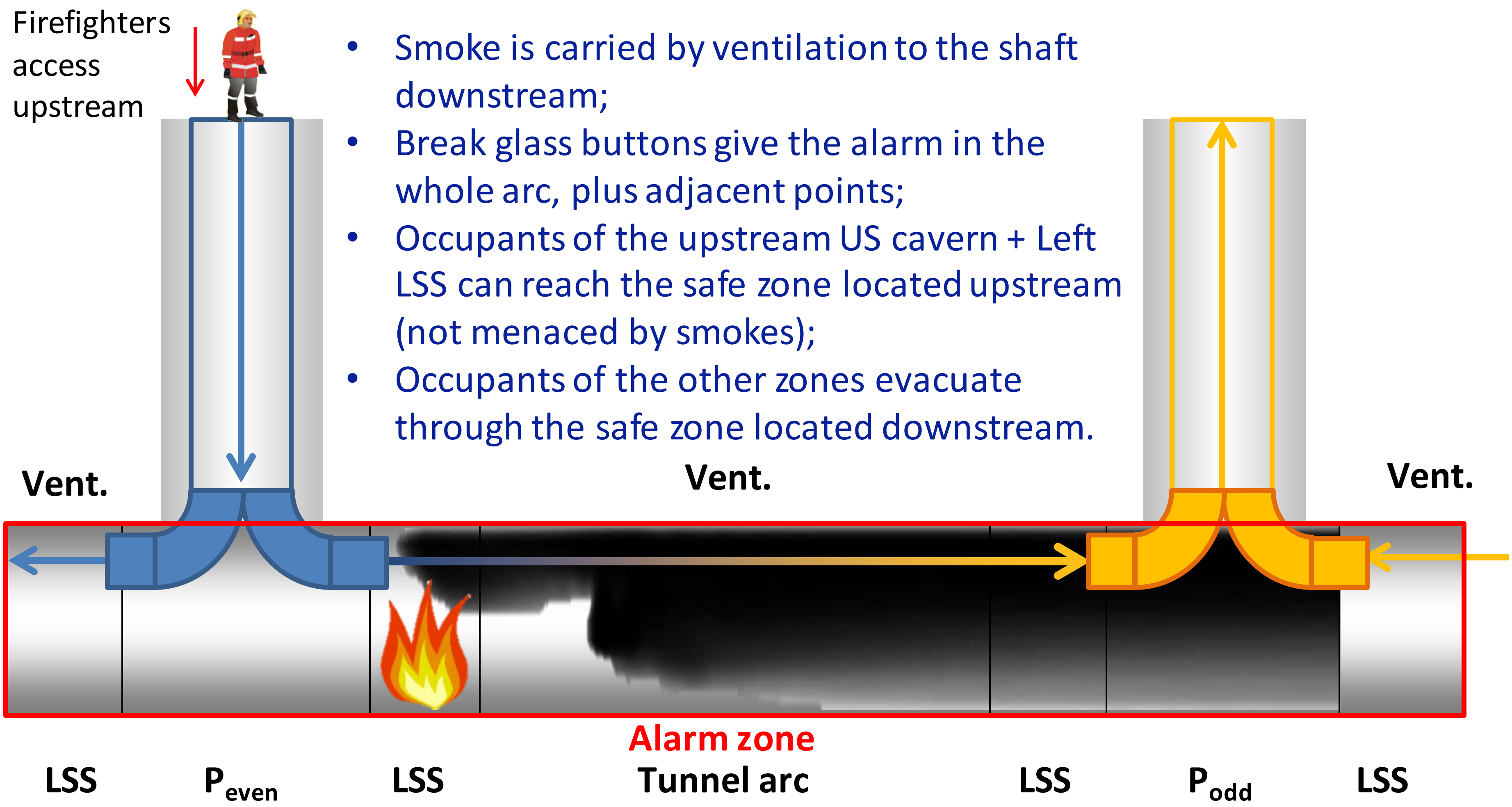
1.2m/s Smoke temperature



All pictures from the presentation by F. Corsanego EDMS 1236477 ver.1

Worst-case scenario: fire in the upstream LSS

- Smoke is carried by ventilation to the shaft downstream;
- Break glass buttons give the alarm in the whole arc, plus adjacent points;
- Occupants of the upstream US cavern + Left LSS can reach the safe zone located upstream (not menaced by smokes);
- Occupants of the other zones evacuate through the safe zone located downstream.



Simplified (Excel) model based on a balance equation

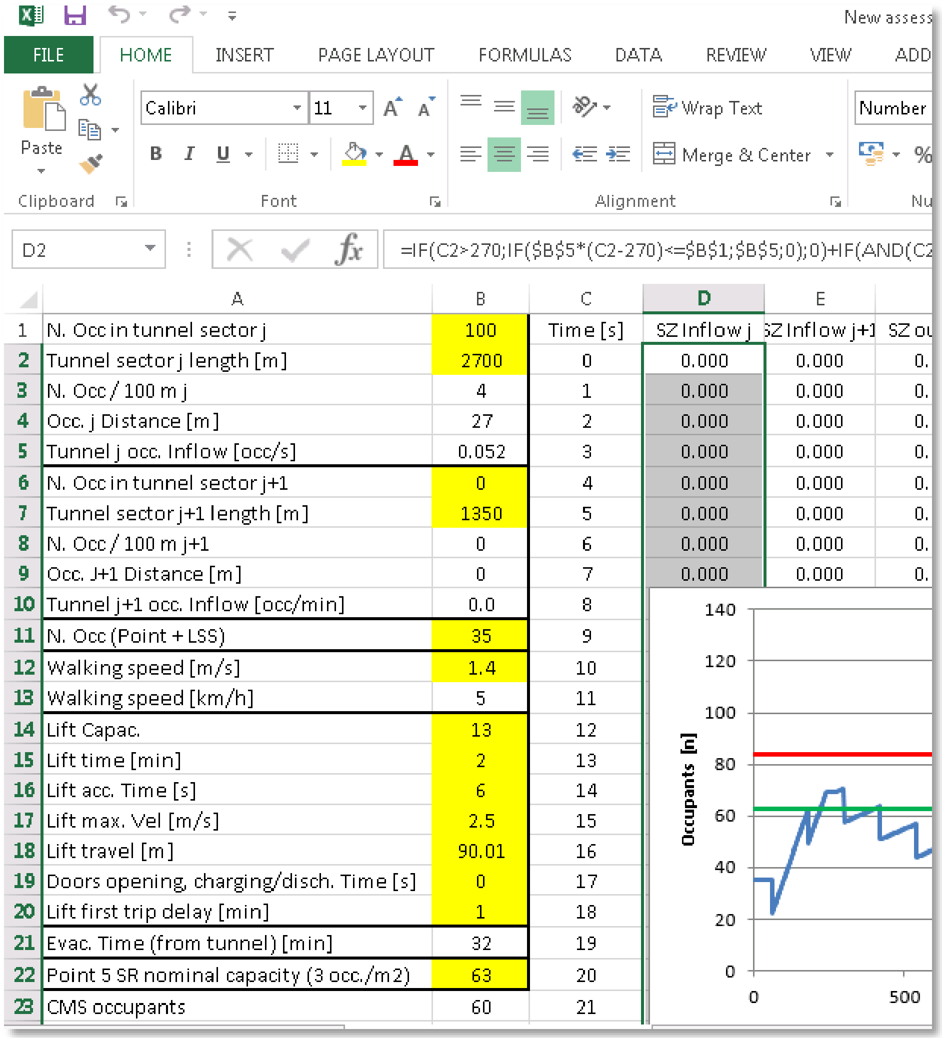
At the end of time step i+1, the number of occupants inside the safe zone is calculated considering that:

$$n^{i+1} = n^{i} + n_{in}{}^{i+1} - n_{out}{}^{i+1}$$

The inflow is the sum of occupants coming from the:

