Uncoordinated Egress
An Experiment

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Abstract. People fleeing from an overcrowded fire scene may delay their own escape by obstructing the emergency exit by themselves. In a controlled environment free of obstacle, evacuation experiments were performed where firefighters trainees had to escape through a single door with a 1.12 meter span, varying the crowd density. In the filming, besides the formation of supporting arches where people get stuck to each other and against the walls, it was observed turbulence, characterized by random and involuntary movements of people within the crowd. The simulation model proposed by Helbing, Farkas and Vicsek (2000) was validated with experimental data and then used to investigate the relationship between door size and evacuation time.

1. INTRODUCTION

On 27th January 2013, a fire at the nightclub Kiss caused the death of 242 people in Santa Maria, Brazil [6]. Investigators [6], [7] concluded that the fire was caused by use of flare stick whose sparks burned the flammable sound insulation foam (polyurethane made). In a few seconds, black and toxic smoke spread throughout the nightclub, causing many people to faint. Others did strive towards the doors (1.75m and 1.6m), which were only one meter far from each other. The crowd rapidly blocked those exits, and firefighters and volunteers tried to open an alternative mean of escape on the wall by using a sledgehammer. The Kiss tragedy alerted Brazilian authorities that the fire safety codes must be improved.

As units of the Brazilian federation, each state, through its fire department, is responsible to define the fire safety code and assure its application. For example, less than two years after Kiss, Santa Catarina Military Fire Department (CBMSC), launched a new fire safety code (known as Normative Instructions or INs), being more explicit in prohibiting the use of any type of fireworks and flammable foam in closed rooms. However, defining the size and number of terminal emergency exit, being both safe and cost-effective is not as simple as setting another article in a code. CBMSC made an experiment in order to analyze what happens during an uncoordinated egress like the one that took place at Kiss.

As part of a monograph of CBMSC's Military Academy, an experiment was done to analyze what happens inside the crowd during an uncoordinated egress like the one that took place at Kiss. This paper presents some of those results, such as exit blockages, crowd turbulence, egress time and egress flow. The variable utilized was crowd density, varying it from 0.5 to 4.0 individuals per square meter. Lastly, a computer model was validated with the experiment's results and used to evaluate the Normative Instructions Nr 09 (IN 09), specifically regarding evacuation capability through doors at the ground floor of nightclubs and similar.

2. UNCOORDINATED EGRESS

Evacuation capability is the ability of occupants, residents, and staff as a group either to evacuate a building or to relocate from the point of occupancy to a point of safety [5]. An evacuation process could be: a) coordinated, when people leaves the place in an ordered queue, constant flow without rush; or b) uncoordinated, when everyone rush for the exit, pressing others ahead, the flow become nonlinear with stops and goes, either with or without mass panic. Based on literature review and empirical research, Helbing et al. [2] lists the events that can occur during an emergency evacuation, right after the identification of the threat, as: (1) people move or try to move considerably faster than normal; (2) individuals start pushing and interactions among people become physical; (3) moving and, in particular, passing of a bottleneck becomes uncoordinated; (4) at exits, arching and clogging are observed; (5) jams build up; (6) the physical interactions in the jammed crowd add up and cause dangerous pressures; (7) escape is further slowed by fallen or injured people acting as obstacles; (8) people show a tendency towards mass behaviour; (9) alternative exits are often overlooked or not efficiently used.

2.1. Experiment

The uncoordinated egress experiment aims to verify some of those events above described. Furthermore, several crowd densities were applied to assert how it influences the egress time and egress flux. Figure 1 shows a top view, out of scale, of part of the CBMSC Military Academy's Sport Hall, detailing the experiment. In a controlled environment, with only a 1.12m exit door, a group of 20 to 30 years old firefighting students were distributed over 70m² emulating a night club environment. At the sound of whistle, all occupants are urged to leave the area immediately, as it would be the reaction observed by people perceiving imminent risk to their lives.
The camera V1 films the crowd from behind. Fixed above the door, the camera V2 records people near the door. V3 is positioned over a vehicle parked next to the exit and facing the door from outside. The angle of view of those cameras are represented by a dashed blue semicircle and red and yellow lines.

