A MULTI AGENT APPROACH TO ANALYSE SHIFT IN PEOPLE BEHAVIOUR UNDER CRITICAL CONDITIONS

F.A. PONZIANI[1,2], A. TINABURRI[1,2], & V. RICCI[1]
[1]Central Direction for prevention and technical safety – Department of firefighters, of the public rescue and civil defence – Ministry of the Interior - Italy.
[2]University of Rome Tor Vergata - Italy.

ABSTRACT

The aim of this study is to illustrate the possibilities offered by using a multi agent approach – agent based modelling (ABM) – to deepen the understanding of behavioural phenomena possibly arising in a multitude of people exposed to a sudden variation in environmental conditions. The environment, people are in, is one typical exhibition hall that is part of a larger interconnected space, such as a mall or an art centre. The normal condition is characterised by the hall with the exhibition of artworks, with people inside to enjoy the performance. Suddenly an alarm is triggered, thus defining the onset of the critical condition, activating the sequence of emergency operations. Thus, there is a change in the behaviour of the people inside the hall: from enjoying the exhibition to finding their way out.

This study tries to figure out some behavioural patterns that may appear to be present among the people in real life situations similar to the one considered here. Once defined the basic quantitative assumptions in terms of spatial domain and number of people involved, a proper toolkit is used to manage the qualitative issues, such as environment modifications and people characteristics. The open source ABM platform NetLogo is adopted for modelling purposes and capturing the resulting behavioural patterns.

Keywords: agent based model, behaviour, complex systems, pattern

1 INTRODUCTION: COMPLEX SYSTEMS

This study is part of a research programme meant to explore Crowd and Fire Dynamics in their essence of Complex Systems [1, 2].

Let's refer to the interactions among people and with their environment in crowd dynamics and regarding flames and combustible targets in flame front propagation in fire dynamics, to only mention two phenomena well observable in real life experience.

This kind of approach is relatively new in these disciplines. As a matter of fact, crowd dynamics started to be studied with a fluid-particle dynamics approach while nowadays the cybernetic approach, with agent based modelling (ABM) is also applied in this field as a sort of frontier in evolution still today. Fire dynamics started to be studied with the classical and advanced models well known (essentially Navier–Stokes with more or less sophisticated boundary layer, turbulence, combustion and heat transfer models), while nowadays there is also a combined deterministic-stochastic approach that, while already employed in some of the advanced models above mentioned (turbulence cascade, radiation transfer, instabilities …), tends to be coupled with interactions (deterministic or stochastic) between parts of the systems behaving as individual entities resembling agents [3].

This paper deals with some aspects of human behaviour in crowd dynamics, especially those that may be encountered in critical situations where two conditions appear in sequence: from normality to emergency, usually through a sudden transition. Since the aim of this study is to try to capture some essential features in the possible change of people's behaviour under critical conditions by means of ABM, an environment is modelled to highlight patterns of the interactions processed in the associated simulations.

ISSN: 2041-9031 (paper format), ISSN: 2041-904X (online), http://www.witpress.com/journals
DOI: 10.2495/SAFE-V8-N1-1-9

Some inputs to the model were based on discussions that come from the personal experience of the authors in attending exhibition events in various premises, ranging from a simple room to a complex auditorium.

The environment chosen is, therefore, a model of an exhibition hall that is part of a larger interconnected space: the focus is on the room itself about what may happen among the people inside visiting the exhibition.

Since the focus on human interaction is essentially in the patterns that may emerge from the movement inside the room done from possible shifts in behaviour, not due to physical threat such as smoke or flames issuing inside but to an alarm sounding at once, there is no need to consider the height of the room: so only the floor plan dimensions and door placements are of interest for this work.

The room has a rectangular plan, 8 meters wide and 16 meters long, with two doors 1.20 meters wide each, placed in the end parts along the left wall as the entrance/exit usable in normal conditions, plus two emergencies exits 0.90 m wide each, placed in the end parts along the opposite right wall that are to be used in emergency.