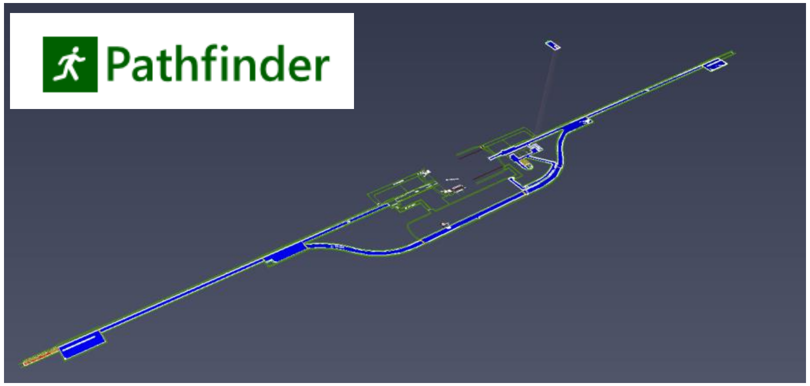
- tunnel arc and
- experimental caverns.

The outflow is calculated taking into account the lifts characteristics (capacity and time required for a round trip).



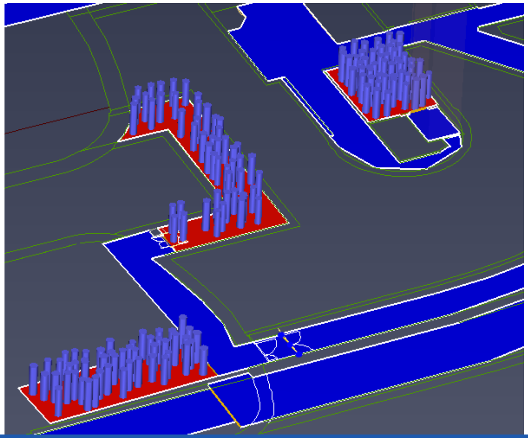
	A	B	C	D	E	
1	N. Occ in tunnel sector j	100	Time [s]	SZ Inflow j	SZ Inflow j+1	SZ ou
2	Tunnel sector j length [m]	2700	0	0.000	0.000	0.
3	N. Occ / 100 m j	4	1	0.000	0.000	0.
4	Occ. j Distance [m]	27	2	0.000	0.000	0.
5	Tunnel j occ. Inflow [occ/s]	0.052	3	0.000	0.000	0.
6	N. Occ in tunnel sector j+1	0	4	0.000	0.000	0.
7	Tunnel sector j+1 length [m]	1350	5	0.000	0.000	0.
8	N. Occ / 100 m j+1	0	6	0.000	0.000	0.
9	Occ. J+1 Distance [m]	0	7	0.000	0.000	0.
10	Tunnel j+1 occ. Inflow [occ/min]	0.0	8			
11	N. Occ (Point + LSS)	35	9			
12	Walking speed [m/s]	1.4	10			
13	Walking speed [km/h]	5	11			
14	Lift Capac.	13	12			
15	Lift time [min]	2	13			
16	Lift acc. Time [s]	6	14			
17	Lift max. Vel [m/s]	2.5	15			
18	Lift travel [m]	90.01	16			
19	Doors opening, charging/disch. Time [s]	0	17			
20	Lift first trip delay [min]	1	18			
21	Evac. Time (from tunnel) [min]	32	19			
22	Point 5 SR nominal capacity (3 occ./m2)	63	20			
23	CMS occupants	60	21			

Advanced avatar-based evacuation model (Pathfinder)

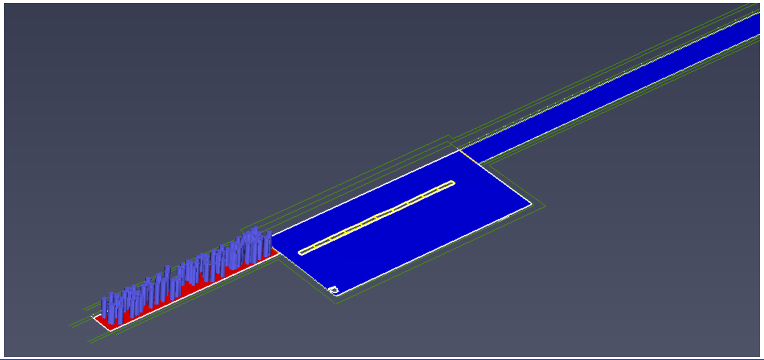


Bypass, Long Straight Sections and CMS experiment model

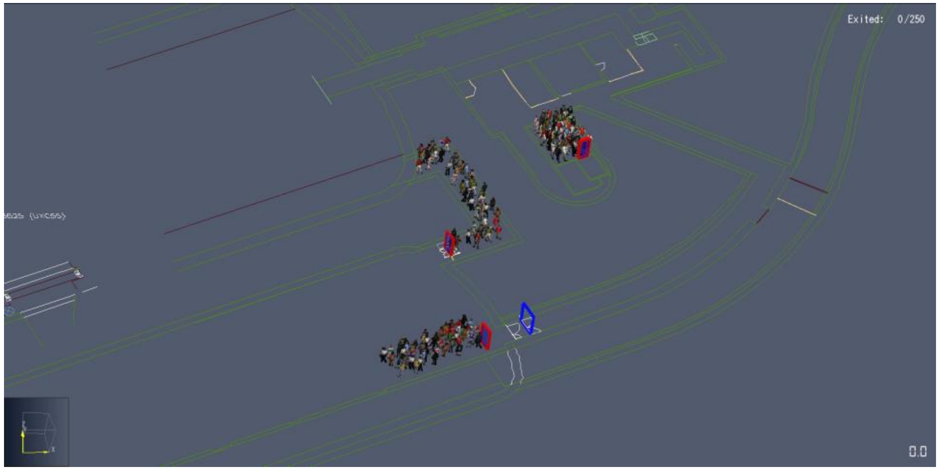
50 occ. UJ56 + 100 occ. CMS (50 from UXC [60-120] s and 50 from USC [180-240] s