During the experiments there were no visibility restriction or lack of fresh air, participants were reasonably homogeneous concerning mobility and decision-making skills, they saw and knew which direction to take to egress and there were no obstacles. Seven trials were performed, varying the initial population as

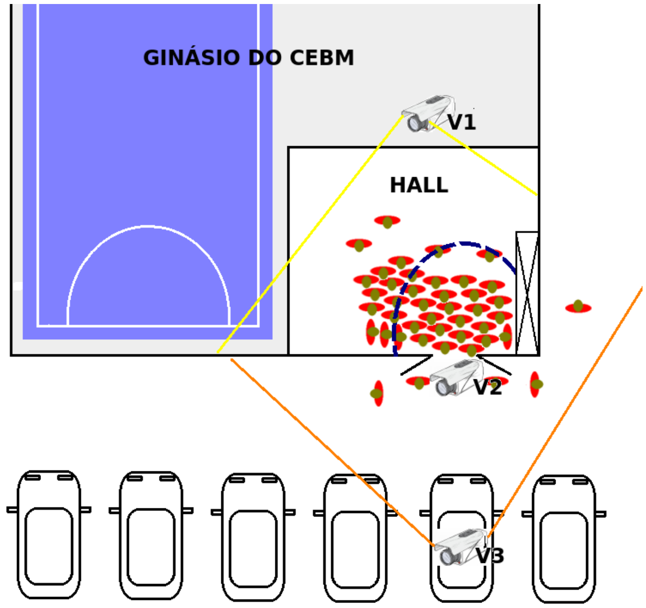

Figure 1. Egress experiment scheme.

follows: 35, 70, 105, 140, 175, 210 and 280. Figure 2 shows a snapshot of cameras V1, V2 and V3 during the experiment.

2.2. Simulation

Helbing, Farkas and Vicsek [2] presented an egress simulation model, here named as "Panic Package". The authors considered that in an emergency, every individual should aim the exit, following a straight path at a desired speed. If those ahead are not at the same speed, they will be crowded by those behind. Once the egress flow is reduced due to door blockages or a crowd, the pressure raises. According to this model, the forces inside a crowd in an uncoordinated egress are: a) physical, reaction to compression and friction either among individuals or against walls; and b) socio-psychological, related to aversion of crowding.

Panic Package is part of the article publicized in Nature on 2000 Helbing et al. [2]. Simulation parameters were maintained as default, except those now described: a) door size, 1.12m; b) room's area, $70m^2$; c) circle (representing an individual) diameter, 47.5±5.0cm; and d) initial number of particles, set according to the number of individuals.

3. RESULTS

The experiment results are here divided in: qualitative, where is presented the blockages and crowd turbulence on videos; and quantitative, regarding to egress time and flow analysis. Then, "Panic Package" simulation results are compared

Figure 2. Simultaneous snapshots taken during the experiment.

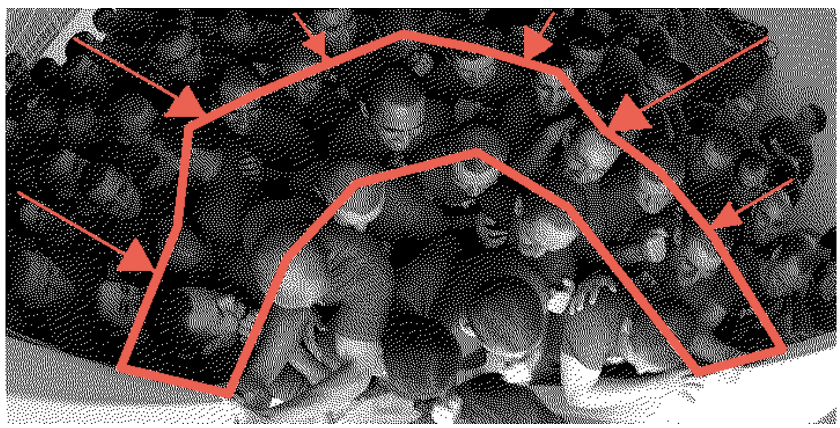

Figure 3. Snapshot highlighting the arch.

with the experimental ones. That validated simulation model is used to check effectiveness of some aspects of IN 09 regarding nightclub's emergency egress.

3.1. Qualitative Results

Figure 3 presents a snapshot, at a point of the 175 crowd experiment, highlighting two semicircles of individuals, shoulder to shoulder, forming an arch format. Those individuals composing the arches withstand a huge compressive force and transmit that shoulder to shoulder to the wall. The more people push towards the arch, the more it compacts itself.

