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COMPARATIVE ANALYSIS OF EVACUATION MODELLING USING DIFFERENT NUMERICAL MODELS

Abstract. The paper presents comparative analysis of numerical modelling of evacuation, which concerns advanced movement simulation combined with high-quality 3-D animated results. Occupants moving from their starting locations to an exit must choose a route to follow when walking towards their chosen exit. This route selection process significantly affects the overall simulation results, as time spent waiting in queues and time spent walking affect the time it takes all agents to reach their objectives. Therefore two simulation models have been analysed in the paper: steering model and SFPE model. In case of the first one, agents proceed independently to their goal, while avoiding other occupants and obstacles. Door flow rates are not specified but result from the interaction of occupants with each other and with boundaries. In SFPE model, agents use behaviours that follow SFPE guidelines, with density-dependent walking speeds and flow limits to doors. SFPE results provide a useful baseline for comparison with other results, but SFPE calculations do not prevent multiple persons occupying the same space.
Keywords: evacuation, numerical modelling, steering model, SFPE model, safety.

ANALIZA PORÓWNAWCZA WYNIKÓW MODELOWANIA EWAKUACJI Z WYKORZYSTANIEM RÓŻNYCH MODELI NUMERYCZNYCH

Streszczenie. W ramach pracy przeprowadzono analizę porównawczą wyników modelowania ewakuacji osób, która obejmowała zaawansowaną symulację dyslokacji połączoną z wysokiej jakości renderingiem 3D. Modelowane obiekty podczas ewakuacji przemieszczając się z miejsca początkowego do wyjścia, dokonują wyboru optymalnej trasy ewakuacji z wykorzystaniem jednego z dwóch algorytmów. Proces ten w istotny sposób wpływa na końcowe wyniki symulacji z uwagi na fakt, iż czas spędzony przez

pojedynczy obiekt w kolejce do wyjścia oraz czas przemieszczania bezpośrednio wpływa na czas ewakuacji wszystkich obiektów. W związku z powyższym analizie poddano dwa algorytmy decyzyjne: model zmienno-sterujący i model SFPE. W przypadku pierwszego z nich, indywidualne obiekty zmierzają do celu, unikając pozostałych obiektów i przeszkód. Przepływy obiektów przez drzwi wynikają z interakcji geometrycznej pomiędzy obiektami oraz otoczeniem. W modelu SFPE obiekty wykorzystują zachowania zgodne z wytycznymi SFPE wraz z zależnymi od zagęszczenia prędkościami przemieszczania oraz przepływami przez drzwi. Wyniki wygenerowane z zastosowaniem tego modelu nie eliminują jednak możliwości zajmowania tej samej przestrzeni prze kilka obiektów.
Słowa kluczowe: ewakuacja, modelowanie numeryczne, model zmienno-sterujący, model SFPE, bezpieczeństwo.

Introduction

The increasing computational capability is one of the factors leading to high interest in numerical modelling [4, 5]. This research tool is also commonly applied in analysis concerning emergency evacuation especially during fires. Several modelling approaches have been applied within last years to deal with the above mentioned issue, which is of great importance as people in danger can react in many different ways. Traces and evacuation times of people familiar and unfamiliar with the environment can differ significantly especially in the first minutes of the evacuation. These first minutes are considered to be critical in terms of the successful evacuation [8]. Moreover there are occupants (disabled, intoxicated, etc.) who are not able to self-evacuate under any circumstances. Statistics show that over 60% of injures and over 50% of dead in building fires could have evacuated but instead they were performing activities that delayed the evacuation including fighting the fire or attempting to rescue others [2]. That is why the simulation of evacuation requires advanced models which provide high consistency with the reality and take into account all the most important factors influencing human behaviour during fires. The mathematical model developers are also constantly working on improving the usability of numerical models, making them more accessible and embedding more behavioural sophistication [6].