100 occupants tunnel sector, door flow limited at 3.1 pers/min

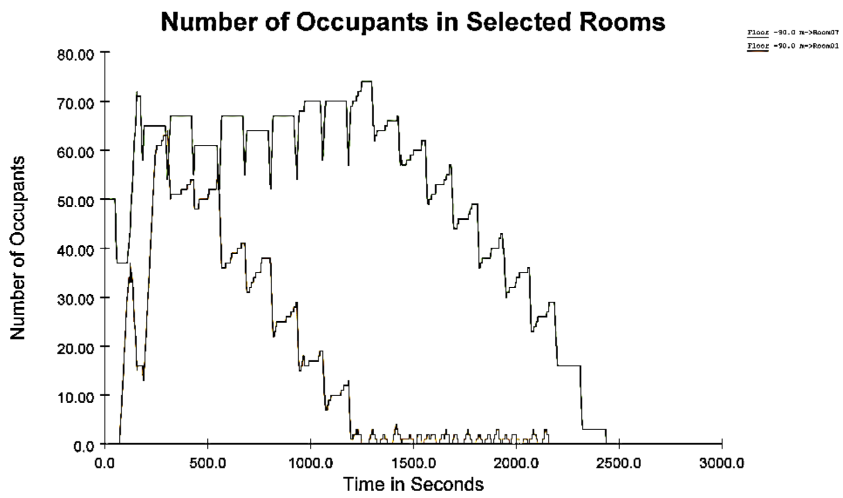


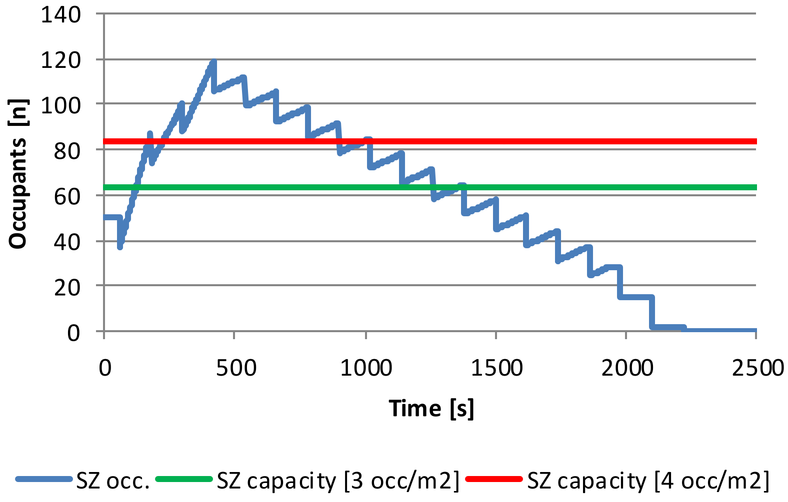
Comparison: Avatar-based vs simplified models



Key results

- Maximum occupancy of US 56: **74 persons => 3.5 occ/m²**
- Max n. Of people waiting outside the safe zone: 64
- As expected, occ. density does not increase indefinitely in the avatar-based model





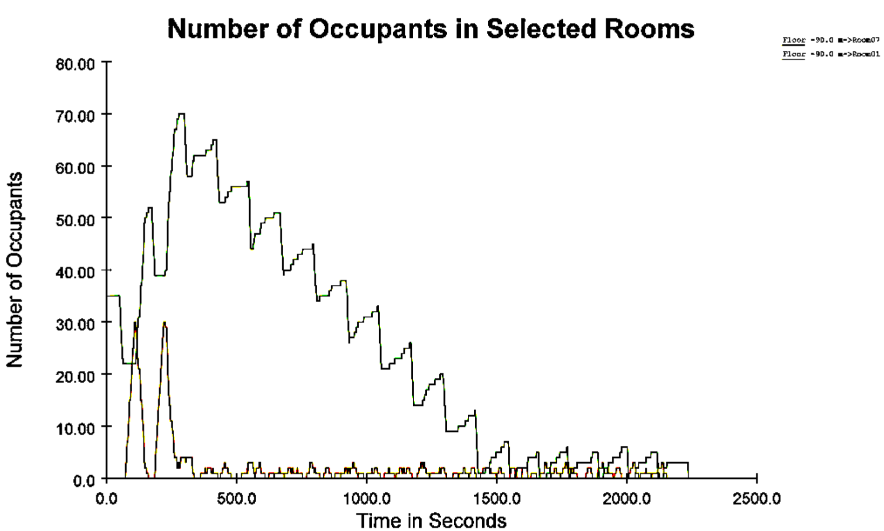
CMS: Proposal of occupants reduction (PM54 lift unavailable)

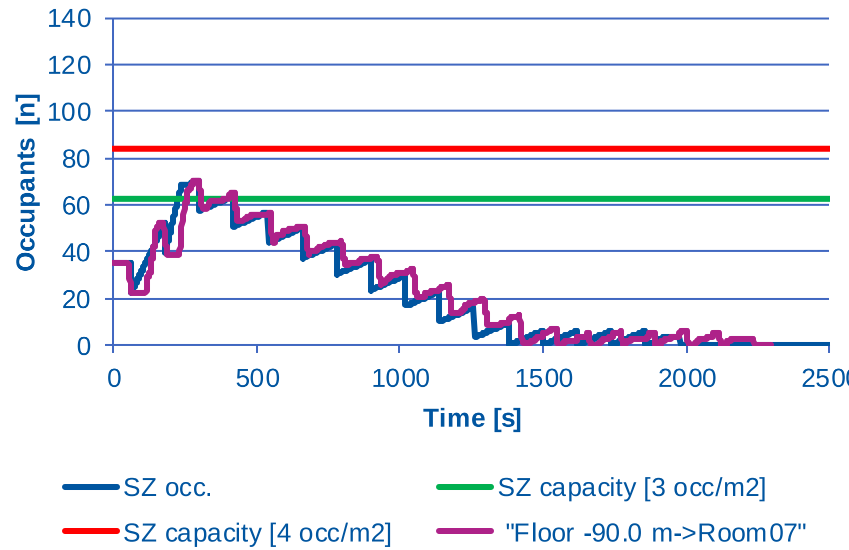
N. Occ in tunnel sector j	100
Tunnel sector j length [m]	2700
N. Occ / 100 m j	4
Occ. j Distance [m]	27
Tunnel j occ. Inflow [occ/s]	0.052
N. Occ in tunnel sector j+1	0
Tunnel sector j+1 length [m]	1350
N. Occ / 100 m j+1	0
Occ. J+1 Distance [m]	0
Tunnel j+1 occ. Inflow [occ/min]	0.0
N. Occ (Point + LSS)	35
Walking speed [m/s]	1.4
Walking speed [km/h]	5