One of the consequences of the arches is that the individual closest to the wall can be imprisoned there. It was observed that an individual stood 32 seconds, next the door looking outside, pressed against the wall without moving itself regardless his efforts. The consequences of higher crowd pressures could be turbulent flow, trampling and crushes. From those 3, just the first was observed at the experiments. Figure 4 overlays 15 screenshots taken from video at the 175

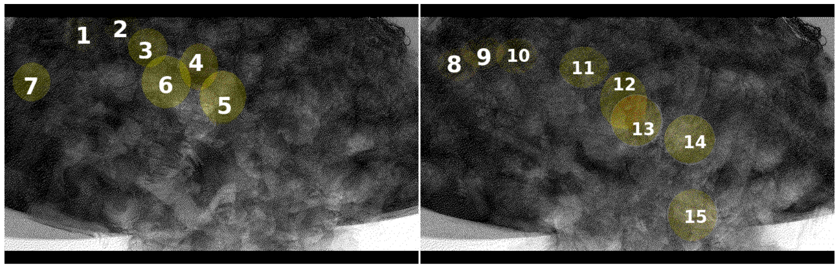

Figure 4. Screenshots overlaid showing how turbulence affects the path followed by a person (1 is the first position and 15 the egress)

	experiment uncoordinated egress		**IN 09 coordinated egress**	
initial population	time s	mean flow s^{-1}	time s	mean flow s^{-1}
35	6.41	5.46	10.50	3,33
70	17.25	4.06	21.00	3,33
105	26.95	3.90	31.50	3,33
140	36.61	3.82	42.00	3,33
175	54.55	3.19	52.50	3,33
210	73.26	2.87	63.00	3,33
280	85.00	3.29	84.00	3,33

Table 1. Egress time and mean flow versus population

individuals egress experiment. The head of the tallest and heaviest individual is highlighted and numbered, representing the turbulent path that the crowd pushed him to follow.

3.2. Quantitative Results

In a coordinated egress, that means people walking in an ordered queue flow, through each 0.55m of the door's width will pass 100 individuals per minute [4],[3]. That means egress flow is controlled by the size of the door. For example, where there are 100 individuals, they will take around 30 seconds to cross a 1.10m sized door. By linearity, the egress of 200 would last a minute. However, in an uncoordinated egress, the crowd dynamics don't follow a linear pattern. Table 1 presents the egress time and mean egress flow in two condition: a) uncoordinated egress experiments; and b) coordinated egress as expected following the Normative Instruction 09 [3].

As the initial population was increased in the experiments, the egress flow diminishes. However, the most crowded experiment (280) presented a flow higher than expected. Checking out the videos viewing the crowd from its back (V1), it was verified that people had not pressed for escape as they should. As a lesson learned from the experiments, participants perceived on their own that

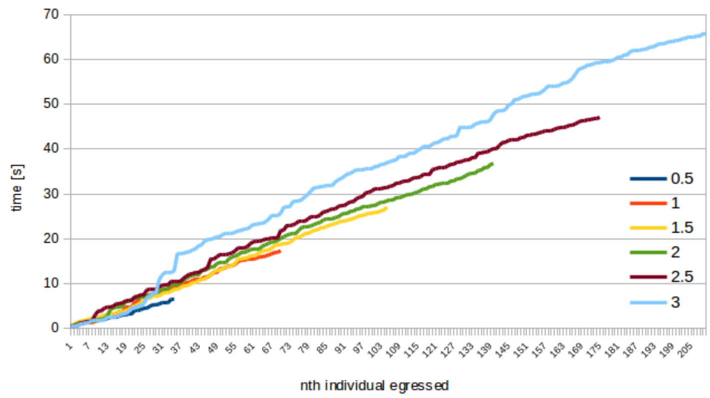

Figure 5. Egress time for several crowd initial density [individuals/m^2].

the more they press the longer will be the wait. Furthermore, it is observed how uncoordinated is faster than an expected coordinated egress for the experiments up to crowd's density of 2.5 (175 individuals)

However, the experiments only considered a will to exit, no individual reentries were stimulated. Reentry is the act of an egressed individual who tries to come back inside the building seeking someone else. Besides of helping obstructing the doorway reentries can make the others confused about the right direction to take [1]. To compare graphically all the experiments, Figure 5 presents the egress time against the nth individual for all initial crowd's density, excepting 4.0 (280 individuals).

