MASSMOTION – A STEP IN THE RIGHT DIRECTION

Dermot O'Donnell, Tim Roberts & Peter Debney
Arup

INTRODUCTION

The use of advanced evacuation modelling has become an integral part of the performance based design process to ensure buildings remain 'safe' for their occupants. There is currently a number of existing evacuation modelling packages on the market today. MassMotion[1] is one of the most recent commercially available packages.

Through working on one of its pedestrian planning projects Arup found that the existing modelling packages on the market at the time were insufficient for the requirements of that particular project and Arup created its own program, MassMotion, to apply to the project.

MassMotion has been in development for the past 10 years and has become commercially available in the last year. The package started life as a pedestrian movement simulator and has evolved into an evacuation package which can accurately simulate people's movement in fire. It is one of the world's most advanced software packages of its kind featuring 3D environments, automatic way-finding, discrete event logic and much more. MassMotion is designed for the creation and execution of large scale (1,000,000+ individuals) 3D crowd simulations. The MassMotion toolset has been successfully applied to some of the most demanding environments in the world including mass-transit stations, performance venues, airports, and stadiums.

HOW DOES IT WORK?

MassMotion is founded on the construction of behavioural profiles for people, and the construction of a 3D environment for these people to inhabit. The behavioural profiles are based on industry standard metrics such as Fruin's work[1] on pedestrian characteristics, and a variety of original data sets including evacuation and route choice surveys.

Agent movements and decision making in MassMotion is done by dividing crowd movement calculations into two distinct processes: reflexive and contemplative. The reflexive component governs the agents' basic movements and responses to the environment.

The movement of individual agents in MassMotion is based on a social forces algorithm[2] modified for MassMotion. The social forces model[2] represents individuals as objects which have a number of forces acting upon them including goal, obstacle, and neighbour forces.

The contemplative component of crowd activity is concerned with network path planning between origins and destinations. This component enables agents to analyse distance, congestion and terrain, develop costs for routes available to the agent's goal, and select the most appropriate route (most cost effective – the "cheapest") on a dynamic basis. The simplified algorithm for total route cost is provided in the equation below:

$cost = (W_D * D_G/V) + (W_Q * Q) + (W_L * L)$

W_D	Distance weight (random agent property)
D_G	Total distance from agent position to ultimate goal
V	Agents desired velocity*
W_Q	Queue weight*
Q	Expected time in queue before reaching link entrance
W_L	Link traversal weight*
L	Link type cost (level, ramp, stair, etc)

*Randomly applied to agents from a distribution

This approach allows MassMotion models to exhibit the kinds of emergent phenomena that occur every day in the real world. For example, agents that have the ability to recognise congestion and to consider alternate routes based on their familiarity with an environment will adapt their decisions to their current situation. MassMotion with its calibrated approach to modelling behaviour patterns can effectively simulate both existing and proposed scenarios.

WHY IS IT DIFFERENT?

To realise the potential of MassMotion, it is important to highlight the key features of the software.

MassMotion operates on a full 3D model environment. Each individual agent is made aware of their environment through bit map representations of free and obstructed space on all walk-able surfaces of the 3D simulation environment. Each agent determines their best available target location for the next frame of the simulation and adjusts their velocity and orientation to achieve that position.
This calculation is executed at a rate of five frames per second of simulated time which is frequent enough to allow agents to adjust to dynamically changing conditions within the environment without encroaching on locations occupied by obstructions or other agents.

A significant advantage of the MassMotion system is that design alternatives may be explored by simply replacing or modifying environment geometry. This is result of an automatic organisation and costing of routes through a pedestrian network. The sparse node network will update itself based on the new geometric relationships, while the availability and cost of routes within the network will likewise adjust to new model geometry. As the software will manage the network assignment of agents on an individual basis there is no need for the user to specify assignments at junctions. This is particularly advantageous when simulating complex interconnected environments, where the effort required in manually assigning volume splits at junctions per destination would result in an unmanageable number of permutations to be defined[4].

Apart from the O-D (origin-destination) way-finding process itself, MassMotion features built-in events for the agents to undertake activities that would be normally executed in real life at large complex buildings. For example: the process of buying a ticket at rail station or checking-in and security clearance at the airport terminal.