Lift Capac.	13
Lift time [min]	2
Lift acc. Time [s]	6
Lift max. Vel [m/s]	2.5
Lift travel [m]	90.01
Doors opening, charging/disch. Time [s]	0
Lift first trip delay [min]	1
Evac. Time (from tunnel) [min]	32
Point 5 SR nominal capacity (3 occ./m2)	63
CMS occupants (x2)	30
Start time [s]	60
Duration [s]	120
Start time [s]	180
Duration [s]	60

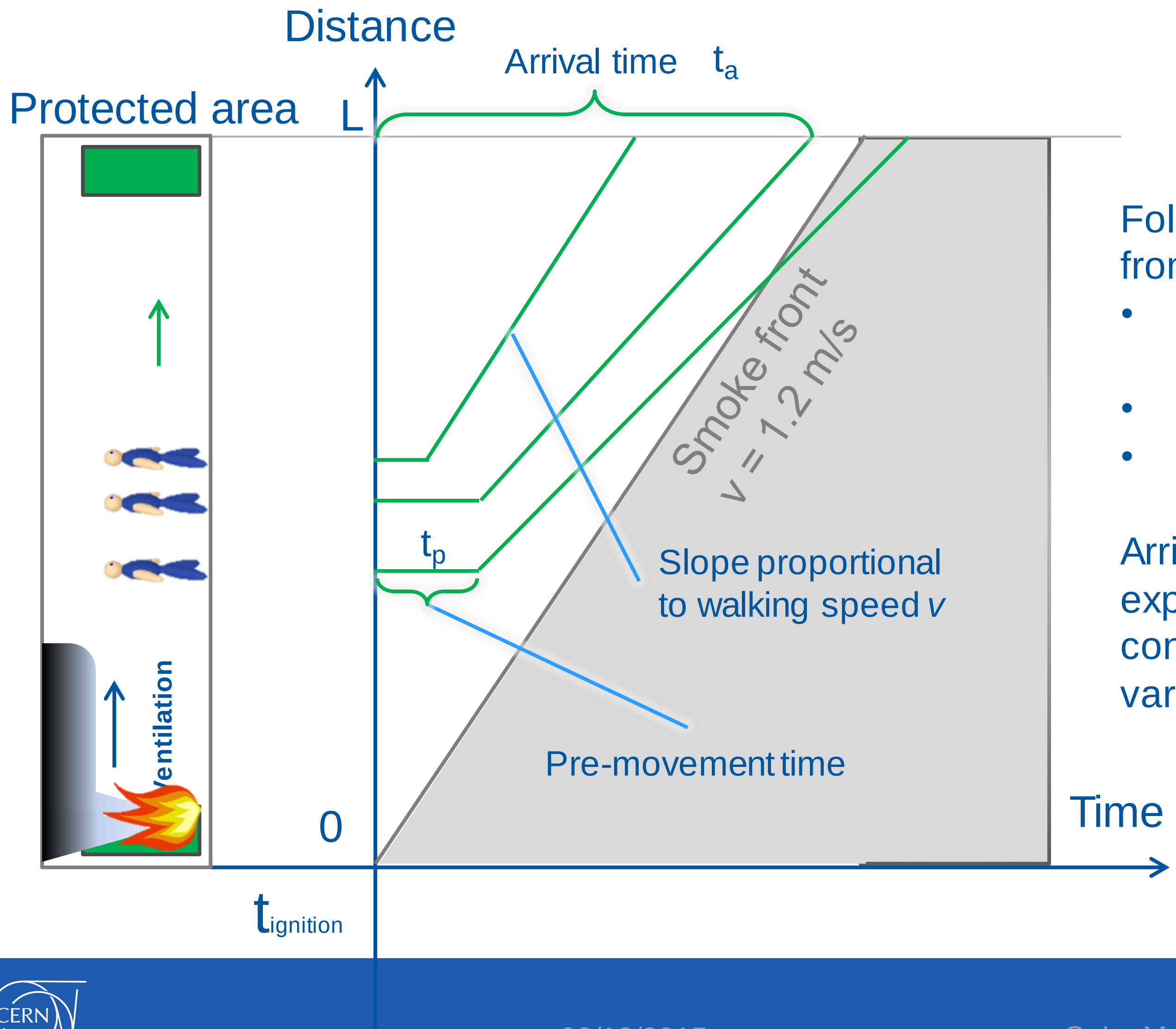
In case of unavailability of the PM 54 lift, a reduction of the occupants number is necessary.

Occupants machine side: 35
Occupants of the experiment: 60





A Monte Carlo approach to refine the simplified model
Basic kinematics



Following assumptions improved from Excel model:

- Occupants no more equally spaced along tunnel;
- Variable pre-movement time
- Variable walking speed.

Arrival time of occupants from experiment can also be considered as a stochastic variable

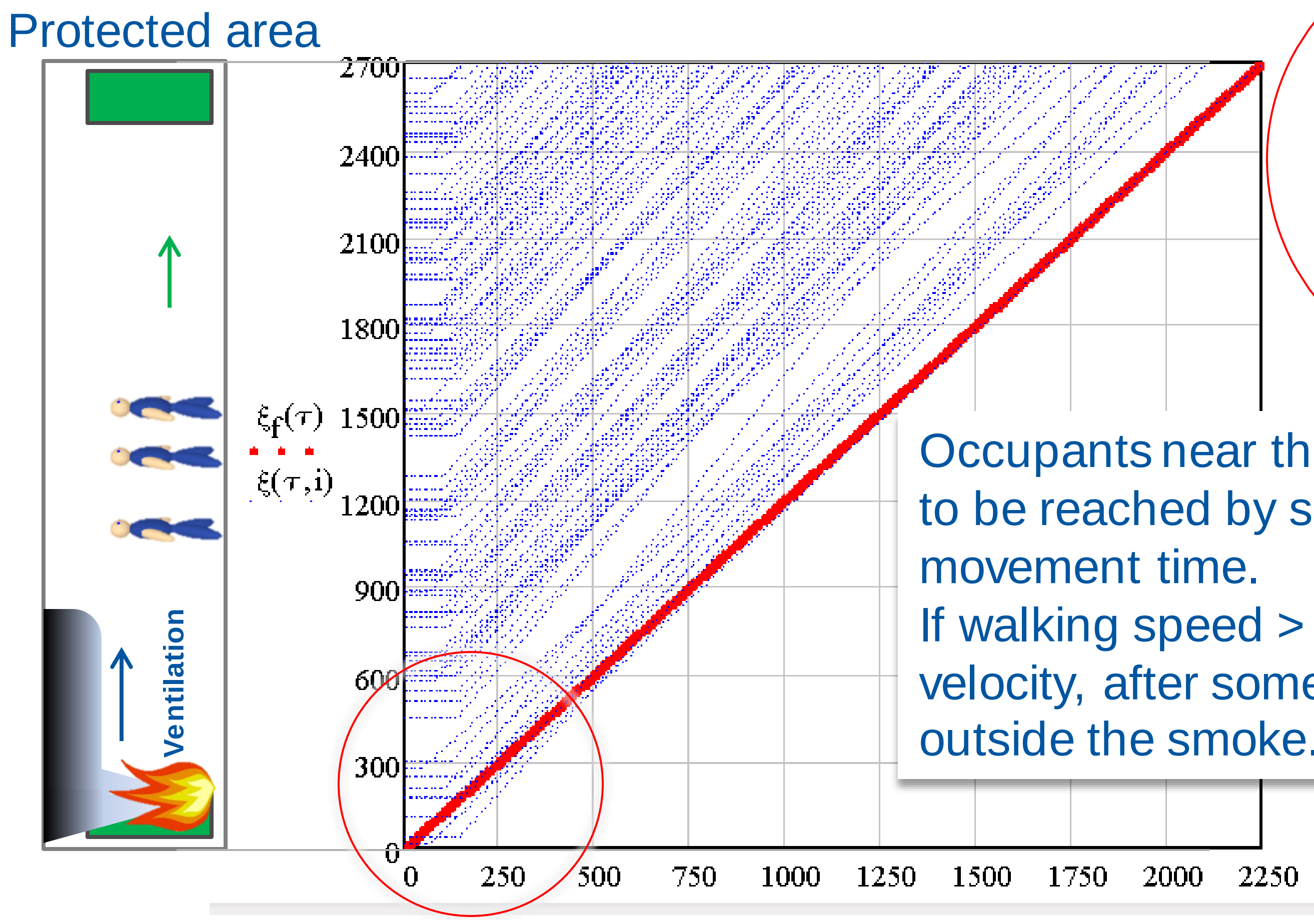
A Monte Carlo approach to refine the simplified model
Assumptions for stochastic input variables