The dark blue curve (crowd's density of 0.5, or 35 individuals) has a quite constant slope, meaning no blockages, almost a coordinated egress. The light blue curve, presents a sharp slope at the 29th individual escape, which is the mathematical representation of a door blockage. Another way to see the blockages is through the time's void between two individual's exit, which is presented in Figure 6.

There are eight peaks over one second in Figure 6, that means, during the emergency egress there were eight moments when the door was blocked longer than a minute. During a peak, crowd pressure raises until the arch breaks and several individuals are expelled through the door. That is the mathematical view of what is observed in video, people were right in front of the door, striving to egress but blocking one against other, those behind giving more pressure until the blockage is broken and a stream of individuals breaks through the door. By instance, right before the 37th individual to exit, the egress flow was stopped during more than 3.5 seconds.

3.3. Verifying Simulation Model

Figures 7 and 8 presents the comparison between experiment and simulation.

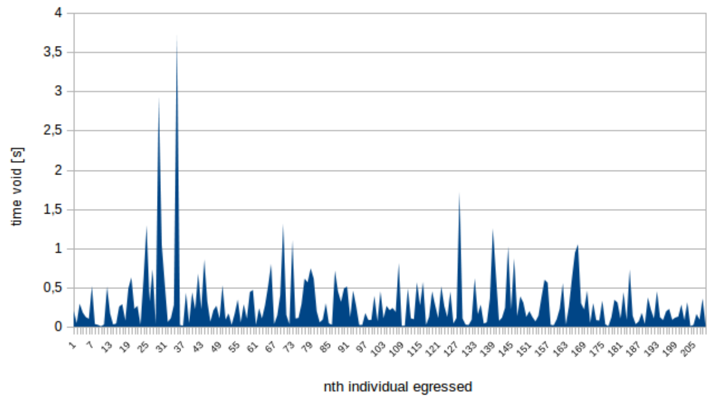

Figure 6. Time void between egresses for 210 individuals experiment.

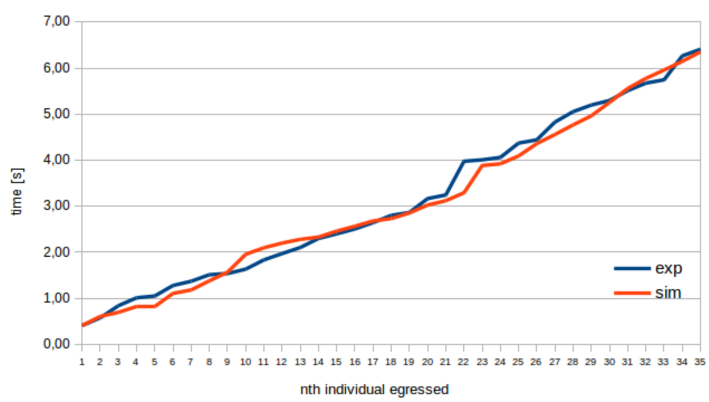

Figure 7. Experiment versus simulation: 35 individuals egressed.

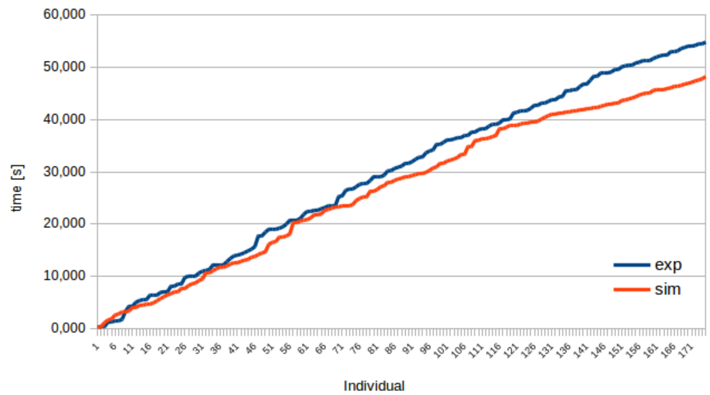

Figure 8. Experiment versus simulation: 175 individuals egressed.

