CabinetOffice

Emergency Planning College

Understanding Crowd Behaviours:

Simulation Tools

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The research was carried out, and the report series produced, by Organisational Psychologists at the Centre for Socio-Technical Systems Design (CSTSD) and the Centre for Organisational Strategy, Learning and Change (COSLAC) at Leeds University Business School.

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DISCLAIMER

Please note, the recommendations made in this report regarding good practice for event preparation and crowd management are an interpretation of best practice made on the basis of knowledge and expertise gained from literature and interviews. They are not definitive rules of event preparation and crowd management.

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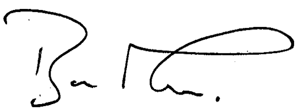
Foreword

Foreword

I am pleased to be able to commend this guidance to you. It was sponsored and funded by the Civil Contingencies Secretariat, project-managed by the Emergency Planning College and written by a team of specialists in organisational psychology from Leeds University Business School. It is the product of a year's research involving a detailed literature review and primary research with practitioners and specialists in the field. It summarises our knowledge, articulates our current understanding of good practice in crowd management and gives planners clear direction, and supporting information, regarding the safe assumptions that may be made about crowd behaviour. As such, this guidance fills what had been a significant gap in our canon of guidance, and contains information that will be of value to a broad cross-section of the public safety and resilience community.



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A Guide for Readers

A Guide for Readers

You should read this report if you are interested or involved in – or wish to become involved in – the simulation of crowd behaviours to aid event preparation.

- This report contains a detailed review of three of the leading agent-based simulation tools currently available, along with an assessment of the ways in which we feel future simulation tools should be developed.
- It is particularly relevant to those already involved with simulating crowd behaviours, or those who are looking to use simulation tools to assist with event preparation.
- It may also be of interest to those who wish to understand the thinking behind the good practice guidelines for crowd simulation techniques.

EXECUTIVE SUMMARY

Executive Summary

- This research was sponsored and funded by the Cabinet Office, as part of the canon of civil protection literature and guidance, and is published on their UK Resilience website (http://www.cabinetoffice.gov.uk/ukresilience.aspx).

- For ease of reading, the research has been divided into a series of four, inter-related reports, namely: -

  - **Understanding Crowd Behaviours: Guidance and Lessons Identified**
  - **Understanding Crowd Behaviours: Supporting Evidence**
  - **Understanding Crowd Behaviours: Simulation Tools**
  - **Understanding Crowd Behaviours: Supporting Documentation**

- This Executive Summary provides an overview of the whole research project (i.e., of all four reports), summarising the Research Aims, Methodology, Key Messages, Good Practice Guidelines, Lessons Identified and Recommendations for Further Research.

- For completeness, this Executive Summary is included at the beginning of each report.

- In addition, a separate guide has been prepared for readers of the reports, which aims to help identify which reports may be of most relevance and use.

  - **Understanding Crowd Behaviours: A Guide for Readers**

- **We recommend that anyone with a professional interest in crowd behaviours should read this Executive Summary.**

Research Aims

- To review – and identify gaps in – existing research, theoretical literatures, and available knowledge on crowds and their behaviour, in both normal and emergency situations.

- To review how the leading simulation software tools accommodate crowd behaviours, and consider how approaches to modelling and simulating crowd behaviours might be enhanced for the future, incorporating both psychological and technical concerns.

- To identify ways forward for the field of crowd management, particularly in relation to planning for very large scale crowd events, which will take place over consecutive days and across multiple locations.

- To produce a set of professional guidelines for emergency planners and responders, specifying reasonable assumptions which can be made with regard to crowd behaviours in normal and emergency situations, against which current assumptions can be tested, and with which future planning can be informed.

Methodology

- A rigorous methodology was undertaken during this research, to gain a wealth of information regarding crowds, their behaviours and methods of simulation, from a wide range of sources (see **Understanding Crowd Behaviours: Supporting Documentation**, 'Research Methodology', pages 43 to 56).

- In-depth literature reviews examining over 550 academic papers, books and official reports were carried out (see **Understanding Crowd Behaviours: Supporting Evidence**, 'Part 3 – Review of the Literature', pages 54 to 242). These specifically concerned: -

    - The key theories of crowd behaviours, with particular focus on the underlying assumptions and rules governing human behaviour, in both normal and emergency situations.

    - Relevant disasters and mishaps involving crowds, with particular emphasis on crowd behaviours, and the often interconnected nature of contributory factors.

    - The key methods used to model and simulate crowd behaviours.

- In addition, three of the leading simulation techniques currently available were reviewed – through utilising accessible literature and conducting interviews with both users and creators of the tools – focusing on their underlying behavioural assumptions and rules (see **Understanding Crowd Behaviours: Simulation Tools**).

- 27 semi-structured interviews were conducted with a wide range of individuals acknowledged to be experts in the field of crowds and crowd behaviours, including leading academics, experienced police officers, and key crowd event and management practitioners (see **Understanding Crowd Behaviours: Supporting Evidence**, 'Part 4 – Expert Interview Findings', pages 243 to 275).

    - The interviewees were specifically chosen for their wealth of experience, ranging from a few to over 30 years. The majority had over ten years' experience in the field.

    - They had a range of roles and responsibilities, including overseeing public order at major events, emergency planning, operational planning and safety management.

    - Experience of major crowd events amongst the interviewees included Notting Hill Carnival, The Matthew Street Festival, Glastonbury, Liverpool Capital of Culture 2008, Hogmanay, New Year's Eve in London, large scale marches in London (such as Stop the City, Stop the War, May Day protests), and events at Wembley Stadium.

- In addition the lead author of this report: -

    - Attended two crowd-related courses held at the Emergency Planning College, on Crowd Dynamics, and on Public Safety at Sports Grounds and Events.

    - Spent a day with police officers at the Metropolitan Police Public Order Training Centre, Gravesend, and a day with Lothian and Borders Police during a visit from the Queen.

- Particular attention has been paid to examining very large scale crowd events, which will take place over multiple days and across multiple sites (see **Understanding Crowd Behaviours: Supporting Evidence**, 'Part 1 – Very Large Scale Crowd Events', pages 10 to 21), focusing on: -

    - The differences between very large scale, multi-day, multi-site events and other, more frequent or one-off events, specifically with regards to preparation and crowd management.

  - The new and additional risks that arise in light of these differences and the findings of this research, which will need careful and rigorous analysis and mitigation by appropriate professionals.

- Analysis has also been undertaken of the problems occurring at the opening of Heathrow Terminal 5 (see **Understanding Crowd Behaviours: Supporting Evidence**, 'Part 2 – A Cautionary Tale: Heathrow Terminal 5', pages 22 to 53), since this provides an excellent recent example of a major infrastructure and operational investment which was badly planned and managed. There are important lessons to identify from this case study.

