

A Simulation Study of Exit Choice based on Effective Throughput of an Exit Area in a Multi-Exit Evacuation Situation

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Abstract—To individuals evacuating, many multi-exit environments do not allow visibility of all the exits due to line-of-sight constraint. In addition, the environment can be dark or smoky, not allowing visibility to even a single exit. In such a situation, given that each individual in the crowd is accompanied with a helping device globally connected with a central server, a 'directional guidance' towards an optimal exit is a real possibility. In this context, the 'occupant density' around exits (within a static 'exit area') has been used in conjunction with the corresponding distances to devise a probabilistic strategy for optimal exit suggestion [1]. In this paper, we related the exit area with the level of visibility of the environment (the more the visibility, the more the exit area and vice versa). In this way, a more realistic human-behavioral model is implemented in which an individual viewing (seeing) an exit would always direct towards that exit, irrespective of the directional guidance provided. When an individual is not at any of the exit areas (not viewing even a single exit), a directional guidance is provided assuming that the individual is adhering to it. Additionally we used the measure of 'effective throughput' instead of occupant density, in conjunction with the corresponding distances. Through simulation results, we found a marked improvement in the evacuation time, when effective throughput was modeled instead of occupant density.

Crowd Evacuation, Occupant Density, Crowd Simulation.

I. INTRODUCTION

Most crowd evacuation simulation systems are based on human perceptions, particularly the sense of sight and hearing. In a socio-technical system, some (or more) individuals are equipped with at least one helping device, thus providing a possibility of utilizing device-to-device interaction for more efficient evacuation. Device-to-device interaction is dependent on the communication range of the devices and may result in the formation of different communication zones, for example, local neighborhood, clusters or groups (of varying sizes) and a global network. Group dynamics, being a more complex and demanding phenomena, involve more social behavioral aspects, thus resulting in a deviation from a 'simple-to-start' socio-technical system in which humans and devices have a one-to-one relation. That is the reason, in this paper; we only concentrate on the local neighborhood on one hand and a global network on the other. These effectively two extremes are more popularly categorized by the research community as microscopic and macroscopic interaction.

Emerging crowd behavior at the macroscopic level cannot be modeled without understanding of behavior of the individuals at the microscopic level [2]. Alternatively, modeling behavior at the local level accumulates to an emerging behavior at the global level. Understanding the dynamics of emerging behavior at the macroscopic level, potentially suggests a continuous feedback to the individuals, helping them readjust their local behavior to achieve the desired patterns at the global level. More specifically, during the crowd evacuation process, through the microscopic level interaction, an individual (or a device holder) may know about the local neighborhood and make a decision about the next site to move to. If the macroscopic interaction is active (suggestions provided by a server to the individual), the decision about the next site would be under the influence of the exit suggestion provided. A cumulative microscopic activity in a region changes the global situation, and may result in a slightly different suggestion to the same individual for the next time.

The most prominent global goal of any evacuation system is to increase the overall evacuation efficiency. Mostly, the evacuation efficiency is a measure of evacuation time i.e. the iterations required to evacuate all (or most of) the population. Given that each of the individual is equipped with a device, the environmental conditions (particularly its location) can be communicated to a central server. As a result of application of a macroscopic model at the server, each individual (or device) in the population may be provided with the optimal directional guidance. A directional guidance provided in this way is indigenously dependent on the macroscopic view of the environment based on the phenomena of interest.

For the systems targeting the evacuation efficiency, the phenomena of interest is related with the structure of the environment. For example placement & level of threat(s), damaged regions & presence of obstacles, geometry of confinement area, population density and the visibility level. Population density can be defined as a number of individuals in a region. Traditionally, researchers have used Exit Area (EA), i.e. area surrounded by an exit, as a more effective region to measure the population density; the measure known as Occupant Density (OD) at an exit. In this respect, the main premise of the evacuation strategies is that an individual potentially diverts from 'nearest' exit and selects one of the remaining exits as its destination, considering the OD at exits [3]. Mathematically this strategy was introduced

as a mechanism of calculating the 'exit-choice-probability' for all possible exits [1]. A choice is adopted if probability difference exceeds a pre-defined 'sensitivity' level. For the purpose of our research, we have redefined the EA as an area around an exit which allows an occupant to 'see' the exit in the limited visibility. It is a novel but logical definition of an EA. Due to the obstacles and building structure, it is rare for each member of the population to have a view of one (or more) of the exits even if there is a perfect visibility. Therefore, an EA should not be a static region around an exit. It must be related with the visibility level of the environment. Ignoring all other contributing factors, the more the visibility is, the more is the EA around that exit and vice versa.