The exhibition consists of a series of artworks, which may be not only physical (such as paintings, statues, sculptures) but also virtual (to generate a landscape of images, sounds, holograms).

The agents chosen as models of people are subdivided in sets of different type each one having differing behavioural rules under normal conditions at the start of the simulation.

Two basic sets are considered: one formed by a group of visitors with a leader as a guide to follow a path along the artworks, one composed by a group of visitors wandering at random in the exhibition hall.

The following parts of the study describe the principal features considered in the model, and are presented in a form resembling the so-called ODD protocol (Overview, Design concepts, Details) used in some ABM community [4].

2 THE ODD PROTOCOL: OVERVIEW, DESIGN CONCEPTS, DETAILS

ODD is a schedule to describe the features of the model in an organised synthetic manner.

The Overview: the approach of multi agents, or Multi Agents System (MAS) – i.e. ABM albeit with slightly different definitions in view of the overall vision of the concepts involved here – is adopted to model and explore possible variations in the behaviour of people while the environment conditions change significantly. The ABM approach makes it possible to investigate individual entities and the interactions that may intuitively be expected to appear, stabilise and disappear. The people's behaviour shifts as a result of the environmental conditions changing from a normal state to an emergency state via a sudden transition. This means that each agent performs a task that will tend to be different depending on the state of the environment, on the perception sensitivity, and on the response capability of the agent, so that each agent will possibly have its own internal different state of performance. Furthermore, some effect of the internal state of the agent could be coupled with the state of the environment. In order to capture the essentials of interactions and behaviour, proper spatial and temporal scales have to be chosen and modelled: thus scales too short or too long will be discarded, once the lifespan of the process or phenomenon studied is understood or foreseen or observed.

The Design concepts: the model aims at studying the basic aspects of this complex system, such as interaction, prediction, emergence, adaptation, stochasticity, learning, etc., and then characterising properties of the complex system: e.g. connectivity, autonomy, emergence, nonequilibrium, nonlinearity, self-organisation, co-evolution [5].

The Details: initialisation, input data, submodels. The model is initialised by designing the environment and the agents. No recorded data are used to start the model; some estimations are made from personal experience and literature survey instead. The environment represents the interior of a single exhibition room. Since this study does not deal with fire code compliance, the assumed exit doors width is a good starting point for exploring the appearance of phenomena like queuing or attraction.

The artworks inside the exhibition room represent virtual installations placed in a closed loop following the walls at a distance: since they display images on the walls and diffuse sound from the ceiling, people – i.e. the agents – are not forced to move around them. In such a way, people use all the space available inside the exhibition room. There will be a need to consider boundary effects (people to people, people to walls) with an avoidance of collision during the interactions, unless collision is permitted as a contact or packaging effect.

The agents represent the people inside the exhibition room. Starting from some maximum occupancy threshold fixed by some code used in a design teamwork contest, a lower number of people inside is considered because this is best suited to a situation of crowd dynamics that arises and is observed in real life, where there is usually a limitation in the admitted number of visitors. Nonetheless, varying the number of people inside will help to track some trend.

In this step of the research, all of the agents are considered entirely inside the room at the start in normal condition – as when an exhibition is performing and there is no more admittance inside – with no agent entering from the doors. Therefore, the only link to the outside is through the exits that are the only ones to be used in emergency condition – as when the doors used as entrance/exit are blocked or become unavailable. At the onset of an alarm trigger, the condition changes from normal to emergency: once the agents perceive the alarm and sense the change of the situation, either all together at once or with different response times, they will change from viewing the exhibition to finding their way out.

The input data of the environment are the geometry (plan area, walls, doors, exits, artworks) and the effects (solid boundaries, unavailable doors, exits to way out, alarm set). The input data of the agents are the position (number, spatial distribution) and the characteristics (physical and cognitive). The submodels here specifically refer to the actions of the agents and the effects of the environment. The actions of the agents involve movement (visit, wander, move out, stop) and decisions (reactive or adaptive). The effects of the environment involve signalling (alarm triggering, doors blocking, exits availability) and attraction to way out (random, not random).