Key Messages

The key messages to take away from this report are: -

- A great deal is known about crowds and how to plan for and manage crowd events. However, this has not been captured and articulated in a single guidance document until now.

- Key advice for successful crowd management includes: -

  - Thorough planning and preparation, using a wide range of "what if...?" scenarios, including unexpected scenarios.

  - Adoption of a system-wide approach.

  - Coordination between all agencies involved.

  - Utilisation of personnel who have plentiful first-hand knowledge, skills and experience in planning for and managing crowd events.

  - Communication with the whole crowd – both audio and visual – particularly in emergency situations.

  - Leadership and guidance to initiate crowd movement in emergencies.

  - Acknowledgement that seemingly small problems occurring in combination can have a significant impact on event success.

- Nevertheless, there are significant gaps in our understanding of crowd behaviours and in the current capability of crowd simulation tools.

- These gaps are exemplified by the special circumstances of very large scale, multi-day, multi-site crowd events, which will be very different to more frequent, one-off events in a number of ways and, therefore, are likely to involve new or additional risks which will require careful analysis and mitigation.

- In particular, focusing on these very large scale, multi-day, multi-site events, there is a need to consider the potential risks surrounding: -

    - The different types of crowds and their likely behaviours.

    - The behaviours of non-ticket holders who will be attracted to the events, for a range of motives (both legal and illegal).

    - The boundaries – i.e., the scope and scale – of the system we are trying to plan for and manage.

    - The range of "what if...?" scenarios that need to be considered.

    - The knock-on effects of an incident over consecutive days.

    - The importance of coordination between all agencies, across widespread geographical locations.

    - The need to ensure all personnel – from all agencies and in all locations – are consistently and effectively educated, trained and briefed, for both normal and emergency circumstances.

    - The development of new capabilities and facilities for simulation tools, in order to accommodate the above issues.

- There are also some important lessons to identify from the experiences of the Heathrow Terminal 5 opening, in particular that: -

    - Combinations of failures in preparation and management can come together to create major inconvenience to the users of new facilities.

    - These factors include apparently mundane failures such as delays in the completion of the building programme, corner-cutting in training and familiarisation, initial software problems with new computing facilities, a failure to listen to the end users, and so on.

    - These can happen on such a scale as to represent a public relations debacle for the companies and authorities concerned and for the UK more generally.

  - Careful preparations need to be made for such everyday contingencies.

Good Practice Guidelines

- A comprehensive set of good practice guidelines has been collated and established for all professionals and practitioners involved in the field of crowds, including crowd events, crowd management, crowd control and emergency services (see **Understanding Crowd Behaviours: Guidance and Lessons Identified**, 'Guidelines for Good Practice', pages 10 to 39). These guidelines focus on: -

  - Good practice for crowd management.

    - For example, concerned with: thorough planning and preparation; minor risks combining to create major problems; multi-agency teamworking; utilisation of experienced personnel; cross-agency coordination; strategies for communicating with the crowd; differentiation of different types of crowd; and awareness of different behaviours from different types of crowd.

  - Good practice for emergency situations and evacuations.

    - For example, concerned with: leadership and guidance during an emergency situation; initiating crowd evacuation as quickly as possible; strategies for communicating with the crowd and providing information; and awareness of how individuals are likely to behave during an emergency.

  - Good practice for crowd simulation techniques.

    - For example, concerned with: trying to model more accurately crowd movements and behaviours; incorporating different types of crowd and crowd member; including family or other small groups within simulation models, rather than just focusing on individuals; and modelling interactions between crowds and other groups, and between crowd members.

Lessons Identified

- A comprehensive set of lessons identified has been produced (see **Understanding Crowd Behaviours: Guidance and Lessons Identified**, 'Lessons Identified', pages 40 to 85), concerning: -
    - Definitions and types of crowd.
    - Assumptions about crowds – including crowd movement and self-organisation, crowd behaviours in normal and emergency situations, crowd disorder, and ways of improving crowd management.
    - Ways in which crowds and their behaviours can be simulated.

Recommendations for Further Research

- Recommendations for future research and practice have been suggested (see **Understanding Crowd Behaviours: Guidance and Lessons Identified**, 'Recommendations for Further Research, pages 94 to 134), with the main priorities concerning further work on: -
    - The development of a rigorous risk assessment tool, which will enable its users to identify the full range of risks associated with different kinds of events and circumstances involving crowds.
    - How new risks associated with the building and subsequent operation of a range of new facilities and sporting events, over an extended period, can be managed and mitigated – i.e., drawing on the lessons that can be identified from an analysis of what is different about very large scale, multi-day, multi-site crowd events, and of the multiple problems which contributed to the problematic opening of Heathrow Terminal 5.
    - Stewarding and its impact on crowd behaviours. At present, there appears to be no research investigating the interactions between crowds and stewards, despite stewards undertaking a crucial role during crowd events and often being the first point of contact for crowd members.
    - Individuals who wish to be part of an event but do not have tickets to attend the event itself – i.e., non-ticketed event crowds – and the impact which their behaviour has on the preparation for, and overall management of, an event.

- The scope of “what if...?” scenarios used during preparations to think about potential problems and to test out the suitability and sufficiency of the plans in place. A wide range of scenarios should be tested, considering not only major risks such as bomb threats, but also less dramatic, but probably more likely, risks such as tripping hazards or software problems, which have the potential to contribute towards more major incidents. Moreover, scenarios should be extended to consider the wider event environment, along with the knock-on effects of incidents occurring in succession or combination.

- The next generation of simulation tools, incorporating issues such as: behaviours of groups within a crowd; different types of crowd and crowd member; interactions between crowds and other groups and between fellow crowd members; emotions; tipping points; unexpected scenarios; different system scopes; multi-purpose behaviours; incomplete information; and theoretical underpinning.

- A definition and comprehensive typology of different kinds of crowds, considering dimensions such as: the purpose and duration of the crowd; level of movement possible within the crowd; the event atmosphere; levels of crowd membership identification and heterogeneity; levels of interaction, both within the crowd and with external groups; the size of groups within the larger crowd; and the amount of luggage or baggage crowd members have.

Simulation Tools Reviewed

Simulation Tools Reviewed

- This section reviews three of the leading agent-based simulation tools currently available namely: -
    - Legion (for further information see www.legion.com)
    - Myriad II (for further information see www.crowddynamics.com)
    - Mass Motion
- As these are commercially available tools, access to detailed information was limited. Therefore, for the following reviews: -
    - Legion has been compiled from information available from the public domain (www.legion.com) and from interviews with users.
    - Myriad II has been derived from information available from the public domain (www.crowddynamics.com) and from an interview with the creator (Professor Keith Still, Crowd Dynamics).
    - Mass Motion has been derived from an interview with the creator (Erin Morrow, Arup).

