Hazards Forum

Crowd Control and Crowd Safety

4 March 2004

Sponsored by:

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Institution of Civil Engineers

and

LEGION
Legion Limited
Programme

Crowd Safety and Crowd Dynamics

Thursday, 4 March, 2004 at the Institution of Civil Engineers, One Great George Street, London.

Event Programme
16.45 Tea.
17.00 Chairman’s welcome

\textbf{Mr David Eves} CB Ex Deputy Director General, HSE

17.15 Presentations.

\textbf{Helen Muir} Professor of Aerospace Psychology, Cranfield University
\textit{‘Emergency evacuation from aircraft’}

\textbf{Mr Martin Band} Chief Executive, Legion Ltd
\textit{‘Simulating pedestrians: essential foresight for designers, operators and owners’}

18.15 Discussion period
19.15 Concluding remarks by Chairman
19.25 - 20.20 Light refreshments.

Background
A risk averse society, the increasingly cautious stance adopted by regulators and increasing urban populations are placing ever greater pressure on designers and operators of large sites and transport systems to ensure that activities attracting large numbers of people, such as entertainment, shopping or travelling, are conducted safely. This event provides the opportunity to witness aircraft evacuation and to see a demonstration of Legion’s predictive pedestrian simulation software, used by Olympic planners and by London Underground and Crossrail to plan stations capable of coping with increasing passenger loads.
CROWD SAFETY AND CROWD CONTROL

Attendance List

CHAIRMAN
Mr David Eves CB - Ex Deputy Director General, HSE

SPEAKERS
Professor Helen Muir – Professor of Aerospace Psychology, Cranfield University
Mr Martin Band - Chief Executive, Legion Ltd

GUESTS
Mr Nick Agnew - Safety and Contingency Planning Manager and London Resilience Team
Mr David Atton – Institution of Mechanical Engineers
Mr Michael Barrett - Chief Safety Engineer, British Waterways
Ms Liz Bennett, Institution of Civil Engineers
Mr Jan Bugaj - BA London Eye
Mr Phil Cable - HSE Rail
Mr Nick Connor - Commercial Director, Legion Ltd
Mr Miller Crockart, Snr Account Manager, Legion Ltd
Sir David Davies - Chairman, Hazards Forum
Dr Sam Freeth - Geological Hazards Research
Mr Jeff Galilee - Head of Health, Safety and Licensing Division, London Borough of Brent
Dr Alex Gerodimos - Production Development Manager, Legion Ltd
Dr David Giachardi - Secretary General and Chief Executive, Royal Society of Chemistry
Dr Dougal Goodman - Foundation for Science and Technology
Mr Peter Graham - Individual Member, Hazards Forum
Mr Philip Greenish - Chief Executive, Royal Academy of Engineering
Dr Kate Hammer - Marketing Manager, Legion Ltd
Ms Lucinder Hensman – Sancroft International
Mr Ken Hope - Rossmore Group
Mr John Lacey - President, IOSH
Mr Jim Lambert - Managing Director, BMT Reliability Consultants
Dr Ian Lawrenson - Editor, Hazards Forum Newsletter
Mr John Lee - Secretary, Hazards Forum
Mr Julian Lockett - Principal Consultant, BMT Reliability Consultants
Snr Vicente López - Technical Manager, Madrid Metro
Mr Ifran Malik, Assistant Director of Environment, London Borough of Brent
Ms Suzanne May - Chair, London Transport Users Committee
Mr Jerome Munroe-Lafone, Director, Scott Wilson
Dr D Peace - Fire Research Division, ODPM
Mr Fred Pell - Bombardier Transportation UK Ltd
Mr Anthony Piekos - Eurogears Ltd
Professor Simon Pollard - Professor of Waste Technology, Cranfield University
Ms Bernadette Redfern - New Civil Engineer
Mr Chris Rooney - Arup
Mr Gabriel Santos - Head of Security and Safety, Madrid Metro
Mr Reg Sell - Ergonomics Society
Mrs Sell - Observer
Mr Gordon Senior CBE - Hazards Forum
Professor Ernest Shannon CBE FREng - Hazards Forum
Mr Dennis Streeter - Divisional Officer, Transport Fire Safety Group
Dr Brian Thompson - Individual Member, Hazards Forum
Mrs Peta Walmisley - British Computer Society
Mr Greg Washington – Shell, UK
Mr Michael Woods - Head of Operation and Research, Rail Safety and Standards Board
Event Report