The evacuation models

An agent-based egress simulator has been used during the analysis. It provides two models of occupant motion:

- SFPE model,
- steering model.

The SFPE is a flow model, where walking speeds are determined by occupant density within each room and flow through doors is controlled by door width. It implements the concepts and assumptions of the SFPE Handbook of Fire Protection Engineering [7] as follows:

- the occupants move toward the exits using the shortest path,
- the maximum occupant speed is a function of room density,
- occupants move independently and can occupy the same space as other occupants,
- queues form at doors with the flow rate through the door as specified by SFPE guidelines.

The second analysed model – the steering model – is based on the idea of inverse steering behaviours and allows more complex behaviour to naturally emerge as a by-product of the movement algorithms. It eliminates the need for explicit door queues and density calculations [3].

The numerical setup

The computational domain was defined as a set of seven double rooms of 15 m^2 area (5 m x 3 m), one single room of 10 m^2 area (5 m x 2 m) and 1 m wide T-shaped corridor with two evacuation exits. Fifteen occupants are initially located in rooms and assigned to specific exits (Fig. 1). The location of occupants in each room was random but the same for both analysed models.

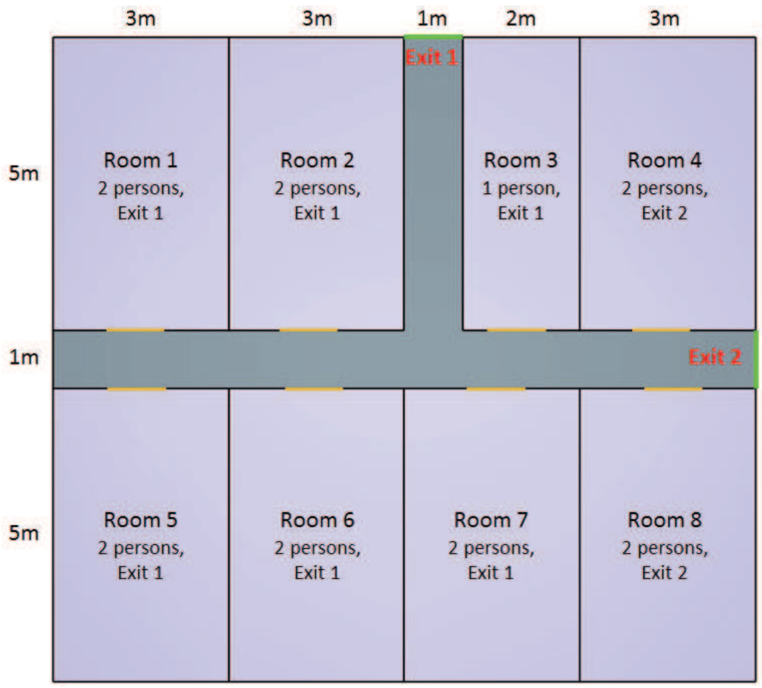


Fig. 1. Room arrangement in the test case

The occupants in the left six rooms are assigned to Exit No. 1. The occupants in the remaining two rooms are assigned to Exit No. 2. Occupants are given a profile corresponding to males 30-50 years old (Table 1).

Table 1. Walking speeds on flat terrain [1]

Population groups	Walking speeds on flat terrain	
	min [m/s]	max [m/s]
Females younger than 30 years	0.93	1.55
Females 30-50 years old	0.71	1.19
Females older than 50 years	0.56	0.94
Males younger than 30 years	1.11	1.85
Males 30-50 years old	**0.97**	**1.62**
Males older than 50 years	0.84	1.4

The results

The paths of occupants calculated using both analysed models are depicted in Fig. 2. The location of occupants at 5, 10 and 15 seconds after the beginning of evacuation for the SFPE and steering model are depicted in Table 3. The total evacuation time (the last occupant to go through the exit) in case of steering model was nearly 36% longer than for the SFPE model. The CPU time was 80% longer in case of the steering model. Detailed evacuation data obtained with the two analysed models are presented in Table 2. The exit times at selected rooms obtained for the SFPE and steering model are depicted in Fig. 3.