Legion

Applications of Legion

- Legion software is predominantly used to assist with: -
  - Design – e.g., of all spaces used by people.
  - Operations – e.g., to design optimal procedures for crowd event venues.
  - Strategic planning – e.g., to evaluate costs and benefits of major capital projects prior to implementation.
  - Safety and security – e.g., to design, test and improve evacuation procedures.
  - 3D visualisations – e.g., to demonstrate visually how a scheme would function in reality.

- Legion software can be used to model human behaviour in the following market sectors: -
  - Sports and stadia events – e.g., to design new stadia, to test safe ingress and egress capacities, and for operations training.
  - Public realm and commercial buildings – e.g., to design and test evacuation procedures, to investigate transport integration, and to help urban planners and architects in building or public space design.
  - Air – e.g., to design new airports, to test the effectiveness of new or improved security measures, and to analyse and improve boarding procedures.
  - Rail and metro – e.g., to test and design evacuation procedures, to assess and improve station safety, and for operational integration with large scale crowd events, such as festivals.
  - Retail – e.g., to design new retail facilities, to evaluate signage and communication systems, and to develop optimal operational and management plans.
  - Traffic – e.g., to evaluate traffic management strategies, to forecast traffic demands, and to assess the capacity of road networks.

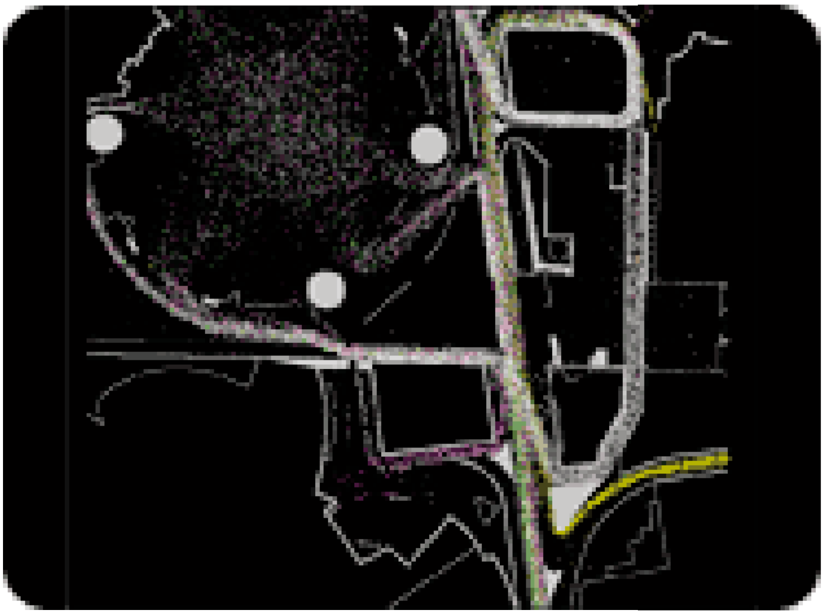
Legion Software

- The two main software tools within Legion are : -

  - Legion Studio C t fpsue ahfm hg efmUr fps ppr C which enables pedestrian movement within any defined space to be simulated (latest version C Legion Studio 2006).

> *most widely adopted, most powerful and most*
>
> (Quote retrieved from http://www.legion.com/software/studio-2006.php)

Figure 1. Screenshot from a Legion Studio simulation of crowd movement in the Sydney 2000 Olympic stadium
(Taken from http://www.legion.com/case-studies/sydney-olympics.php)



- ‘Legion 3D’, which, when used in combination with Studio, can be used to visualise any simulation model in a three dimensional environment (latest version – Legion 3D 2006).

Figure 2. Screenshot from a Legion 3D visualisation, showing a large cityscape with simulated pedestrians and vehicles
(Taken from http://www.legion.com/services/3Danimation.php)

- Legion also now has a software package called ‘Aimsun for Legion’ which enables the interface of pedestrians and traffic to be simulated, through an alliance between Legion and ‘Aimsun’, the leading traffic simulation software company. This software package enables the accurate simulation of vehicles and people at road crossings, for example.

Approaches to Simulation

- Observations of crowds and how they move is crucial to building up a comprehensive knowledge base of different environments, event types and crowd behaviours, so that more realistic, accurate models can be designed.

- Talking to those involved with crowds on a daily basis C e.g., event organisers, crowd control personnel, and station managers C is very helpful for learning about crowds and how they move in particular environments.

- Modellers need to be experienced and to have observed numerous crowd events, so that they are able to provide qualitative input into the model.

- Legion personnel have developed a good knowledge of how crowds behave and move from observing previous/ similar events, and from talking to experienced event planners and station managers.

- Legion is an agent-based simulation tool, with environment layouts based on computer-aided design (CAD).

- Each agent can be seen to move through the environment C from an origin to a destination, weaving through the crowd and performing various activities and behaviours on the journey C as an individual capable of making independent decisions.

- Agents move through the environment according to the principle of least effort C i.e., with minimal time, minimal costs (dissatisfaction and discomfort), minimal congestion and maximum speed.

> [illegible]*he movement of pedestrians footstep-by-footstep in a quantitatively verifiable manner calculating how individuals interact with each other and with the physical obstacles in their environment.*
>
> (Quote retrieved from http://www.legion.com/software/studio-2006.php)

- Agents also have the ability to make decisions based on their environmental circumstances. For instance, if an agent gets off a train and there is a choice of three escalators, they may consider proximity, how busy each is, and where each leads in relation to their destination before deciding which escalator to take.

- Agents are assigned through the available space in the simulated environment. They move around the space randomly, coming together to congregate and form groups at particular areas, and then moving apart again, just as is observed in reality.

- Legion can account for the multi-purpose use of areas within the environment, for instance, using a particular area for both queuing and as a passageway.

- Random elements of behaviour can be introduced to make the simulation more realistic, e.g., entity size, speed, age, and luggage.

- Accordingly, there are different algorithms within Legion to accommodate different types of crowd member, including: -

    - Size of people
    - Walking speed
    - Degree of knowledge of environment or journey to be taken
    - Size and quantity of luggage
    - Disabilities

- The impact of chance events – for example, the late arrival of a train, or the closure of an exit – on crowd movement can also be assessed.

- The demand from the crowd to be modelled in the simulation – in terms of crowd profile, e.g., size, age – is determined by forecasts, knowing the event schedule, knowing venue capacities, and from observations and knowledge of the demand at previous or similar events.