Introduction

The Chairman, Mr David Eves, CB, welcomed 47 guests to the Institution of Civil Engineers for the first of the Hazards Forum events in 2004. He first thanked the Institution and Legion Ltd for sponsoring the event and then explained his interest in the subject. As a part-time consultant to Sancroft International he had come into contact with Legion Ltd. Their work interested him because of his own experience while working for Her Majesty’s Factory Inspectorate at Bethnal Green in 1964. While there he learned of the accident which had occurred at Bethnal Green Underground Station during an air raid in the 2nd World War. 162 people were killed accessing the station when they fell down the stairs because of the crush. He also explained that he was a resident of Pinner, in Middlesex, which holds an annual fair. Thousands come into the Fair and then have to leave and this presents problems of access for emergency services. Unfortunately these risks are not thought about until an accident occurs as demonstrated by the Hillsborough and Ibrox Stadium disasters. In concluding his opening introduction, the Chairman referred to a former Health and Safety Commission Chairman, Mr Bill Simpson, who had coined the expression ‘Catastrophe Kindles Care’. An appropriate thought for all those associated with risk and pertinent to this evenings event. He then invited Professor Helen Muir to make the first presentation.
EMERGENCY EVACUATION FROM AIRCRAFT

Helen Muir, Professor of Aerospace Psychology, Head of Department of Human Factors and Air Transport, School of Engineering, Cranfield University

Professor Muir opened her presentation by showing a number of air crash scenes and advising on the numbers who either escaped or were killed. On the surface it appeared strange that survival rates between the crashes were so diverse but Professor Muir explained that there were several factors which influenced survival.

**Factors influencing survival**

First the design of the aircraft could play a significant part in this. Lives could be saved by improving the crashworthiness of the aircraft, by reducing the number of seats so that gangways would be greater, increasing the size of the exits, by using fire resistant materials in the construction of the plane and incorporating water sprays. However all these measures cost money and at the end of the day a balance has to be struck between what measures are taken and how much the passengers are prepared to pay.

Second the quality of the emergency procedures and their communication to passengers is important. However too detailed and lengthy pre flight demonstrations lead to boredom and inattention for irregular travellers while regular passengers probably don’t listen at all.

Next the number of staff on the aircraft and the quality of their training will also affect survival rates in the event of a crash. In addition the environments, both inside and outside the aircraft, and the clarity of evacuation aids, such as exit signs, floor proximity lighting and directional noise will make a contribution.

Finally and by no means least in level of importance is human behaviour. Professor Muir explained that her research had shown a marked difference in the behaviour of passengers on holiday charter flights where there could be a high percentage of families with children and less used to travelling by air, compared say with a scheduled flight occupied predominantly by business people who flew regularly. The chances of surviving a crash would be much higher in the latter case.

**Human Behaviour**

The human response to a crisis will vary according to the individual’s perception of the danger. A packet of cigarettes, for example, carries the words ‘Smoking Kills’ but its effect on a hardened smoker is negligible. If a fire alarm sounds with no apparent signs of fire, evacuation from buildings or aircraft takes considerably longer than if flames and smoke are clearly visible.

One of the problems faced by researchers in this field is to simulate conditions of emergency so that results are meaningful.

We all possess a fight/flight instinct but if we elect to fight successfully then the equipment must be simple and above all intuitive to use. If on the other hand we choose to flee then the escape route must be clear and there must be sufficient space in the event of a rush.