3 NETLOGO MODELS: RULES OF INTERACTION

The toolkit used in this research is NetLogo [6], an open source environment properly designed for research and design in the ABM realm. NetLogo uses specific entities for modelling: the very basic are the patches and the turtles. The patches model the space, the turtles model the agents. The patches and the turtles represent the world [7]. The world is 'wrapped on' when the turtles pass the patches at an edge of the world reappearing on the opposite edge (torus topology), is 'wrapped off' when this is not allowed. By varying the scales of the model, it is possible to adopt discrete or continuous descriptions. In this study the world is wrapped off (need boundaries for people), with continuous space and discrete time.

The agents are considered with similar characteristics, physical and cognitive; the position of the agents is chosen at random at the start, unless the group of visitors with the leader are placed near some chosen artwork. The movement of the agents depends on the type of agent and the state of the situation: in condition of normality the leader will guide his group of visitors along the artworks, while the remaining visitors will wander around the artworks;

during the onset of the alarm each agent will immediately understand and will change its behaviour to way out finding; in condition of emergency the leader and the other visitors not linked to the leader will try to move out to the chosen exit, while the visitors linked to the leader will try to continue to follow the leader. Two options of choice for the exit to move out are modelled for the agents: either the nearest or a random exit.

The spatial and time scales of the model are set or tuned depending on the state of the condition – normality versus emergency – to reasonably represent and visualise the moves of a visitor in an exhibition room. In order to describe the rules of the agents it is convenient to adopt an agent-centric viewpoint: a particular useful mindset where the rules are described as seen by the agent, not by an external observer. The rules are quite a few, just needed for starting actions and activate reactions, with the intent of letting the system of agents and environment evolve to some state with some pattern by themselves.

Here they are described, for each type of agent set: leader of a group, visitor of the group, individual autonomous visitor. The rules for movement are different depending on the agent. The leader of the group of visitors will move along the artworks following some circulation path until an alarm is triggered, then proceeding to his/her chosen exit. A visitor belonging to the group with a leader will follow the leader while observing the artworks and will try to continue to follow the leader when the alarm is triggered to move out.

An individual autonomous visitor will wander from artwork to artwork following some random path until an alarm is triggered, then will move out to his/her chosen exit.

The following Table 1 shows the rules of behaviour for the agents and their priorities.

Table 1: Behavioural rules for movement and priorities for decision.

Action	Agent set	Behaviour priority
To visit	• Leader of the group	1. Point one artwork. 2. Check for obstacles. 3. Move along the artworks.
	• Visitor belonging to the group	1. Point the leader. 2. Check for obstacles. 3. Move following the leader.
	• Individual autonomous visitor	Action not performed
To wander	• Leader • Visitor belonging to the group	Action not performed
	• Individual autonomous visitor	1. Check for obstacles. 2. Wander about.
To move out	• Leader • Individual autonomous visitor	1. Choose the exit. 2. Check for obstacles. 3. Move to the exit. 4. Exit.
	• Visitor belonging to the group	1. Choose the exit trying to follow the leader. 2. Check for obstacles. 3. Move to the exit. 4. Exit.

The alarm onset triggers the shift from visit/wander to move out performed by the agent.

For each agent set a sequence of decisions is programmed with diverse priority depending on the action that is to follow and the constraints encountered. Once located at random at the start, the agents have their own types of movement: to visit, to wander and to move out.

The criteria adopted by the agents for selecting the exit path may vary from the nearest exit to one exit chosen at random, while the time of doing the choice may vary from choosing at the start of the visit, choosing at the alarm onset, choosing from the alarm onset. When choosing *at* some defined time, the choice is done and frozen for the rest of the time; when choosing *from* some defined time, the choice is repeated for each successive time step.