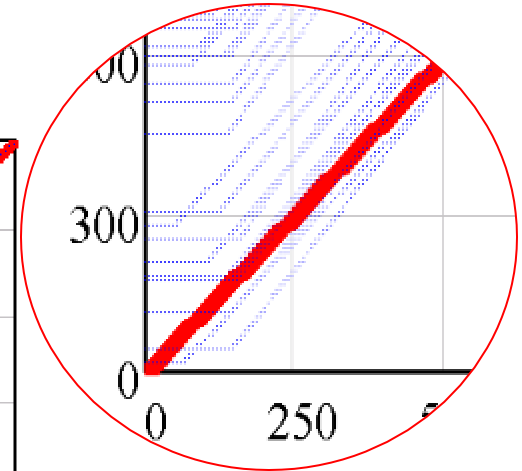
$$t_a = t_p + \frac{L - x}{v}$$

Symbol	Quantity	PDF.	μ	CV (σ/μ)	Lower Limit	Upper Limit
t_p	Pre-movement time	Normal	60 / 0 s	0.3	0	h
x	Initial position	Uniform	$L/2$	$L^2/12$	0	L
V	Walking speed	Normal	1.4 m/s	0.1	1.0	1.8
L	Length of tunnel arc	Deterministic L = 2700 m				

t_a is the arrival time to the safe zone of the *i*-th occupant

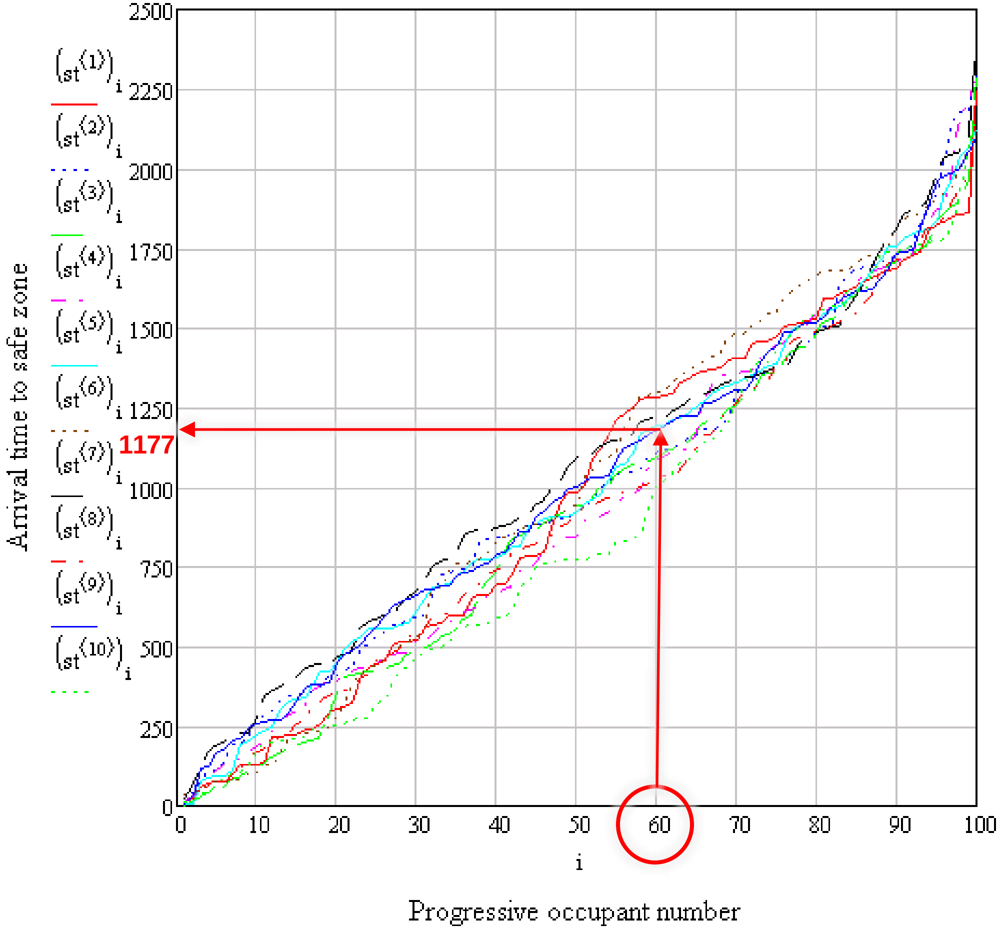
Motion of occupants vs time for a given MC simulation





Occupants near the fire are most likely to be reached by smoke during pre-movement time.
If walking speed > smoke propagation velocity, after some time they walk outside the smoke.