There are several behavioural responses. The response may be orderly, ie people calmly but quickly react, following clearly marked escape routes in which case the chances of escape are high. If behaviour is disorderly ie people move with one intention and then change their minds and move in another direction without real purpose then the chances of escape will reduce.

Another kind of response could be inaction, due either to misunderstanding the seriousness of
the situation or through terror. There may be panic and it is also known that in an emergency people are able to demonstrate enhanced physical performance. Factors influencing successful escape include, the perceived level of threat; awareness of the situation; the existence of a well rehearsed emergency plan; the performance of staff in control; the type of people involved in the incident; their familiarity with the vehicle; the clarity of the evacuation signage; the behavioural responses; and possibly the most important of all the design of the emergency equipment should result in intuitive operation.

Professor Muir then showed several excerpts from a video showing the results of research carried out at Cranfield. She iterated that reproducing true emergency conditions was difficult but believed that offering £5 to the first 30 people who emerged from the aircraft at least went some way to achieving this. The comparison between the behaviour when no incentive was given to that when £5 was on offer certainly supported this claim. Film of evacuations through varying sized bulkheads within the aircraft, and from bulkhead and over wing exits was shown. Under incentive conditions the additional incidence of body mass blocking exits was clearly demonstrated. Also clearly demonstrated was the point about intuitive design. The normal over-wing door has to be physically detached from the aircraft and then thrown out. This caused far more problem for the volunteers trying to follow the instructions than a vertically sliding intuitive design.

A bar chart of time for first 30 to evacuate against width of bulkhead exit showed reduced times as the exit width increased and this may appear obvious. However, a similar chart for over-wing exits showed that for such a small exit there was an optimum amount of space required; with too little or too much space both causing problems.

Professor Muir finally mentioned the steps being taken to address the additional problems faced when designing escape routes in very large aircraft. Issues being researched included: exit size, location and access; aisle size and location; configurations for cabin seating; sill heights; slides and post egress conditions; emergency lighting; access to the upper deck and novel interiors.

She concluded by stating the challenges for this kind of research. Namely that rehearsal exercises were difficult, there were ethical issues about placing people at risk and in particular the ability to provide realism while considering safety. Unavoidably in this respect there had to be some trade off.
EMERGENCY EVACUATION FROM AIRCRAFT

Helen Muir
Professor of Aerospace Psychology
Head of Department of Human Factors and Air Transport
School of Engineering
Cranfield University

Factors influencing survival
1. Design of Vehicle e.g. crashworthiness, numbers and location of seats and sizes of exits, fire resistant materials, water sprays.
2. Emergency Procedures and Instructions e.g. whether to evacuate vehicle, communication with public.
3. Training and performance of staff e.g. number of staff and duties
4. Internal environment e.g. smoke, heat.
5. External environment e.g. risks of injury post evacuation
6. Evacuation aids e.g. exit signs, floor proximity lighting, directional noise
7. Human behaviour e.g. actions, physical capabilities
Human Responses in a Crisis

- Source of threat
- Perception of fire vs reality
- Fight-flight instinct (fear/anxiety)
- If fight
  - equipment, simple and intuitive
- If flight
  - escape route clear
  - Sufficient space in event of rush

Behavioural Responses

- Orderly behaviour
- Disorderly behaviour
- Behavioural inaction
- Affiliative behaviour
- Panic
- Focused attention
- Enhanced physical performance

Factors influencing successful escape

- Perceived level of threat
- Situational awareness
- Emergency plan
- Performance of staff
- Type of people
- Familiarity with vehicle
- Evacuation signage
- Behavioural responses
- Importance of intuitive design

Simulation of survivor escape door and seating of fatalities

- Faculty
- Unoccupied seat
- Air cabin staff

Bar Chart of Bulkhead Evacuations

Bulkhead Configuration vs Number of Persons Evacuated
Bar Chart For Overwing Evacuations