Rules for collision avoidance are the same for all of the agents: to change direction if there is an obstacle in their cone of vision. Furthermore, each agent will maintain a free space around as a buffer zone of defined radius, with the two alternatives of contact or proximity.

Several ways of setting the parameters and activating the variables of the model are available to design a NetLogo controller, that allow not only to varying the values of the variables, performing data analysis and trend monitoring, but also the chance of checking for some threshold value in a behavioural space of the system under study.

In the controller, two groups of specific parameters are set concerning the agent motion: by means of the vision cone and the moves. The former defines the radius of vision and the angle of vision for the agent it refers to, the latter defines the wiggle angles on the right and on the left and the forward advancement for the agent at each time step of the simulation. All of these parameters can be varied as well, with the values fixed in advance or changed with some criteria during the simulation run. In order to let the system evolve, the heading of each agent (the direction the agent points to) is set in the code programming as dynamically variable, and in the phase of the moving out it serves to orientate the agent towards the exit chosen.

4 NETLOGO MODELS: PATTERNS OF SHIFTED BEHAVIOUR

The use of an ABM toolkit requires to model the system doing several runs for each kind of situation taken into account: in this way, not only the intrinsic nature of variability will be considered (i.e. agents positioning at the start) but also data analysis will be performed to examine some trend (i.e. averages and tails) [8]. In this study, the runs are carried out in order to observe the emerging patterns of movement of the agents from the normal condition of visiting the artworks in the exhibition to the emergency condition of finding their way out towards the chosen exit from the time of alarm onset.

So, the shift in behaviour will appear (at least) in the patterns of movement, thus encouraging further investigations in terms of way out (i.e. queue reduction) and of agent characteristics (i.e. reaction time to the alarm).

Here follow some snapshots coming from a series of runs showing examples of movement tracking obtained due to the nature of the system modelled, with the rules of less distant exit or random exit to way out and the buffer zone of contact or proximity. The snapshots show the setup (start time) and the final reaching of the exits for all of the agents (end of the simulation run).

The person-like shape of the agent is chosen as a rendering effect of the various clustered and scattered positions set up at random at the start, but is not scaled to represent the same proportion between agent and space. Colours are used to differentiate the behaviours and highlight the patterns. The agents are black if the leader, grey if the visitor of the group, orange if the individual autonomous visitor. The tracking lines are coloured in consequence during the normal condition of enjoying the exhibition, and take the colour of the chosen exit (two exits hence two shades of green) during the emergency condition of finding the way out.

The parameters used in the runs – where one patch models a square of 0.20 m – are summarised in the following Table.

Here follow some snapshots rendering the trends of movement for different behavioural choices for way out exit while the buffer zone is set as contact or proximity, such as:

a) Less distant exit at the start (Fig. 1)
b) Random choice of exit at the start (Fig. 2)
c) Less distant exit at the alarm onset (Fig. 3)
d) Random choice of exit at the alarm onset (Fig. 4).

Each couple of pictures shows the start and the end of the run for one simulation of each type.

Table 2: Vision cones and moves of the agents.

Action	Vision Cones		Moves
	Radius	Angle	Behaviour
To visit	30 patch units	30°	Wiggle right 30° Wiggle left 30° Forward 0.25 patch units
To wander	1 patch units	120°	Wiggle right 30° Wiggle left 30° Forward 1.00 patch units
To move out	10 patch units	180°	Wiggle right 20° Wiggle left 20° Forward 0.25 patch units