Arrival times of occupants to safe zone



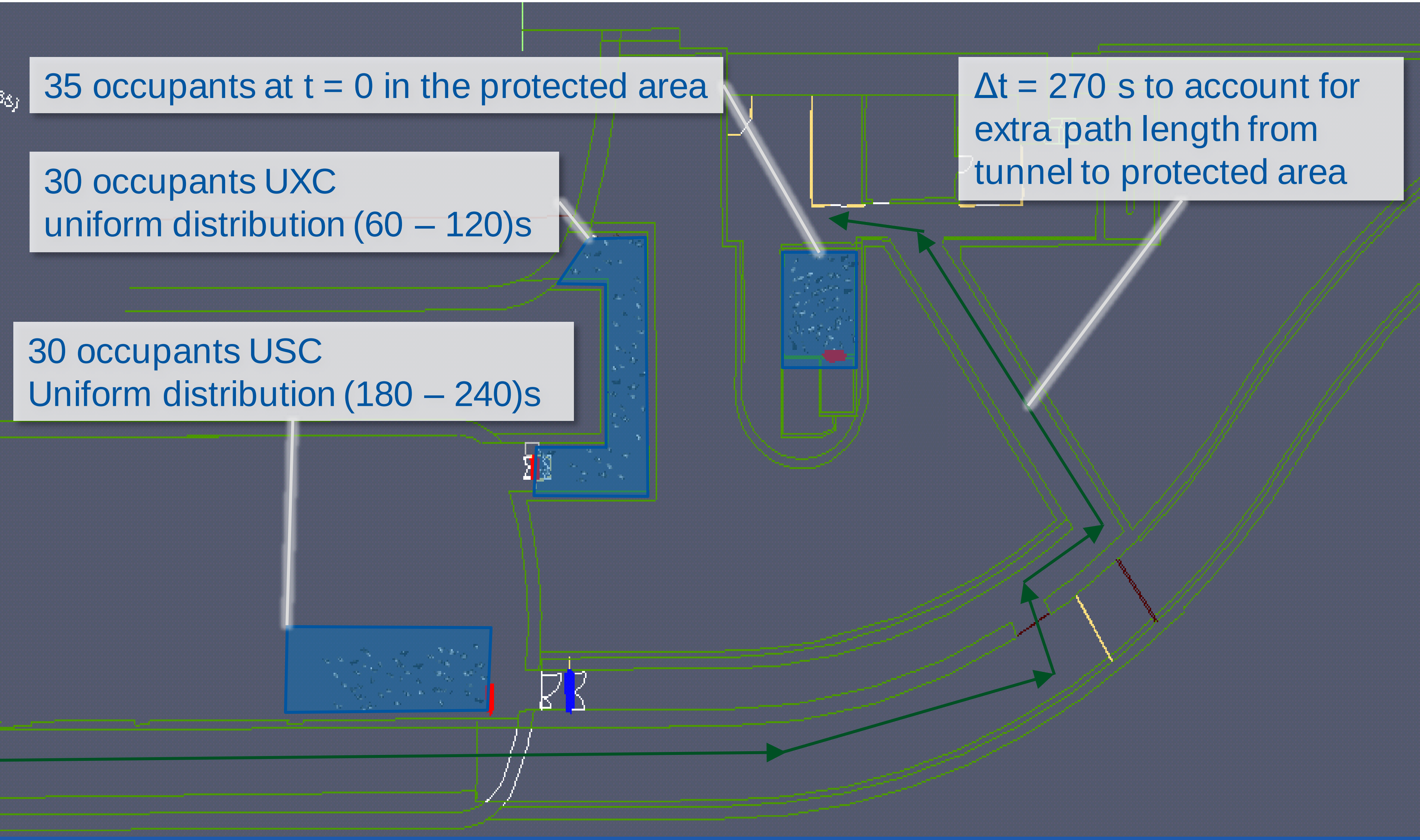
- 100 occupants assumed in the tunnel arc;
- 200 MC simulations (first 10 curves shown)