AGE AND SEX OF VOLUNTEERS ACHIEVING BONUS PAYMENTS

<table>
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<th>No. of bonuses</th>
<th>% of volunteers</th>
<th>% of males</th>
<th>Mean age (yrs)</th>
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<td>56.7</td>
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</tr>
<tr>
<td>4</td>
<td>8.7</td>
<td>82.1</td>
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</tbody>
</table>

Very Large Transport Aircraft

- Exit size, Location and Access
- Aisle Size and Location
- Cabin Seating
- Sill Heights
- Slides and Post Egress
- Emergency Lighting
- Access to upper deck
- Novel Interiors

Challenges for research

- Rehearsal exercises difficult
- Ethics
- Safety/Realism trade off
Martin Band opened his presentation by showing crowd scenes of different densities at Wimbledon and on underground platforms. He explained that certain density crowds presented little risk but when densities become as high as 5 people per sq metre this results in uncomfortable or unsafe overcrowding. He also explained that individuals within a crowd behave differently. Regular users of an underground or railway station, for example, will probably already have their ticket, know exactly where to go and pass through the network almost without thinking. The behaviour of someone unfamiliar with the system will behave very differently, the tourist, a Mother with children or an elderly person, in particular, is likely to proceed more erratically and slowly.

Legion Ltd, Martin explained, had developed pedestrian simulation software taking account of all the diversities previously mentioned, the aim being to design out situations resulting in overcrowding. The software simulates reality, thus enabling tests to be carried out and optimising the results to make a venue better within the safety of a computer. The system is uniquely based on advanced modelling techniques and detailed measurements of how people move and interact with each other and their surroundings.

Using Wong Nai Chung Road underground station as an example Martin Band showed a picture of simulated people, in the form of moving coloured dots, referred to as entities. The design of the concourse and the simulation showed that individuals had decision making abilities, had diverse characteristics, had individual objectives and an ability to react to the surrounding environment. The Legion diagnosis demonstrated cross-flows in the main concourse area, uneven use of turnstiles across the gateline and areas of unused space. By repositioning gates, information boards and ticket machines a smoother flow through the turnstiles was achieved and serious overcrowding at pinch points eliminated.

Martin Band described the Legion product as a simulation which predicts the movements of individual people in a crowd, footstep by footstep. The software tests different designs or scenarios, assessing the impact of events that have not yet happened. The outputs represent rich and detailed data in graphs and maps that are easy to understand. The Legion system can therefore be used to evaluate configurations and operating schemes, and analyse scenarios in order to improve safety, efficiency and visitor experience. Above all the highly visual nature of simulations makes Legion’s software a powerful tool to support decision making because the visual output from the simulation is easy to understand by non-specialists.

Examples undertaken by Legion to reduce crowd risk at optimum cost were then demonstrated using a series of moving entity dot simulations. A top football stadium required to be emptied in 8 minutes and this was demonstrated as possible. However outside the stadium severe crowding took place for up to 40 minutes because of congestion in the perimeter roads. Legion demonstrated that by simply doubling the width of the egress road from 12.5 metres to 25 metres no other alterations would be necessary and the crowd would disperse in half the time.
When the Sydney Olympic Stadium was being designed, Legion software was used to check the risk of uncomfortable or high risk levels of crowding. It was found that in the original design there would be unsafe congestion on Olympic Boulevard between 22.50 and 23.10 after the games had finished for the day when crowd density was predicted to reach 5 people per sq metre. By introducing a foot bridge over the rail tracks and a one-way circulation system the crowd density could be reduced to just two people per sq metre and this design was used. During the Games a UK visitor to the Sydney Olympic Games was reported as saying, ‘We expected long queues and crowding, but it was absolutely fine. We had a 4-month old Daughter with pushchair. We were so taken with how easy it was that we did everything we wanted to do while at the Olympic Park. Friends of ours went back for an extra day and saw more events. It was a total joy getting around.’ This exercise was a good example of how Legion’s pioneering software simulation system can predict how thousands of pedestrians will move in reality. It demonstrated to the decision-makers how the design would work in practice and, in the event, enabled visitors to the Olympic Park to have a safe and enjoyable experience. Associated with this piece of work Martin Band then demonstrated the effect of extreme demands on Olympic Station. As with the arena the station had to cope for half an hour either side of 11.00pm when between 1000 and 2000 people per minute passed through the station. In this case the answer appeared to be a queue management system. Legion simulations first demonstrated the safety risks posed by the demand on the station. Several design options for a queuing corral system were tested and the simulations helped define the final design which worked successfully for the Games.