- Questions which can be answered through Legion simulations include: -

    - Will the venue be able to cope with the projected demand?
    - What is the average queuing time at facilities during peak periods?
    - Will queues in front of facilities, such as ticket windows or cash machines, hinder the main crowd flow?

- Which operational scheme enables customers to experience optimal service?
- In the case of an emergency, can the venue be evacuated safely and in sufficient time?
- What are the likely crowd densities at bottleneck points, such as main entrances or stairways?

- Outputs include Fruin's levels of service, journey times, rates of movement, rates of people moving through critical areas of the environment, and number of people waiting.

Assumptions Underlying Crowd Behaviours

- Legion is comprised of different user groups – i.e., different types of crowd and crowd member – which are based on observations of real crowds. These user groups include :-
  - UK commuter
  - Hong Kong commuter
  - Stadium leavers
  - Tourists

- A UK commuter crowd typically has characteristics including: -
  - A faster walking speed – mean speed of 1.3 metres per second.
  - Small entities – i.e., with little luggage or baggage.
  - Travel swiftly from A to B – i.e., good knowledge of their route, good awareness of the best routes to take, use the same origin and destination on each journey, and rarely need to buy tickets.

- A tourist crowd, by contrast, typically has characteristics including: -
  - A slower walking speed.
  - Larger entities – i.e., more baggage.
  - Less familiarity with the environment, therefore take longer routes, and frequently stop to consult signs or maps.

- However, Legion software does allow these user groups to be modified to include whatever characteristics are most appropriate for the particular group to be simulated. For example, modifications can be made in terms of walking speed, age, entity size, size and volume of luggage and restricted mobility (e.g., pushchairs, wheelchairs).

- The amount of crowd management, for instance, will have an effect on crowd movement. For example, at a well managed event, crowd movement is typically well directed and, therefore, easier to predict. At a less managed event, individuals generally have more choice of movement, although the majority will still aim to get from A to B using the least amount of effort.

- Further assumptions are made about: -

    - How early people will arrive for an event – i.e., there will typically be a steady flow followed by a last minute rush.

    - What people will do after an event – i.e., there will typically be a mass exodus with everyone trying to leave at once.

    - Where people will congregate – i.e., at service areas, or areas with the best view.

    - How people will use the spectator services – e.g., an increased density would be expected at lunchtime.

    - What directions the crowd will move in – i.e., typically, crowd members will: -

        - Move in the direction of the main crowd flow (i.e., rarely move against the main flow of the crowd).

        - Follow the routes they always take.

        - Take the shortest route from A to B.

        - Usually self-organise and form lanes.

        - Follow a leader.

Evaluation of Legion

Validation

- Legion is continually being validated by observing and analysing crowd movements at numerous locations and in varying situations (e.g., Berrou et al., 2005). For example, validation studies have been carried out at the Monaco Grand Prix (2000, 2001, 2002), in the London Underground and in Grand Central Station, New York.

Strengths of Legion

- Legion is able to accommodate multiple types of crowd and multiple types of crowd member.
- Individual agents can be randomly assigned characteristics and attributes to more accurately represent the population to be simulated.
- Legion has a wide range of uses and is applicable to a wide variety of market sectors.
- Legion is very easy to observe and understand, therefore making it very easy to convey a situation to a lay audience.
- Legion is user friendly, with good presentation graphics, which greatly appeals to customers.
- Lots of statistical information is produced, relating to factors such as levels of service, journey times, rates of flow, and densities, which can be used to assist with event preparation.

Weaknesses of Legion

- At present, Legion is less successful at modelling groups of people within a crowd.

- Legion does not account for the psychological state of an individual, for instance, levels of stress or emotion.
- The process of simulating a complex environment is very time consuming.
- Much computing power is needed to support the model.
- More qualitative elements need to be built into the Legion software, for instance, concerning the choice of routes.

Myriad II

Applications of Myriad II

- Myriad II was developed by Professor Keith Still and colleagues at Crowd Dynamics.
- Myriad II is a general purpose crowd analysis tool, applicable to all market sectors and crowd events studied thus far.
- The main purpose of Myriad II is to test how, when and where the system will fail, so that preventative measures can be taken and contingency plans be produced to cope with potential problems during a crowd event.

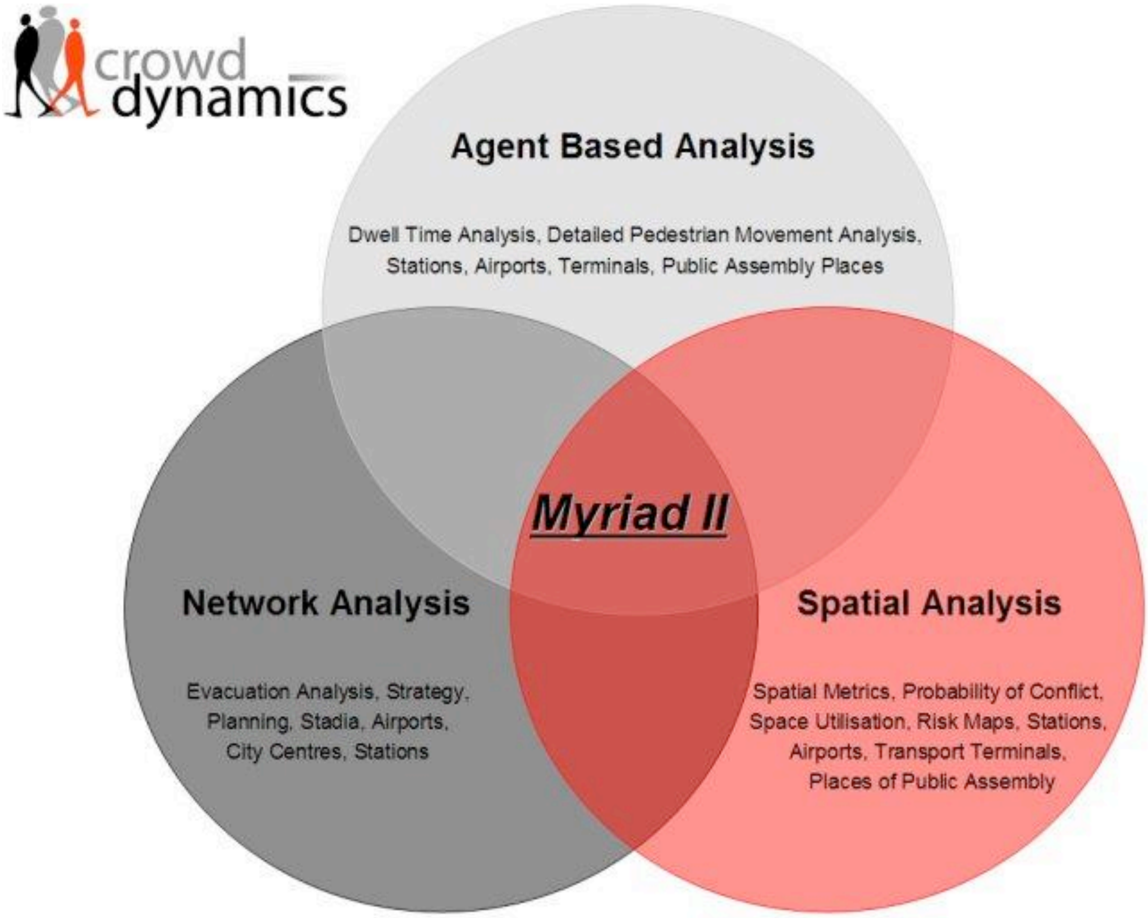
Approaches to Simulation

- Myriad is unique because it models different environments in one, integrated modelling suite, comprising: -
    - Network analysis
    - Spatial analysis
    - Agent-based analysis