In this paper we have presented the results of a simulation study, evaluating the affects of visibility (or EA range) on the evacuation efficiency. Additionally, we have modified the strategy (based on OD alone) presented in [1] and realized a significant improvement. Keeping the basic framework intact, our strategy is based on Effective Throughput (ET) of exits which considers Exit Capacity (EC) as an essential augmenting measure along with the OD. In addition to be more efficient, our model induces potentially less panic in the population (by avoiding very frequent diversions). Moreover, our strategy works better than that of the strategy presented in [1], for both extremes of the visibility level (high and low). The next section discusses microscopic-level 'next-site selection' and macroscopic-level 'exit selection' model, followed by the section devoted to the simulation and results evaluation.

II. SIMULATION MODEL

A. Modeling for Next-Site Selection

The next-site selection model is based on Cellular Automata (CA) modeling technique. A CA model is based on a regular grid of the cells in which each cell is occupied by a single individual. The space and local rules in combination, describe the next cells an individual needs to occupy at each time stamp. Space rules are based on the states of the cells around a cell whereas the local rules are based on the individuals' characteristics in the neighborhood. In particular, our 'next site selection' model is motivated by the CA model presented at [4]. However we generalized this model (originally based on the von Neuman's model of the neighborhood) for the Moore's model of the neighborhood [5]. We also performed experimental evaluation to validate the site choice mechanism proposed in the model. A detailed discussion of model and empirical evidence can be found at [6].

B. Modeling for Exit Selection

The model is concerned with designing an exit selection strategy. Each individual is directed towards the most suitable exit keeping in view the global conditions at the EAs. However, at the microscopic level, the 'next site selection' is an independent local strategy presented in [6]. Exit selection model is based on three parameters.

- 1) Distance (dist): Distance of an individual from an exit.
- 2) Occupant Density (OD): Number of individuals occupying EA of an exit.
- 3) Exit Capacity (EC): Number of sites constituting an exit (exit width).

The model is incremental in nature starting from strategy 1 which utilizes the *dist* parameter alone (only included for comparison purposes). Strategy 2 combines *dist* along with OD, assigning a sensitivity level (according to the requirements) to the *dist* and OD each. Strategy 3 combines *dist* along with Effective Throughput (ET) assigning a sensitivity level (according to the requirements) to the *dist* and ET each. ET is a normalized version of OD which considers EC. As mentioned in section 1, the OD (and ET) is a function of the *Visibility* and an EA of an exit is a region in which an occupant can view that exit.

1) Strategy 1: Move to Nearest Exit

In this strategy we let the individuals move towards their nearest exit. Intuitively, if an exit is visible to an individual, it means that he/she is inside the EA of that exit. In this situation, the evacuee would always direct towards the exit in sight. If an individual cannot see any of the exit, it means that he/she has to rely on directional guidance provided by the device which is essentially a guidance towards the nearest exit irrespective of congestion and jamming conditions towards that exit.

2) Strategy 2: Considering OD with Distance

Strategy 2 is based on a theoretical model for exit selection in a multiple exit environment. The model [1] is based on the occupants density around exits i.e. EAs. The model focuses on the concept of attraction forces; 'position attraction' being the force of attraction determined by the distance of the site from the exit (shorter the distance, larger the attraction), and 'density attraction' being the force of attraction determined by the occupants density around that exit (lower the density, greater the attraction). As given in [1], the distance-dependent probability of each exit can be calculated as:

$$P_{i-r} = \frac{1-(N-1)r_i}{R} \quad (1)$$

where i is the exit-id, N is the total number of exits, r is the distance of exit from a site and R is defined as:

$$R = \sum_{i=1}^N r_i \quad (2)$$

Similarly the density-dependent probability can be calculated simply by replacing $r(R)$ with $d(D)$, and given as:

$$P_{i-d} = \frac{1-(N-1)d_i}{D} \quad (3)$$

Since the interrelationship between distance and density affects the exit choice decision, following model was developed to combine P_{i-r} and P_{i-d} :

$$P_i = \frac{\alpha P_{i-r} + \beta P_{i-d}}{\alpha + \beta} \quad (4)$$

where α and β are proportional to the disparity in the distances and densities respectively and can be calculated as:

$$\alpha = \frac{1}{N} \sum_{j=1}^N \left(\frac{1-r_j}{R} \right)^{k_\alpha} \quad (5)$$

$$\beta = \frac{1}{N} \sum_{j=1}^N \left(\frac{1-d_j}{D} \right)^{k_\beta} \quad (6)$$

where k_α and k_β are constants representing sensitivity of each exit.