Martin Band then described and demonstrated work Legion had carried out on an underground station in Hong Kong with a three way track interchange handling 1 million passengers per day. Each of the six platforms was assessed and the peak and average platform space density measured. Analysing the whole station it was found that congestion occurred generally only in queuing areas to escalators.

Having graphically demonstrated several projects Martin Band then went on to explain the basis of Legion simulation. First the desired walking speed of many different types of individual was measured in different contexts. To date some 1.4 million observations of people have taken place. The findings are then validated, for example the entities in a Legion simulation naturally form lanes when people are moving in opposite directions. This was found to be exactly what happens in practice. Similarly, for an existing installation, simulations were carried out to predict flow of people on a stairway. The same stairway was then measured in practice and the actual and simulated measurements compared very favourably. By such validation methods the simulation is refined and improved.

In summary:
- Tools such as Legion can inform safety debate and remove reliance on personal opinion
- Greater safety can be achieved at lower overall cost
  - Money can be spent where it will have the most impact on performance
- Hazards can be identified and designed out before commitment to build
- Not all crowding is dangerous
- Hot spots can be identified and concentrated upon
- Regulations and guidelines are necessary but insufficient
- Visual technologies can greatly reduce the cost burden of getting to safety consensus

For the future Legion’s view is that:
Applications will be extended into
  – Architecture
  – Town planning
  – Retail
  – Airports

New techniques and products will be developed to
  – Assess evacuation
  – Identify crowd ‘tipping-points’
  – Monitor real time hazards

3 years from now, a safety case will not be complete without the quantitative assessments of scheme viability, such as Legion provides.
LEgion

Sustaining pedests: essential foresight for designers, operators and owners

March 2011

The majority of spectators will access and leave the stadium via only one rail station

Legion pedestrian simulation software

- Legion’s approach aims to design out situations resulting in uncomfortable or unsafe crowding
- Legion software simulates reality, testing and optimising in the safety of a computer how to make a venue better
- Legion provides immense value, materially improving project and bottom line profitability while ensuring venues are safe and comfortable
- Legion modelling is uniquely based on advanced modelling techniques and detailed measurements of how people move and interact with each other and their surroundings

Legion simulations demonstrate how people will move

- Individual decision making abilities
- Individual’s characteristics: gender, age, nationality, commuter
- Individual objectives
- Ability to react to surrounding environment

Agenda

- Crowd risks
- Risk reduction – example projects
- Under the bonnet
- Summary
Legion provides detailed diagnosis
Space utilisation

- Cross-flows in the main concourse area
- Uneven use of turnstiles across the gatedline
- Areas of unused space

Legion gives decision-makers real foresight

- The Legion simulation predicts the movements of individual people in a crowd, footstep by footstep
- The software tests different designs or scenarios, assessing the impact of events that have not yet happened
- The outputs represent rich and detailed data in graphs and maps that are easy to understand
- The Legion system can be used to evaluate configurations and operating schemes, and analyse scenarios in order to improve safety, efficiency and visitor experience
- The highly visual nature of simulations makes Legion's software a powerful tool to support decision making

Will this stadium empty in 8 minutes?

Reducing crowd risk at optimal cost

Seeing and quantifying stadium egress

For efficient egress, what width perimeter road?