Table 2. Evacuation and CPU time for SFPE and steering model

	SFPE model	Steering model
Min evacuation time	3,2 s	5,0 s
Max evacuation time	14,6 s	19,8 s
Average of evacuation time	9,1 s	12,6 s
Standard deviation of evacuation time	3,5 s	4,6 s
CPU time	0,5 s	0,9 s

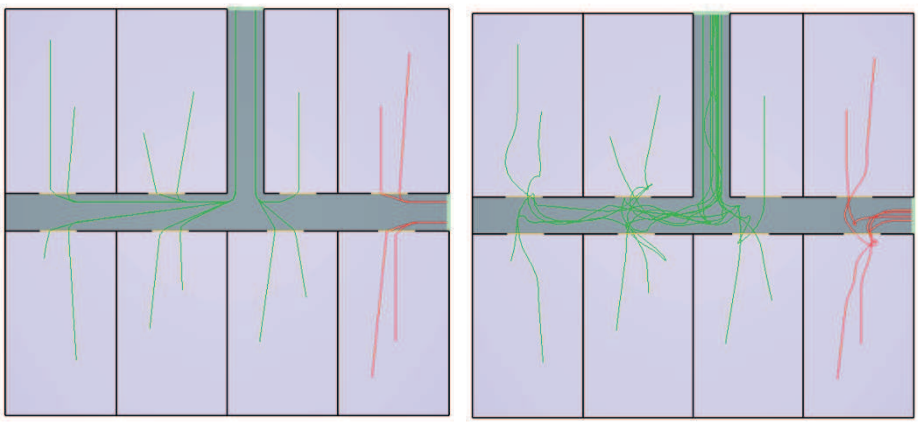
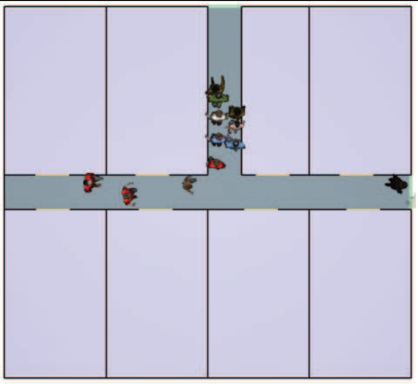
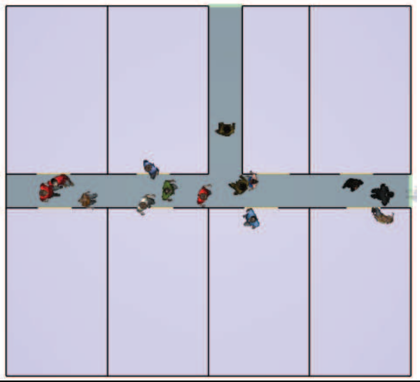
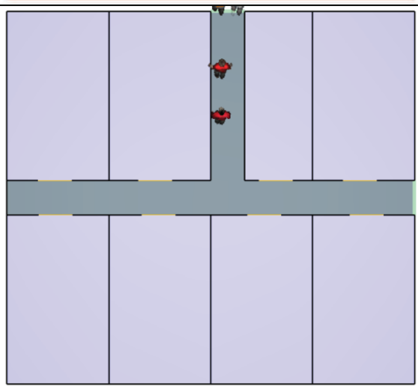
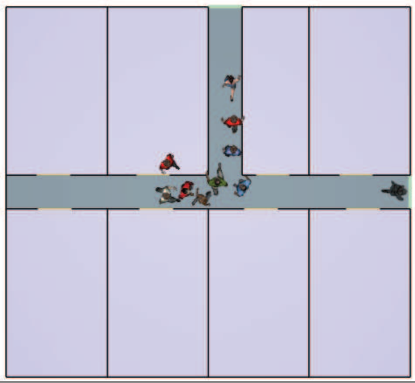
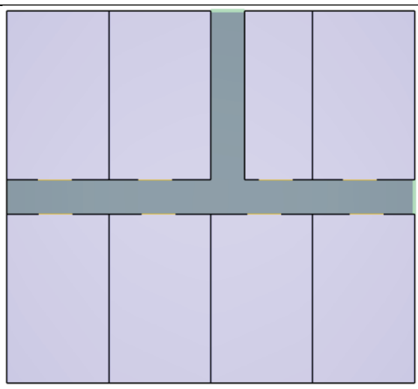
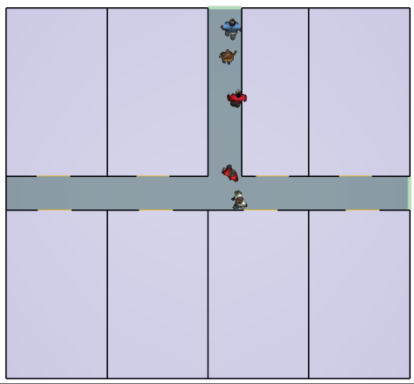