3) Strategy 3: Considering ET with Distance

Strategy 3 is similar to strategy 2 with one difference. Instead of using the individuals' count as a measure of OD, we have used the weighted density (where weight is relative to EC) named as ET. Consequently, the following equation describes the new value of d used in equation 3:

$$d_i = \frac{d_{count(i)}}{EC_i} \quad (7)$$

where $d_{count(i)}$ is count of agents in the EA of exit i and EC_i is the exit capacity (number of sites constituting the exit) of exit i .

III. SIMULATION

The simulation is performed in NetLogo [7] using a square *world* constituted by a grid of 101x101 sites with location of the origin (0, 0) at the center. A site can be of one of the three types; (i) an exit, (ii) part of Exit Area (EA) of an exit, or (iii) a normal site. The simulation was performed for four ranges of the EA; (i) 35 sites, (ii) 20 sites, (iii) 10 sites and (iv) 5 sites. Each of the range represents the relative visibility level of the environment. A single exit is defined by consecutive exit sites and identified by a unified name. For example exit 1 (e_1) at the center of one side of the world (at top) has a width equal to 3 sites as that of exit 3 (e_3) right apposite to e_1 (at bottom). Exit 2 (e_2) at the center of one side of the world (at right) is a single site exit as that of exit 4 (e_4) right apposite to e_2 (at left). Due to dissimilar Exit Capacity (EC), the number of sites in the EA (for EA range = 35 sites, for example) of e_1 (e_3) i.e. 2033 is slightly higher than the number of sites in the EA of e_2 (e_4) i.e. 1961.

All the sites (except that of the exits) are set up with following two variables: 1) *exit-id*: the identity of the nearest exit site, and 2) *dom*: the direction of motion towards exit-id. Each agent out of 1000 generated is set up with the similar set of variables which are: 1) *dest*: the identity of the exit an agent is heading for, and 2) *ort*: the orientation towards the current dest. Within any of the EA, the *dest* of agent is always equal to the *exit-id* of the site on which it is residing (consequently the variable *ort* is equal to *dom*). But anywhere outside EAs, there can be a difference (based on evacuation strategy used), hence differentiating variables of the sites and the corresponding variables of the agents.

The effectiveness of each of the evacuation strategy is measured in terms of evacuation time (the number of iterations required to evacuate the whole population), analyzing the proceedings by plotting the Nearest Exit Dynamics (NED) for each time stamp. NED represents the %age of agents nearest to an exit divided by the corresponding EC. NED also helps defining a *balancing position* to avoid flip-flop behavior of the agents between exits, particularly in later stages of the simulation. After reaching to a balancing position (typically less than 5% accumulated difference between the exits), all the agents direct towards the nearest exit (strategy 1), till the end of the simulation.

A. Simulation Results

Strategy 1 concentrates on directing the agents towards the nearest exit resulting in exits with greater EC exhausting first. It was observed (See Fig. 1) that the two exits with greater EC exhausted at iteration 132 leaving the exits with lesser EC to remain effective till the total evacuation time of 300. As shown in Fig. 1, there is no possibility of reaching to a *balancing position* as the overall difference between the NED values is very high. It is important to note that the results for strategy 1 would remain the same for the other EA ranges as strategy 1 is independent of EA range.

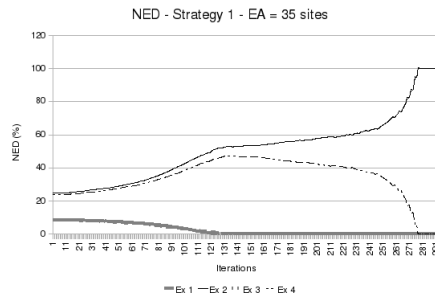


Figure 1: Strategy 1 – Plot of values with EA range = 35 sites.

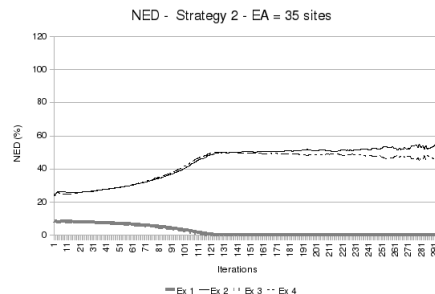


Figure 2: Strategy 2 – Plot of values with EA range = 35 sites.

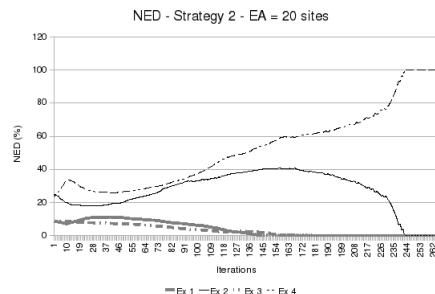


Figure 3: Strategy 2 – Plot of values with EA range = 20 sites.