A model with 1,000,000 agents was successfully run to test software's robustness with such large occupancy. MassMotion can also handle extremely complicated O-D matrices. O-D matrices can be defined through the user interface or with spreadsheet.

CALIBRATION AND VALIDATION

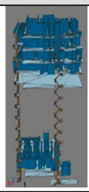
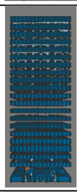
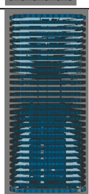
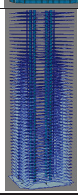
Calibration and validation are essential for users to have confidence in a simulation package. MassMotion has been calibrated to industry standards for both general pedestrian planning and evacuation scenarios. MassMotion has also been validated with extensive survey data from commuter, special events, and evacuation scenarios.

The movement of individual agents in MassMotion is based on the extensively documented Social Forces model[2]. This model represents individuals as objects which have a number of forces acting upon them including goal, obstacle, and neighbour forces. The implementation of Social Forces in MassMotion has been calibrated using the industry standard guidelines for general pedestrian planning in John Fruin's work[1].

Every version of MassMotion is calibrated to produce results consistent with Fruin's guidelines[1] for all levels of service (A through F) for each of these tests. MassMotion has also been validated against real world pedestrian activity and evacuation for both basic pedestrian movement (as defined by Fruin[1]) and for the autonomous route choice functionality. The validation of the dynamic route choice functionality of the software is based on real world surveys of how commuters use a complex rail station to access the downtown core of a major North American city[4].

In addition to above, four separate buildings which represent a range of building scales and populations have been used for comparison to assess the validity of MassMotion for modelling egress scenarios[5]. The evacuation of each of the four buildings was manually observed with journey times, flow rates and evacuation time recorded. Table 1 compares the results of the four models created as part of this validation exercise with the results observed during the evacuation.

Table 1: Summary of Results

Building			Scenario	Evacuation Time (mm:ss)
155 Avenue of the Americas		Floors: 15 (6 modelled) Evacuees: 232	Observed	7:24
			Modelled	7:49
			% Difference	+ 5.6%
10 Hanover Square		Floors: 22 Evacuees: 1,130	Observed	13:00
			Modelled	13:14
			% Difference	+ 1.4%
85 Broad Street		Floors: 30 Evacuees: 1,385	Observed	18:00
			Modelled	16:41
			% Difference	-7.3%
One Canada Square, Canary Wharf		Floors: 50 Evacuees: 5,469	Observed	20:00
			Modelled	21:53
			% Difference	+ 9.5%

The results from the validation exercises indicate that MassMotion is suitable for application as an egress model, producing total evacuation times that are within an acceptable range of 1% to 10% of observed total egress times.

CASE STUDIES

STADIUM MASTERPLANNING

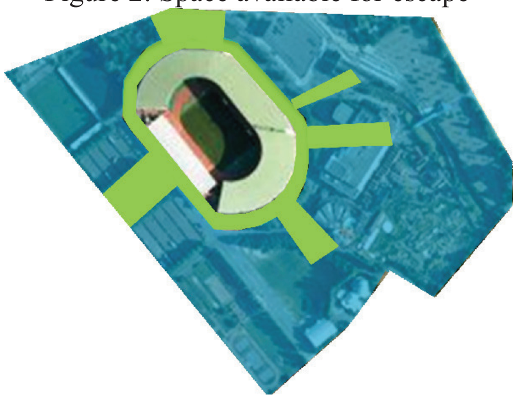
Arup have been involved in the masterplanning for the redevelopment of an existing site which includes a stadium with a maximum capacity of 70,000 persons. The masterplan involved the construction of a number of new buildings in close proximity to the existing stadium. Consequently the evacuation from the stadium needed to be reviewed to ensure the proposed development surrounding the stadium would not adversely affect its means of escape. In addition to maintaining escape from the stadium it was also necessary to ensure adequate vehicle access for emergency services to the stadium.