- These three different types of analysis are integrated in one environment, enabling the best possible model to be produced for the particular situation to be simulated.
    - For example, network analysis would be most appropriate for modelling the parts of the environment where there are few complex interactions – e.g., simple roads or corridors – whereas agent-based analysis would be more appropriate for more complex interactions – e.g., in concourses.
    - Myriad II is able to replace the appropriate parts of the network model with an agent-based model, and data can then be passed between the two. Thus, the overall simulation integrates a network model and an agent-based model, to represent the parts of the environment without complex interactions and with complex interactions, respectively.

- Real time counts – e.g., flow rates, densities, and ingress and egress rates – can be taken at an event and added into a Myriad II model. This enables early assessments of crowd dynamics, such as flow rates and densities, to be calculated and, subsequently, for appropriate measures to be taken to alter these dynamics, thereby improving crowd safety.

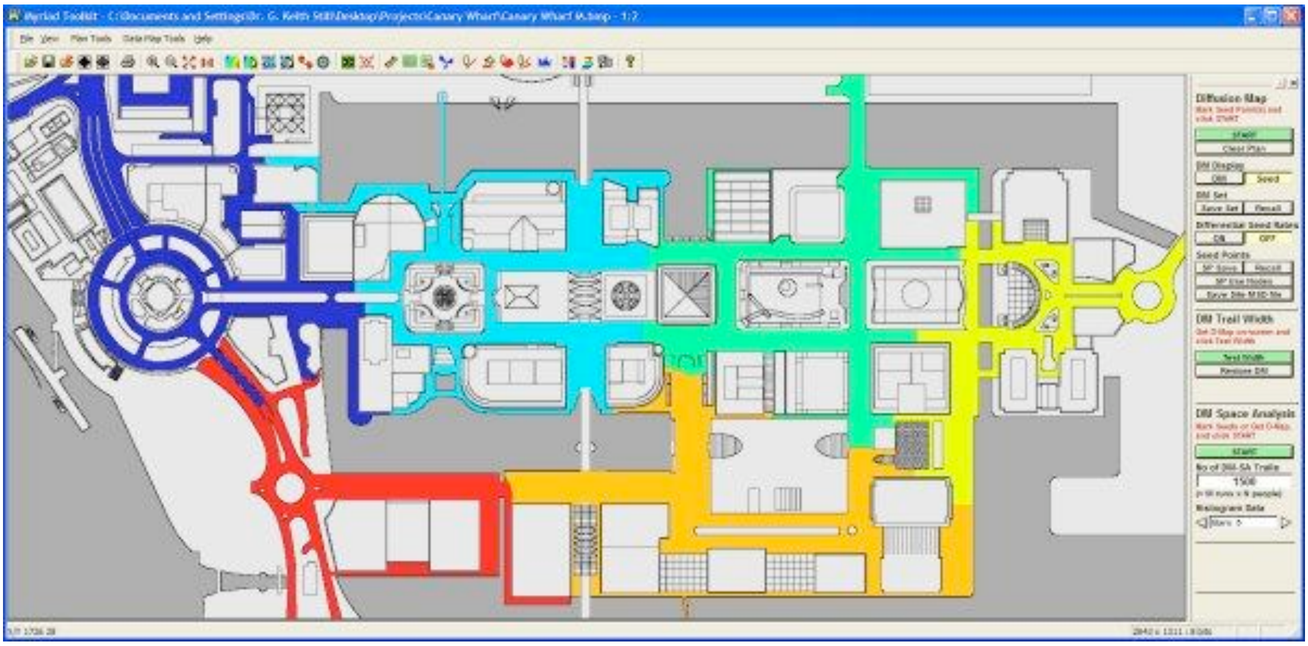
Figure 3. The Myriad II modelling suite
(Taken from http://www.crowddynamics.com/technical/)



Network Analysis

- The network analysis system is design to simulate crowd movements through large complex spaces.
- It comprises a ‘buckets and pipes system’, where real-time crowd flow rates along differing routes – i.e., pipes – can be monitored and the time taken to fill and empty specific areas – i.e., buckets – can be assessed, along with the time taken for the system to potentially over-fill and, subsequently, fail.
- Network analysis is a basic modelling tool, therefore all individuals should be able to use it.