3.4. Are IN-09's Requirements Enough?

According to IN 09, for nightclubs similar to Kiss, the allowable public is double of the room area. That means, in a $100m^2$ place, there will be 200 individuals allowed. Specifically to the terminal exit door, article 65, IV, c) [3], states: "rooms above $400m^2$ must have at least two doors, being one greater than 2m and the others greater than 1.2m". Kiss had $615m^2$ [7], under IN 009, a similar night club should have at most a public of 1230 and the doors must sum a width of at least 6.77m.

As the "Panic Package" does not permit more than one door, it was assumed that the public will split itself and will follow the closest door. For instance, in a 2 doors of 3.38m simulation, it will be done one simulation of one door with half of the public. Two possibilities attending the code will be simulated: a) 2 doors of 3.38m and; b) 3 doors of 2.26m.

Figure 9 presents the simulation results for a nightclub with 1230 individuals. The egress time for a simulation of a nightclub like Kiss with 2 doors is doubly faster than the expected by IN 09, showing that its recommendations are adequately safe. Furthermore, adding a third door reduced the egress time in 28% in simulations.

4. CONCLUSION

The experiments verified how the egress flow was influenced by the rise of crowd density. For higher crowd pressures, door blockages and crowd turbulence were observed. The last experiment, in which individuals became aware that the more they pushed, the longer they waited, proves that lowering the crowd pressure can improve the egress flow.

Regarding the Panic Package simulator, the egress curve obtained was very close to the experimental results, showing it as a good alternative to simulate

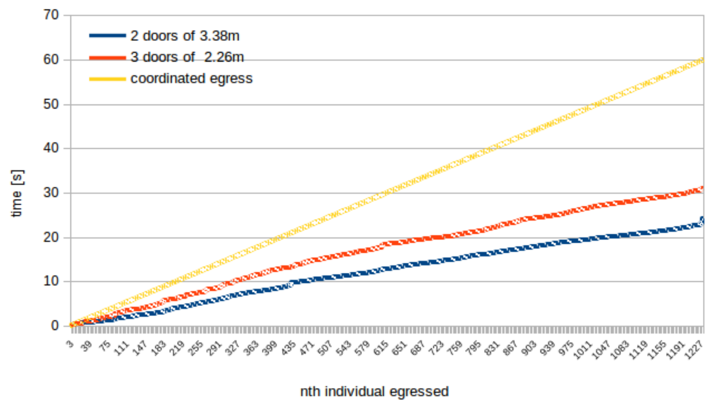

Figure 9. Experiment versus simulation: 1230 individuals egressed.

egress time for a specific door, given an initial number of individuals. Although it was not possible to simulate with more than one door or obstacle, it was possible to estimate how the uncoordinated egress would be in a nightclub with the same area as Kiss if the doors were designed nowadays.

Based on these experiments and simulations, the IN 09 requirements for door width at nightclubs (exit discharge) can be considered safe. The uncoordinated egress was doubly faster than what would be expected from a coordinated egress. However, those simulations assumed simplified conditions, not considering falls or fainting people, smoke and heat from fire, and internal obstacles, which are part of a real nightclub fire scene.

REFERENCES

[1] Bruno Ricardo da Cunha Esteves Costa. "Aplicação de Um Modelo Numérico Na Avaliação Da Evacuação de Um Edifício." 2009.

[2] Dirk Helbing, Illes Farkas, and Tamas Vicsek. "Simulating Dynamical Features of Escape Panic." *Nature* 407 (6803). Nature Publishing Group: 487–490. 2000.

[3] *IN 009/DAT/CBMSC:Sistemas de Saídas de Emergência*. Corpo de Bombeiros Militar de Santa Catarina, Florianópolis. 2014.

[4] *NBR 9077:Saídas de Emergência Em Edifícios*. Associação Brasileira de Normas Técnicas, Rio de Janeiro. 1993.

[5] *NFPA 101:Life Safety Code*. National Fire Protection Association, Quincy, Massachusetts. 2009.

[6] *Relatório Final: Inquérito Policial 94/2013/150501* . Inquérito Policial 94/2013/150501. Rio Grande do Sul. Secretaria de Segurança Pública. Polícia Civil, Santa Maria. 2013.

[7] *Relatório Técnico: Análise Do Sinistro Na Boate Kiss, Em Santa Maria, RS*. Comissão Especial do CREA-RS. Conselho Regional de Engenharia e Agronomia do Rio Grande do Sul, Porto Alegre. 2013.