For example:
The sixtieth occupant

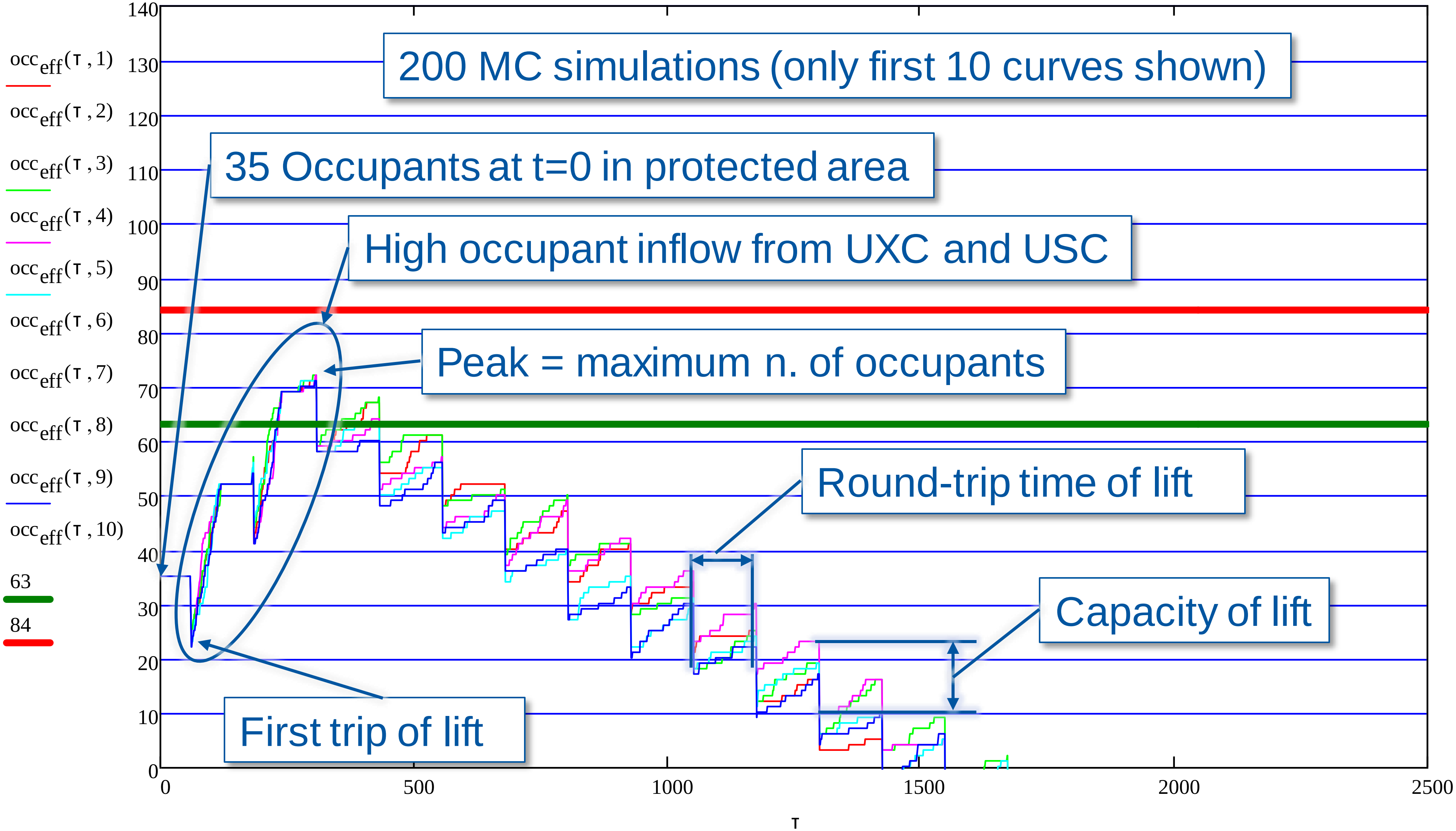
in simulation n. 9

enters the safe zone at t = 1177 s

Additional assumptions



Occupants in protected area vs time

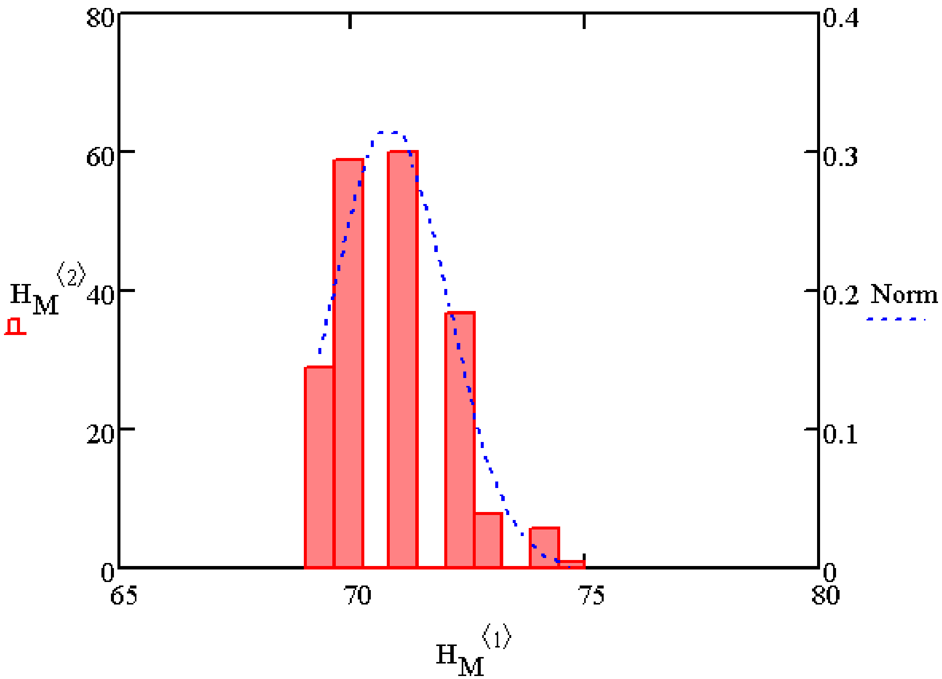


Histogram and fitting for n_{max}

Considering n_{max} as a stochastic variable we can calculate over the 200 MC simulations:

- mean value $\mu = 70.79$;
- standard deviation $\sigma = 1.235$ (CV = 0.017)

and fit the histogram to a normal distribution.

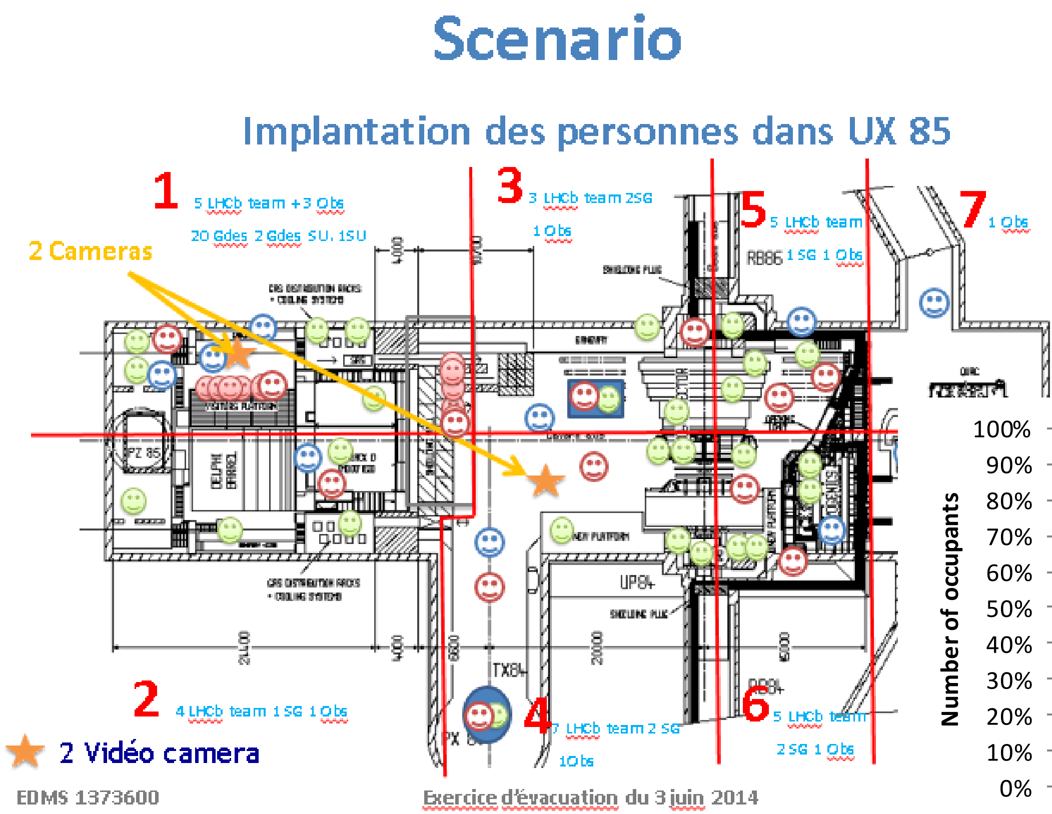


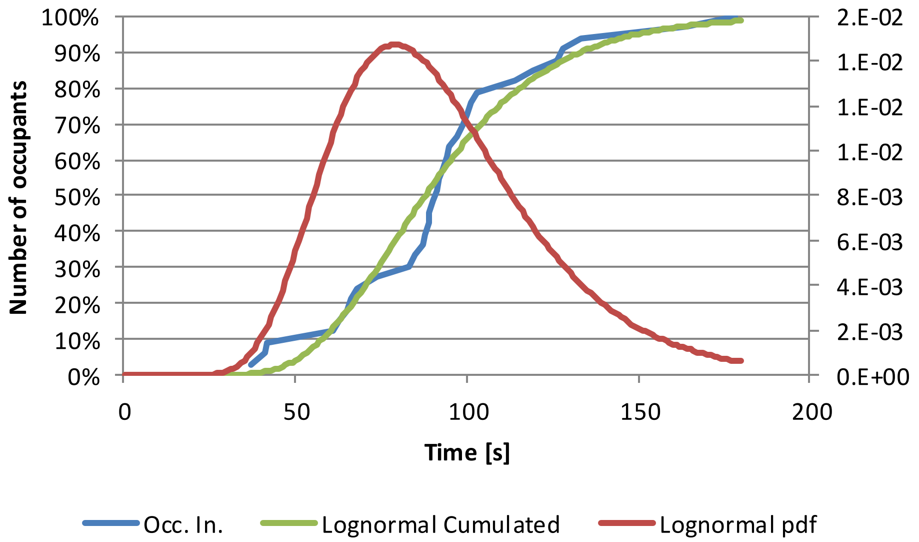
If we fix an exceedance probability (e.g. 1%) we can calculate the n_{max} at 99% as:

$$n_{max,99\%} = \Phi^{-1}(0.99) = 74$$

Where Φ^{-1} is the inverse cumulative normal distribution.