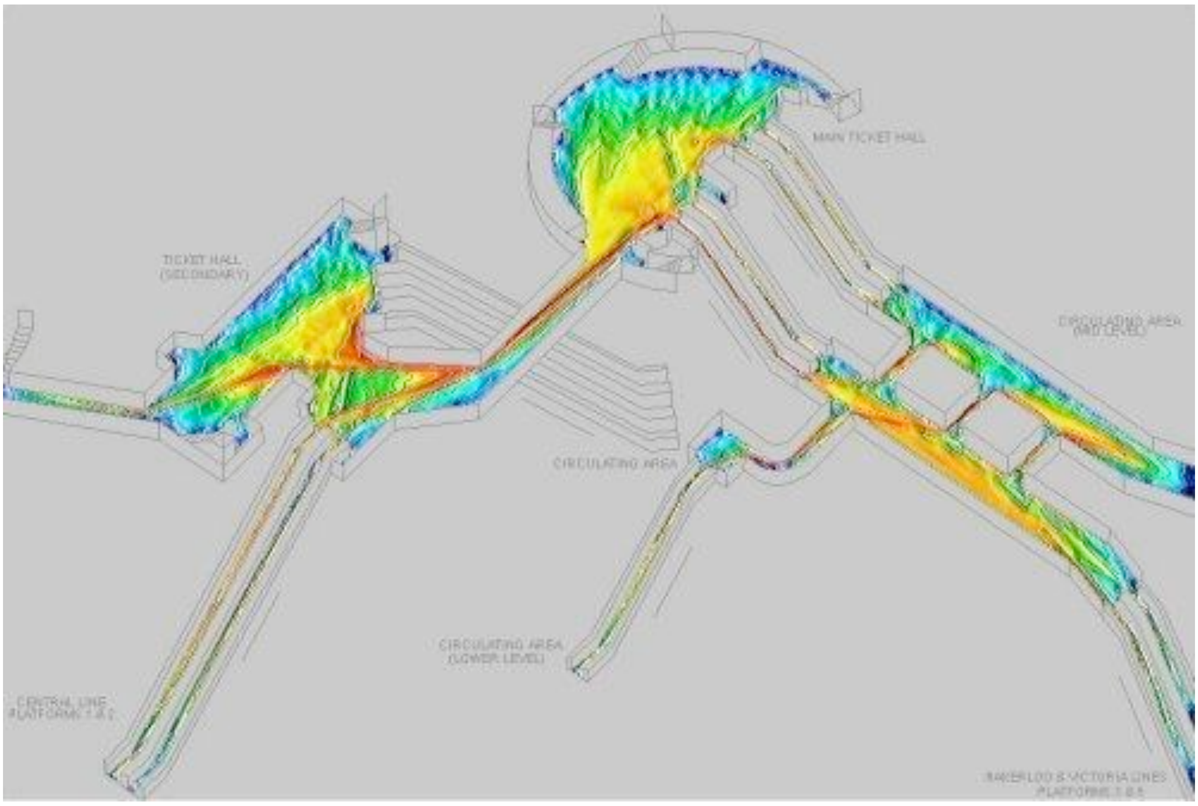
Figure 4. Screenshot of a Network Analysis simulation, with different colours used to indicate the optimal flow capacities for alternative exit routes
(Taken from http://www.crowddynamics.com/technical/)



Spatial Analysis

- The spatial analysis system is designed to simulate how a crowd uses the available space in a particular environment.
- For instance, areas of highest utilisation, areas of under utilisation, most frequently travelled routes, and areas of greatest inter-individual conflict (i.e., in high density bi-directional crowd flow) can all be assessed.
- Accordingly, spatial analysis is able to develop different ‘maps’ – such as a ‘wear and tear’ map, a ‘wasted space’ map and a ‘probability of conflict’ map – to indicate spatial usage.
- This capability is unique to Myriad II.

Figure 5. Example of a Spatial Analysis simulation, indicating variations in crowd density throughout the given environment
(Taken from http://www.crowddynamics.com/technical/)



Agent-Based Analysis

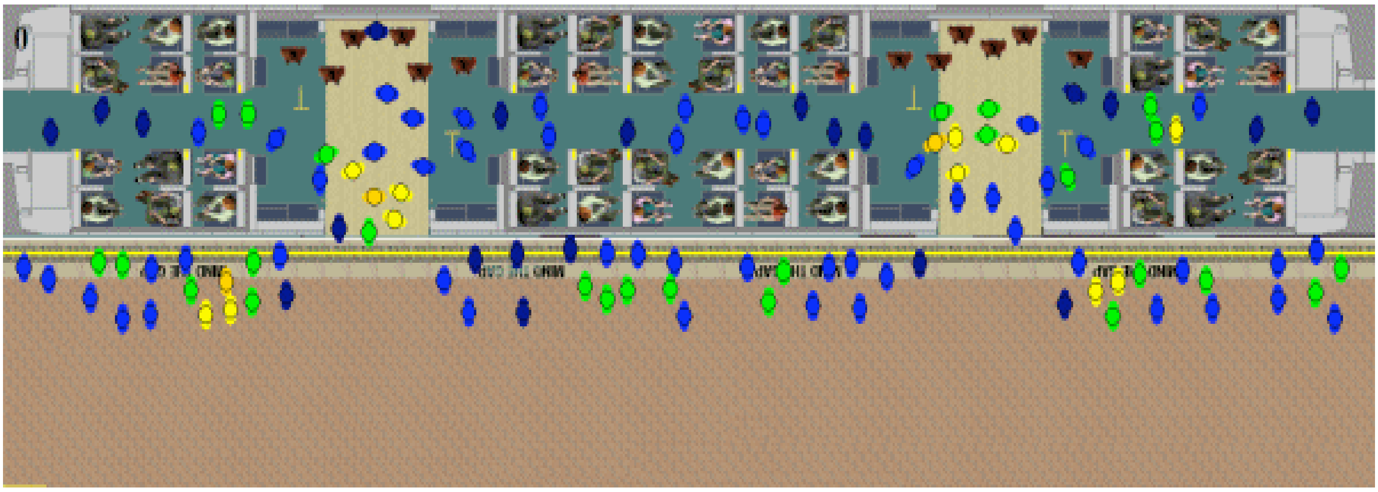
- The agent-based analysis system is more appropriate for use in complex environments and interactions, and is designed to simulate density, speed, agent location and space utilisation in a given environment.

- The system is comprised of individual, autonomous agents, each with individual speeds, densities and attributes. Thus, each agent is capable of scanning, seeing and reacting to the environment.

- Each agent attempts to get from A to B in the fastest possible time according to the principle of least effort – i.e., avoiding high density areas, and covering the shortest distance in the shortest time, with maximum speed.

- Due to the complex nature of this analysis system, it should only be used by experienced modellers.

Figure 6. Screenshot from an Agent-Based Analysis simulation, showing the movement of individuals through a complex environment
(Taken from http://www.crowddynamics.com/technical/)



The Myriad II Suite

- The Myriad II suite is designed to test boundary conditions as opposed to specific circumstances, in order to assess how different crowd compositions are likely to affect the fundamental parameters in the model – i.e., flow rates, density, ingress, circulation and egress – in both normal and emergency conditions.
  - For example, what is the likely impact on these parameters if 5% of the population are elderly? What is the likely impact on these parameters if 2% of the population are aggressive?

- In order to test these boundary conditions, Myriad II uses a flux algorithm, which enables the impact of the numerous potential variations in crowd composition to be more easily assessed.
  - The more specifically characteristics of individuals within a model are defined, the more combinations of different crowd compositions are possible, and the more models are therefore needed to test out the different possibilities.
  - Using a flux algorithm, however, means that only one model is needed to assess these different possibilities. The flux algorithm enables every member of the crowd to possess the different characteristics to be tested at some point during their attendance at the event.
  - Thus, the overall speed-density distribution and composition of the crowd is maintained, but specific attributes are randomly shuffled between individuals within the crowd.

"You can't predict to the nth degree what any individual might do, and I don't think there's any point in trying to. There's a huge benefit in understanding the limits of crowds, such as flow rates, density and the point of collapse, but there's no additional benefit in breaking that down further and further."