Applied to every agent performing the action

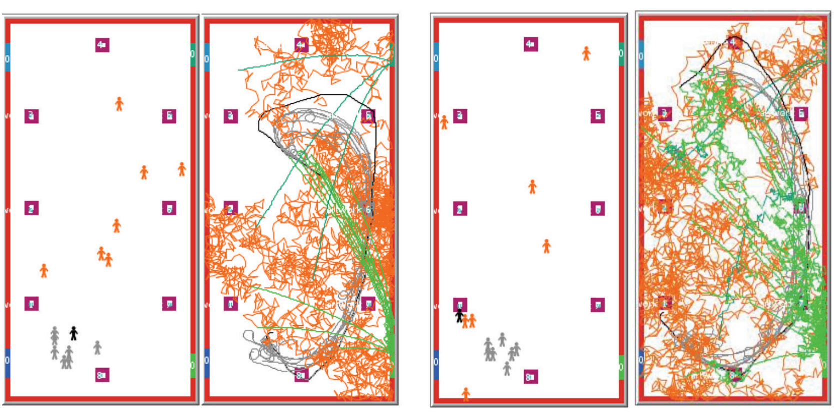

Figure 1: Setup and move-out of one realization run with 15 agents.
Exit choice for the agents is less distant exit at the start.
Buffer zone of agent is set as contact (left) and proximity (right).

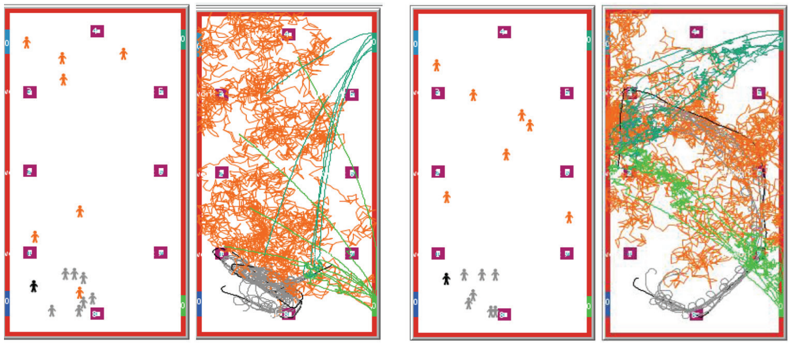

Figure 2: Setup and move-out of one realization run with 15 agents.
Exit choice for the agents is random exit at the start.
Buffer zone of agent is set as contact (left) and proximity (right).

Figure 3: Setup and move-out of one realization run with 15 agents.
Exit choice for the agents is less distant exit at the alarm onset.
Buffer zone of agent is set as contact (left) and proximity (right).

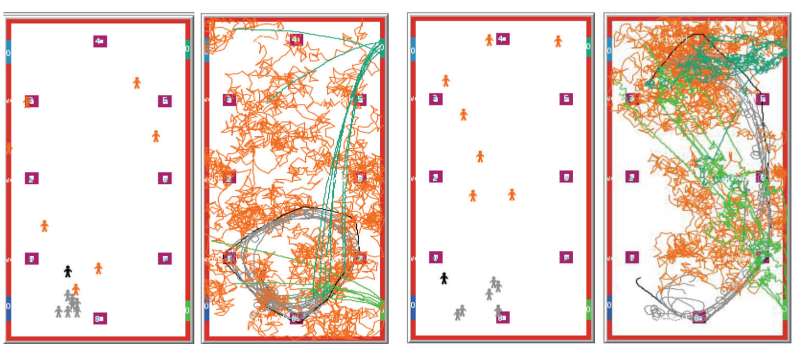

Figure 4: Setup and move-out of one realization run with 15 agents.
Exit choice for the agents is random exit at the alarm onset.
Buffer zone of agent is set as contact (left) and proximity (right).

The patterns of tracked movements of the agents are quite different depending not only on the set of agents (leader of the group, visitors of the group, visitors without leader) but also on the choice strategy of exit for way out and on the buffer zone available for moving.

The tracked paths show different shapes: from the circulating lines of the leader with his group of visitors to the irregular lines of the wanderers (these are presented here as more representative of a casual visitor, while circulating lines appear if the rules for wanderers are set to properly follow the artworks) during the phase preceding the alarm; from the smooth lines of way out when the contact is allowed to the irregular lines of way out when the contact is not allowed and there is a proximity zone to be maintained free among the agents. Once the rendering shows the differences in the emerging patterns of movement at least qualitatively, it is interesting to examine some quantitative trend obtained by means of the several simulation runs launched for each kind of exit strategy and buffer zone.