Fig. 2. Paths of occupants calculated using SFPE (left) and steering model (right)

Table 3. Occupants location at 5, 10 and 15 seconds after the beginning of evacuation for both analysed models

Time [s]	**SFPE model**	**Steering model**
5		
10		
15		

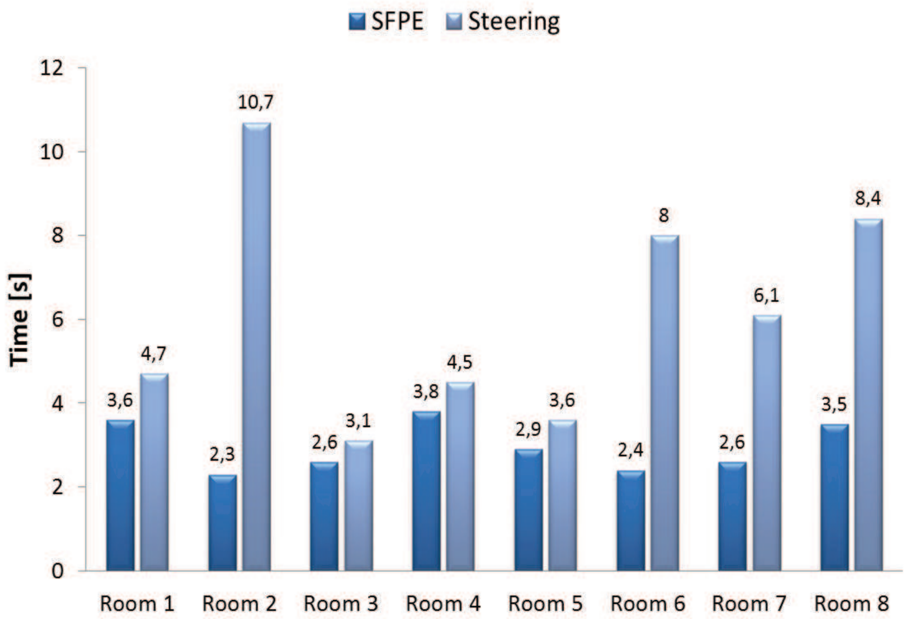


Fig. 3. Exit times of selected rooms

Conclusions

The analysed test case test has been designed in order to match the criteria set by the International Maritime Association. The results for both models indicate that the four occupants directed to Exit 2 evacuated via the specified door. However, this test does not guarantee the proper functioning of the algorithm because the occupants may have made the same choice based on the geometric parameter: nearest exit. That is why the additional verification is needed to ensure exit choice is working properly. Moreover the significant difference in evacuation times generated using the two analysed models needs to be verified experimentally in a test case performed in real conditions.

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