Professor Keith Still
Crowd Dynamics

- The key factors involved with successful crowd management which are considered by Myriad II are: -
    - Ingress, circulation, egress
    - Design, information, management
    - Flow, fill, fail
    - Speed-density distribution
    - Packing coefficient

- Currently, a new part of the Myriad suite – called “event planner” – is being trialled. This system is designed to visualise risk as a dynamic, according to a red-amber-green timeline. Risk changes in time, size, location and shape, therefore it is important to have a more dynamic means of assessment.

Assumptions Underlying Crowd Behaviours

- Influences on crowd behaviours can only manifest themselves in one of four ways, namely, objective, motility, constraint and assimilation (Still, 2000). These have been found to be very robust over the years and have needed very little refinement. They cover all possibilities, e.g., event types, crowd types, attributes, etc.

1. Objective

- What are the individual's objectives? How is he or she going to move?
- Objectives can only cause an individual to move in a certain direction or to remain still, and depend on factors such as information, signage, management and location geometry.

2. Motility

- The rate at which an individual can move.
- Motility is a function of human dynamics – i.e., acceleration, deceleration, and speed of movement – and is dependent on factors including route conditions, weather conditions and crowd composition.

3. Constraint

- Constraints are factors which act on the system to restrict crowd movement.
- For example, increased crowd density and increased location complexity both decrease crowd flow.

4. Assimilation

- This is the time it takes for people to take information onboard and react to it.
- Assimilation depends on issues such as communication system, management strategy and composition of the crowd.

Evaluation of Myriad II

Validation

- Myriad II is continually being validated against video footage and observations made in the field.
- The assumptions made by Myriad II are constantly being refined as a result of more up-to-date data and information. This refinement is vital to ensure a more accurate model is produced.

Strengths of Myriad II

- The main strength of Myriad II over other simulation tools is the use of the three integrated modelling tools in one environment – i.e., network analysis, spatial analysis and agent-based analysis.
- This integration means that an environment can, for instance, be modelled primarily as a network with more complex sections of the data integrated into an agent-based model.
- It is this multi-scalar modelling, enabling different environments to be simulated in one, integrated suite that makes Myriad II unique.
- Models can be set up quickly and results can be obtained quickly.

Weaknesses of Myriad II

- The complex nature of the Myriad II suite – incorporating network, spatial and agent-based modelling – means that the user – i.e., the model builder – needs to have a broad background in modelling, in order to understand the differing modelling techniques and, therefore, to use to tool as appropriate.

Mass Motion

Applications of Mass Motion

- Mass Motion was developed in 2005 by Erin Morrow at Arup – a large, international firm of designers, engineers, planners and business consultants (see www.arup.com).

- The main sectors in which Mass Motion can be applied are: -
  - Transport planning
  - Mass transit
  - Emergency egress
  - Process modelling – e.g., at airports, including check-in and security
  - Retail – e.g., in a station or an airport
  - Sports stadia

- Most of the simulations conducted using Mass Motion involve "what if...?" scenarios, where the design of particular environments require testing with varying crowd populations to ascertain whether they will be able to cope with forecasted crowd demands. If a design is found to be insufficient, alterations can be made accordingly.

- Mass Motion now has an interface that is accessible to the vast majority.

Approaches to Simulation

- Mass Motion is a 3D agent-based simulation tool, populated by individual, autonomous agents capable of making independent decisions in order to achieve a goal.

Figure 7. Screenshot from a Mass Motion simulation of crowd movement at Union Station in Toronto
(Image courtesy of Erin Morrow, Arup, creator of Mass Motion)

- Each agent has a position, an orientation, and a velocity.
- A key part of all Mass Motion modelling is that all agents have a goal – i.e., to achieve a task in the minimum time possible, such as getting from A to B, or exiting a building.
- Agents are aware of physical constraints around them, such as walls, and have a cone of vision in which they are able to see other agents. Taking these factors into consideration, each individual agent makes a best guess of the way forward five times per second – i.e., almost continuously – as occurs automatically in reality.

- There are specific algorithms within each model, which are able to truncate the vast number of possible route choices available to the agents, removing the ones which are senseless or counterproductive in a given environment and situation.

- Signs can be added into a model, which agents will pay attention to, and the information on those signs can also change, for instance on an arrivals board or to show platform changes.

- Agents are programmed to avoid collision, to find open space, and to track a local goal on the way to their destination. However, there are elements of fuzzy logic in this and collisions, thereby, do occur, probably at about the same rate as in real life. These collisions appear to confuse agents but they quickly recover and move forward.

- Mass Motion simulations are able to consider the wider environment, such that the movement of agents throughout a whole environment can be followed – e.g., from a station environment out into the wider city network – rather than focusing on one particular location.

- Currently, work is being carried out to improve the simulation of groups of agents, for example, families or a group of people going to a football match.

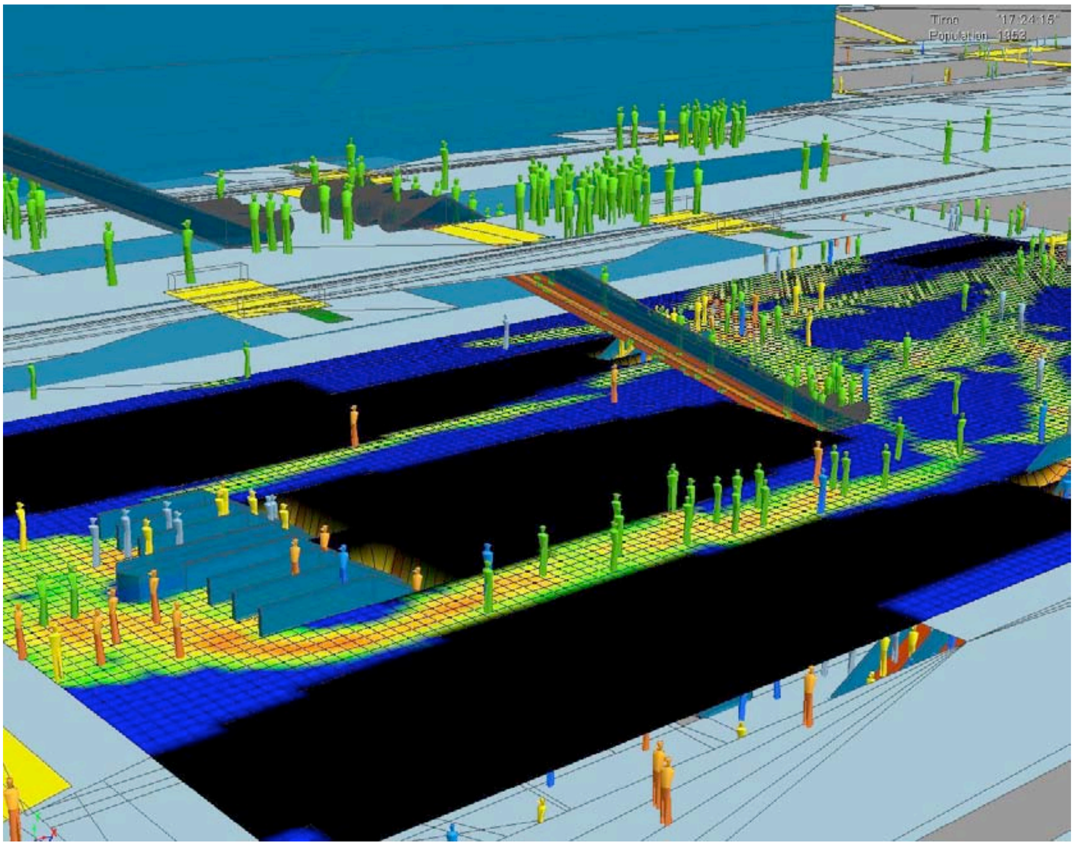
- There are also possibilities of further developments for blind people, disabled people and people carrying large amounts of luggage. These could be catered for using model parameters such as the amount of personal space people need and their speed characteristics.