The results are in terms of the time the simulation ends when all of the agents have reached the exit, in the hypothesis that there is sufficient space outside once arrived at the exit that no block occurs at the exit itself, so that each agent is considered out just when landing at the exit. Moreover, it is convenient to use the 'tick' counter of the program – that marks the advancement of the simulation to the next step when all of the rules of all of the agents are executed in the current step – as the parameter for comparisons.

The results obtained as average and standard deviation over 100 runs for each simulation type are summarised in the following Table 3, with a common value of 60 ticks from the start of the run for the alarm to be triggered and the move out phase to begin. The buffer zones of the agents vary from contact (practically no free zone) to proximity (free zone of about one meter).

The time of choice of the exit (at the start of the simulation – well before the alarm is triggered – versus at the alarm onset) shows a major effect on the time for exiting once the alarm is triggered, together with the buffer zone (contact versus proximity) whose marked effect is on the paths that emerge for moving out. The type of exit choice (less distant versus at random) shows an effect on the time of exiting, too. Combining the effects, the results having the lower ticks when all of the agents are exited in this study come with the exit choice strategy of less distant exit done at the alarm onset with a buffer zone of contact (yet not hindering the agent movement).

Table 3: Ticks when all of the agents are exited (average over 100 runs).

	Ticks to exit from the alarm onset			
	Buffer zone is contact		Buffer zone is proximity	
Exit choice strategy	Average	Standard deviation	Average	Standard deviation
Less distant exit at the start	37	28	46	21
Random exit at the start	40	30	49	20
Less distant exit at the alarm onset	20	10	31	8
Random exit at the alarm onset	31	10	43	9

The alarm is triggered after 60 ticks from the start of the simulation

5 FUTURE STEPS IN THIS RESEARCH PROGRAMME

Future steps of the research programme – with the same environment of exhibition room adopted in this work – will involve the way the agents might express their behaviour. The design of a proper behavioural space in NetLogo will help deepen the understanding of the system. The agents will be considered with different characteristics, physical and cognitive, checking some statistical distribution and variability (gender, age, health). This will have impact, for example, to the movement and to the reaction time. Several alternatives of way out finding will be considered and examined: not only from random choice to less distant exit, but also from gradient following to field attractors. Furthermore, the rules of behaviour of the agents will evolve from reactive to adaptive, and learning from experience will hopefully expand the potential of the agents.

For the rules of the agents considered, a check will be made to try to grade their effect on the overall dynamic of the system, ranging from a forcing term (the system evolution is forced by the rules) to a boundary term (the system evolution is only started by the rules). In addition, it might be useful testing extreme conditions, with higher crowd densities, which in turn require checking some measurable quantity not obscured by the high crowd density itself.

REFERENCES

[1] Erdi, P., *Complexity explained*, Springer, 2008.
[2] Grimm, V. & Railsback, S.F., *Individual-based modeling and ecology*, Princeton University Press, 2005.
[3] AA. VV., *The SFPE Handbook of Fire Protection Engineering*, Hurley, M.J., Editor-in-Chief, Fifth Edition, Springer, 2016.
[4] Grimm, V. & Railsback, S.F., *Agent-based and individual-based modeling*, Princeton University Press, 2012.
[5] Rzevski, G., Harnessing the power of self-organisation. *International Journal of Design & Nature and Ecodynamics*, **11**(4), pp. 483–494, 2016. https://doi.org/10.2495/dne-v11-n4-483-494
[6] NetLogo, available at https://ccl.northwestern.edu/netlogo/
[7] Wilensky, U. & Rand, W., *An Introduction to Agent Based Modeling*, MIT Press, 2015.
[8] Netlogo_Tutorial in MediaWiki, Online.