Further improvement:
defining arrival time of experiments from fire drills data



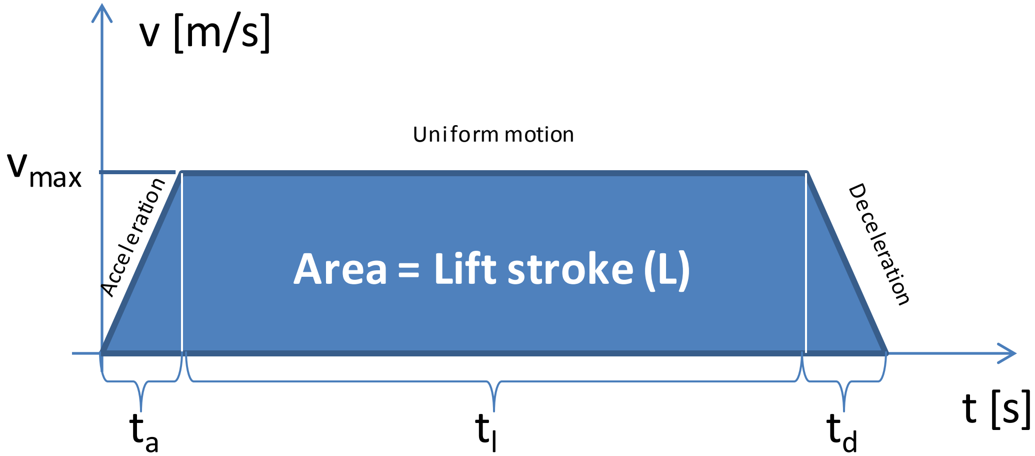


Scénario exercice d'évacuation
UX 85 LHCb EDMS 1373600

Questions?

Thank you for your attention!

Lift round trip travel calculation



$$t_a = t_d$$

$$L = \frac{[(2t_a + t_l) + t_l]v_{max}}{2} = (t_a + t_l)v_{max}$$

$$t_l = \frac{L}{v_{max}} - t_a$$

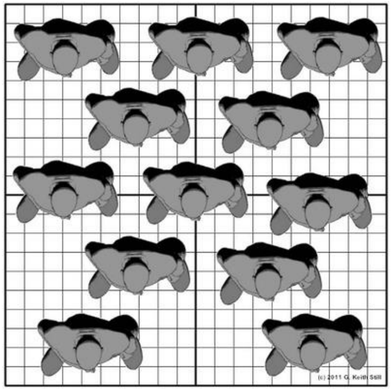
$$t_{travel} = 2t_a + t_l = \frac{L}{v_{max}} + t_a$$

t_c charge (discharge) time: doors opening, charging (discharging), doors closing

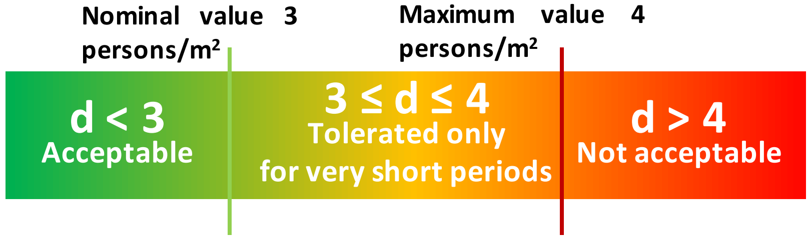
$$t_{round\ trip} = 2(t_{travel} + t_c)$$

Lift	Capacity [n. occ.]	L [m]	v_{max} [m/s]	$t_{a,d}$ [s]	t_{travel} [s]	t_c [s]	$t_{round\ trip}$ [s]
PM56	13	90.01	2.5	6	84	20	124

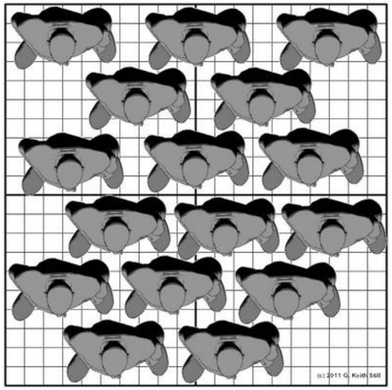
Maximum admissible crowding in safe zones



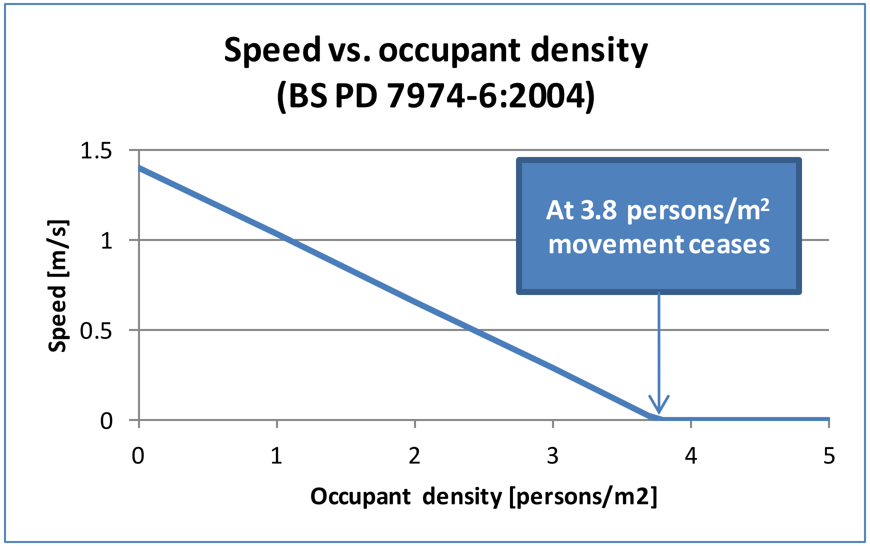
3 persons/m²



Art. L 3 of the ERP regulation fixes a maximum crowding of 3 persons/m² for people attending an event in a room without chairs or benches.



4 persons/m²



Point	Underground zone	Nominal max occupants n. (3 pp/m²)
5	US56	**63**

From the study "LHC Evacuation Assessment for LS1", EDMS 1246565