We implemented strategy 2 with sensitivity constants equal to 1 and 0.125 for k_α and k_β respectively. Application of strategy 2 when the EA range is equal to 35 sites, does not improve the evacuation efficiency that much (evident from the Fig. 2 when compared with Fig. 1) due to the presence of majority of agents in the EAs. Though, the sensitivity of density is eight times as that of the sensitivity of distance, the comparative agents' density at the EAs is almost the same. It forces the distant agents to fall under the influence of distance only. In the later stages of the simulation, when

difference in the EC introduces the sufficient difference between EA densities, all the agents are already in nearest EA (where the strategy 1 is applied). In Fig. 3 (EA range = 20 sites), we see a major portion of agents moving towards exit 4, initially. It is because, at this time, the percentages of agents in EAs of exit 1, 2, 3 and 4 is 10, 10.7, 9.5 and 8.2, respectively. Since, the sensitivity of the density is 8 times as that of the sensitivity of the distance, many agents closer to other exits start moving towards exit 4. This trend reverses in favor of exit 1 after some time (at iteration 13). Later in the simulation, a trend of migration from exit 1 to exit 2 can be seen starting at iteration 30. It is obvious that there is no trend set for reaching to a *balancing position* using NED values, even when EA range is equal to 20 sites. With further decrease in the value of EA (range = 10 sites), we observed more fluctuations in NED values. For the EA range equal to 5 sites, the evacuation time was worse than that of strategy 1 mainly due to increased flip-flop behavior of the agents. Most of the time, the EAs were devoid of any of the agents due to too much sensitivity of the density. We refrain from producing these graphs to save the space.

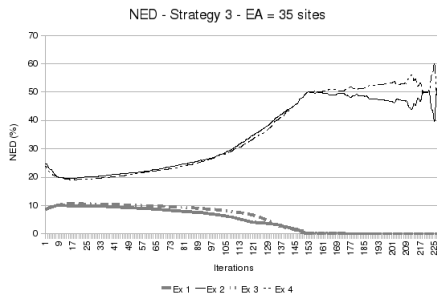


Figure 4: Strategy 3 – Plot of values with EA range = 35 sites.

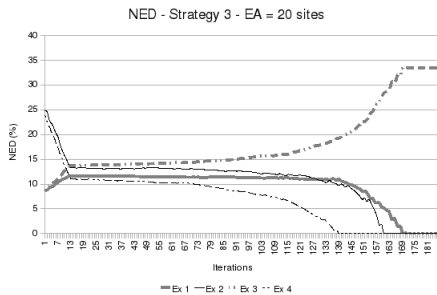


Figure 5: Strategy 3 – Plot of values with EA range = 20 sites.

The simulation results show that strategy 3 increases the evacuation efficiency considerably (compare Fig 4. with Fig. 2). This improvement is mainly due to a real possibility of reaching to a *balancing position*. Though for 35 sites as EA, the agents' behavior did not allow the system to reach to a *balancing position*, still, right from iteration 1, the agents diverted towards exit 1 and exit 3 from exit 2 and exit 4, thus ensuring a substantial difference. This behavior is more evident from a comparison between Fig 5. with Fig. 3, where the EA range is equal to 20 sites. As shown in Fig. 5, a *balancing position* is reached very early in the simulation (around iteration 14), after which strategy 1 has replaced

strategy 3, resulting in an improvement in the evacuation efficiency. The similar line of arguments is valid for EA ranges smaller than 20 sites.

IV. CONCLUSION

The following conclusions can be drawn in the light of simulation result:

- 1) The evacuation efficiency is improved when the occupant density around exits is considered in conjunction with the relative distance of an individual from exits. Improvement in evacuation efficiency is more prominent when EA is smaller, except when the EA is sufficiently small, in which case the evacuation time of strategy 2 is more than that of strategy 1.
- 2) Considering the EC to calculate the 'effective throughput' instead of a simple count for occupants' density at an exit, improves the evacuation efficiency further. The simulation results show that it ensures a reasonable evacuation time even if EA is very small. There is a slight degradation in the efficiency when the EA range slips from intermediate towards smaller, but it is negligible.
- 3) Overall the simulation results verify the fact that the occupant density if considered alone is not as useful measure as when it is applied in conjunction with the EC.
- 4) Finally, even in sufficiently high visibility, a global evacuation strategy yield better results than the human perceptions (compare evacuation time of strategy 1, 2 and 3 when EA range = 35).

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