The Analysis

The aim of the analysis was to study the potential space that could be developed around the stadium without adversely affecting the means of escape from the stadium. Previously the area surrounding the stadium was open and easily allowed evacuating occupants to disperse in the event of an emergency. The proposed masterplan was to build on the areas highlighted blue below and retain the areas highlighted green for escape, emergency vehicle access and circulation.

Figure 1: Proposed masterplan

Figure 2: Space available for escape



MassMotion was used to assess if the proposed routes (green) for escape and vehicle access were sufficient to allow evacuating occupants disperse from the stadium safely in the event of an emergency.

The results of the analysis would then provide future tenders for the development an outline area of land plots that can be constructed on without adversely affecting the stadium evacuation or emergency services access.

Results

Through an iterative modelling process of the proposed escape routes from the stadium a final solution was arrived at which allowed the safe evacuation of stadium occupants and emergency vehicle access to the stadium.

The critical acceptance criteria for the safe evacuation of stadium occupants was the density experienced on the escape streets away from the stadium and directly outside the stadium exits. Density maps for each model were produced to assess this. An example of the density map produced and the model created are shown on the following page.

Figure 3: 3D View of Simulation Results

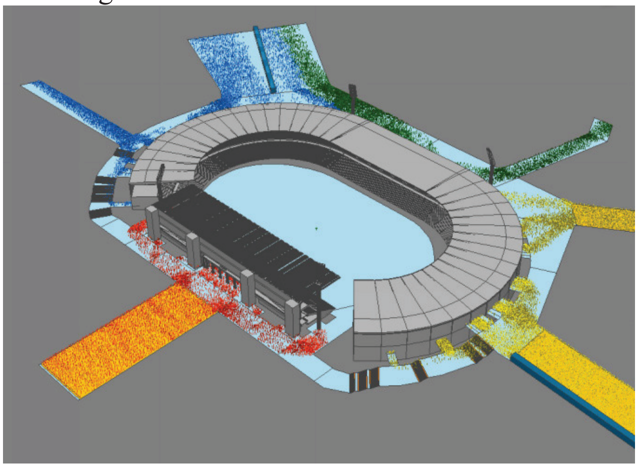
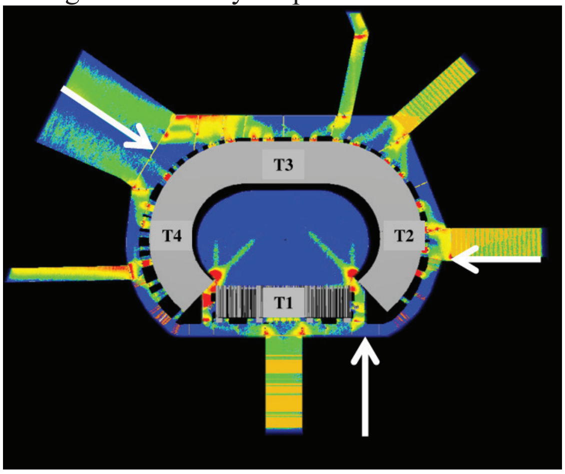


Figure 4: Density Map of Final Solution



MassMotion was particularly useful for this type of project as the 3D graphical nature of the program allowed all stakeholders understand the areas around the stadium that were required for means of escape and remaining areas that could be developed. This ensured our client was able to maximise the use of their land without affecting the existing stadium.

EXISTING SHOPPING CENTRE

The Shopping Centre (which cannot be named for commercial reasons) is located in Ireland. The centre contains 36,000m² of car parking, 28,000m² of retail development, 3,000m² of commercial space, 135 residential units and a 122 bedroom hotel. At peak times the shopping centre can accommodate up to 8,000 people at any one time.

A number of heritage protected structures including an old railway terminus building dating back to the 19th century have been integrated into the modern shopping centre development. This required a sensitive approach and assessment to retain the existing features, structure and facade while refurbishing the building to achieve life safety requirements and the new uses.

The Analysis

Arup Fire provides on-going fire engineering services to the shopping centre management team for this large shopping centre. As a majority of the buildings in the shopping centre are protected structures and therefore cannot be altered, advanced evacuation modelling has become an integral part of their service. MassMotion was used to demonstrate that while code compliant means of escape is not always provided from the existing protected structures, sufficient means of escape to ensure the safe egress of occupants is available.