Assumptions Underlying Crowd Behaviours

- Mass Motion primarily distinguishes two different types of crowd: -
  - A commuter crowd, where published data on walking speeds is used to inform model parameters
  - An evacuation crowd, where the rules are simpler.

- Within a commuter crowd, a further distinction is made between tourists and expert commuters, and the percentages of these within a particular simulation can be varied. Moreover, the percentage of tourists who need to follow signs can fluctuate, as can the percentages who are just looking for a platform, who want to do some shopping or who are seeking a bathroom.

Figure 8. Screenshot from a Mass Motion simulation of crowd movement at Transbay Terminal in San Francisco
(Image courtesy of Erin Morrow, Arup, creator of Mass Motion)



- Differences in individual agents are assigned randomly on a distribution curve. For example, some people walk faster than others, some are more averse to congestion, and some are keen to minimise the distance they travel.

- Mass Motion also utilises two kinds of rules for commuter crowds: -

  - Higher order rules, where people are given an overall target, such as to get to point A. Within that overall target there are additional rules, for example, if area X is congested, deviate to area Y.

  - Local rules, which are more reflexive and involve local decisions to determine the best way for individuals to move through an environment.

- Different rules are used to underpin movement in evacuation crowds. For example, crowds in an evacuation situation are less likely to consider alternative options preferring to behave in the most obvious way, and are more likely to follow others.

Evaluation of Mass Motion

Validation

- Much work has been carried out in order to validate Mass Motion. For example, at Toronto Union Station, city data and census data were used to plot and simulate the flows of commuters. Each exit door and platform was then surveyed to show that the simulation matched the actual pattern of crowd behaviours to within a 5 % error.

- Other validation has been done on a more localised scale, for instance, looking at how many people take an escalator during a certain time period.

Strengths of Mass Motion

- The main benefit of Mass Motion is its ability to simulate the way in which crowd members think, for example, concerning entries and departures. Consequently, usage and flow patterns, as a result of emergent behaviours, can be modelled, without the need to input the pathways into the model initially. No other simulation tools do that.

- A further strength of Mass Motion is its capacity to model the wider environment, enabling the movement of an agent throughout the system as a whole to be simulated, as opposed to movement at one specific location.

Weaknesses of Mass Motion

- To the best of our knowledge, Mass Motion is currently lacking in the following areas: -
    - It does not account sufficiently for groups of individuals moving around a crowd event.
    - Improvements need to be made with regards simulating people with disabilities and large amounts of luggage.
    - It does not consider individuals' emotions and the impact which this can have on their movement and behaviour.

Future
Simulation Tools

Future Simulation Tools

The interviewees agreed that key areas for future simulation tools to focus on include: -

- Developing 3D agents and environments.
- Improving the speed and ease of use.
- Producing quantifiable data.
- Accurately reflecting the different characteristics of different types of crowd and types of crowd member.
- Using research evidence to underpin the choice of characteristics and behavioural assumptions for different types of crowd and crowd member.
- Simulating the behaviour of groups within crowds.
- Incorporating individuals' emotions into simulation models, such as stress, frustration and patience.
- Modelling the interaction between people and traffic – crowds do not exist in isolation, and it is important to examine the interface between crowds and the different elements with which they interact.

Key Learning Points

KEY LEARNING POINTS

– Simulation Tools –

- **Real-time observations of crowds and how they move, in addition to talking to experts involved with crowds first-hand on a regular basis, is vital to develop a realistic simulation model.**
- **Simulation tools can be used to assist with issues such as design, safety and security, and strategic planning, for market sectors including transport, retail, sports and the public realm.**
- **3D software tools offer the most realistic visualisation of an environment.**
- **The most realistic simulation tools are populated by intelligent, autonomous agents, capable of making independent decisions and reacting to environmental conditions.**
- **The principle of least effort appears to be the most utilised algorithm underpinning agent movement, where agents move so as to minimise time, costs and congestion whilst maximising speed.**
- **Different types of crowd, with different characteristics, are acknowledged within the simulation tools, based upon observations and experience rather than research literature. For instance, commuter crowds, tourist crowds and evacuation crowds.**
    - **There does not appear to be a set number of crowd types in each simulation tool – i.e., it is not possible to say that Legion, for example, has X crowd types.**
    - **The characteristics of these key crowd types can be modified to accommodate the type of crowd required.**

- **Agents can be randomly assigned individual attributes, such as size, gender, age, luggage, walking speed, disabilities, and familiarity with the environment.**
    - **There does not appear to be a set number of crowd members types in each simulation tool – i.e., it is not possible to say that Mass Motion, for example, has X crowd member types.**
    - **The simulation tools appear flexible and able to accommodate differing types of crowd member**
- **Assumptions are made regarding likely crowd behaviours in particular environments – based on observations and experience of crowds – such as how early crowds will arrive for an event, at what speed and in which direction individuals are likely to move, and where people are most likely to congregate.**
    - **There does not appear to be a fixed number of rules underpinning crowd behaviour – i.e., it is not possible to say that Myriad II, for example, has X rules relating to crowd behaviour**
    - **The simulation tools appear flexible and able to adapt in order to accommodate anticipated crowd behaviours in specific circumstances.**
- **Simulation tools are continually being validated by observing and analysing crowd events.**
- **A key weakness of current simulation tools is the vast amount of time and computing power they require.**
- **Future simulation tools should aim to include: -**
    - **Groups of people within a crowd.**
    - **Emotions of individuals.**
    - **Interface between people and traffic.**

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