While a large amount of fire engineering and egress analysis has been carried out on the existing shopping centre, evacuation modelling has become particularly useful in the recent fit out of an existing protected structure. Compliant escape capacity was achieved; however it was not possible to provide code compliant travel distances from the upper floors of the unit as this would mean altering the protected structure, which was not possible.

MassMotion was used to demonstrate to the local approving authorities that when one exit was discounted due to fire the escape time from the unit was dictated by the compliant escape width rather than the non-compliant travel distance: occupants will be queuing longer than the time taken to travel to the exit. To further demonstrate the robustness of the theory the speed of the occupant at the furthest travel point was set to an average of 0.675m/s to simulate a mobility impaired person (MIP).

Results

The use of MassMotion and evacuation modelling showed that the overall queuing time in the retail unit would be approximately 130 seconds and the time required for an MIP to travel an extended distance to the exit was 64 seconds. This demonstrated that the escape time for the MIP is dictated by the compliant escape width rather than the non-compliant travel distance. Therefore the extended travel distance in the unit does not pose an issue for an evacuating MIP.

The images below show the position of the MIP (yellow agent) at the furthest point of travel at the beginning of the simulation and at 50 seconds along with the density experienced. It can be clearly seen that the MIP has reached the back of the queue of evacuating occupants and the extended travel distance does not affect the overall means of escape of the MIP.

Figure 5: MIP and Density @ 5 seconds

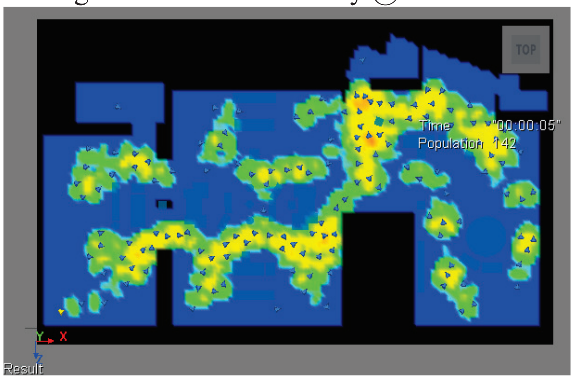
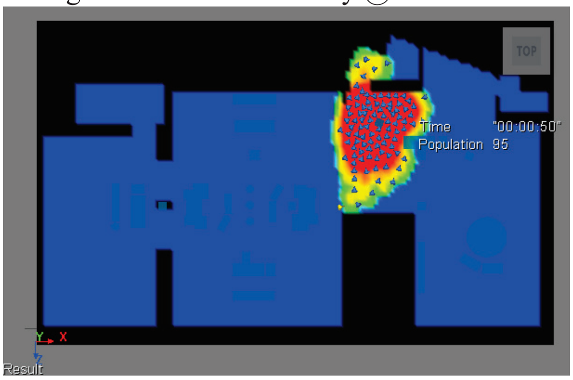


Figure 6: MIP and Density @ 50 seconds



The use of MassMotion can be a particularly useful tool when presenting non code compliant designs to key stakeholders. This type of analysis allowed Arup's client to have freedom in the design of the unit while working in the restrictive confines of a protected structure. The 3D visualisations from MassMotion as shown above ensured a relatively smooth process with a conservative local approving authority that are acutely aware of the needs of disabled occupants during fire evacuation scenarios.

REFERENCES

[1] Fruin, John Pedestrian planning and design, (1971).

[2] Helbing, Dirk; Molnár, Péter Social force model for pedestrian dynamics, (1995).

[3] Morrow, Erin; Edwards, Glenn; Zarnke, Micah; Muggeridge, Christian MassMotion v4.0 Manual Design Simulate Optimize (2011).

[4] Morrow, Erin; Debney, Peter Pedestrian simulation at Toronto's Union Station – a MassMotion case study, The Rail Engineer, July 2012, p 27-28.

[5] Rivers, Eric; Jaynes, Carla; Kimball, Amanda; Morrow, Erin; Zarnke, Micah Using case study data to validate 3d agent-based Simulation tool for egress modelling.

[6] MassMotion www.oasys-software.com/products/engineering/massmotion.