Testing two options – shown here at 5 minutes
Option A: 25m Egress Road  Option B: 12.5m Egress Road

Stadium egress at 10 minutes
Option A: 25m Egress Road  Option B: 12.5m Egress Road
Stadium egress at 15 minutes
Option A: 25m Egress Road  
Option B: 12.5m Egress Road

Stadium egress at 20 minutes
Option A: 25m Egress Road  
Option B: 12.5m Egress Road

Stadium egress at 25 minutes
Option A: 25m Egress Road  
Option B: 12.5m Egress Road

Stadium egress at 30 minutes
Option A: 25m Egress Road  
Option B: 12.5m Egress Road

Stadium egress at 35 minutes
Option A: 25m Egress Road  
Option B: 12.5m Egress Road

Stadium egress at 40 minutes
Option A: 25m Egress Road  
Option B: 12.5m Egress Road

Will the Olympic Park deliver an 'Olympic experience'?

The solution was a 1-way circulation system

Design included a footbridge over the rail tracks closing the circulation loop
Result: unsafe congestion eliminated

Unsafe congestion shown in red

The bottleneck was designed red, with a comparison for cost-time change.

Will the Olympic Station cope with extreme demands?

Testing a queue management system

- Lego simulations demonstrated the safety risk posed by the demand on the station.
- Design options for a queueing control system were tested.
- The simulations helped define the final design (shown right) which was implemented.
- The control system worked successfully for the Games.

Can a 3-way interchange cope with 1M passengers per day?

Platform density comparison

To improve performance, what regions to target?

- Areas with density of 2 pppm² for greater than a total of 10 minutes in the hour shown red, areas experiencing a density of 2 pppm² for at least 1 second in blue.
- Congestion generally only in queueing areas to escalators.
The basis of Legion simulation

Measuring people (example)
Legion measures desired walking speed in different contexts

Validation
Reproducing emergence of lanes
The entities in a Legion simulation naturally form lanes as happens in real environments

Validating simulation outputs with reality

Selected customer list

Summary
- Tools such as Legion can inform safety debate and remove reliance on personal opinion
- Greater safety can be achieved at lower overall cost
  - Money can be spent where it will have the most impact on performance
- Hazards can be identified and designed out before commitment to build
- Not all crowding is dangerous
- Hot spots can be identified and concentrated upon
- Regulations and guidelines are necessary but insufficient
- Visual technologies can greatly reduce the cost burden of getting to safety consensus

Legion’s view: the near future
- Applications will be extended into
  - Architecture
  - Town planning
  - Rail
  - Airports
- New techniques and products will be developed to
  - Assess evacuation
  - Identify crowded ‘hot spots’
  - Monitor real time hazards
- 3 years from now, a safety case will not be complete without the quantitative assessments of scheme viability, such as Legion provides
The Chairman thanked both speakers for their most interesting presentations. He then invited questions from the floor.

To Professor Muir, had the research covered less fit people such as the obese, mobility impaired or persons afraid of heights for example? Professor Muir explained that it had but that there was a dilemma for the researchers. First, in her experience, the will to survive overcomes the fear of height so for example the escape chutes and slides are used. However injuries are liable to occur and while injuries incurred using a chute, including broken backs, are acceptable under real emergency conditions the public find it quite unacceptable when the evacuation is precautionary let alone under research conditions.

Was the Legion simulation valid for cars and car parks? It could be used but would require new measurement and validation.

Should there be better briefing of travellers? Professor Muir explained that there was a conflict of interest. First one must not put people off travelling so a pre-flight briefing is not aimed at frightening passengers. However if every detail was given the ‘briefing’ would take 20 mins and this would be too boring and too long for passengers to assimilate the information.

To Martin Band, when determining your profiles do you take account of consumption of alcohol? Not specifically but there are vast amounts of information on drunk people. Nevertheless Legion have filmed Wembley stadium crowds many of whom will no doubt have had a drink or two, so some account is taken automatically because of the environment being measured.

Again to Martin Band a questioner was interested in the limitations of the software. Did the model use Baysean methods? Passing the question to one of his colleagues it was explained that the model was based on measurement and validation. The context of the situation is paramount the simulation constructed and the results observed. Clearly where there is no precedent then there will be limitations and these need to be explained.

A comment from the floor was that responses differ based on the available information and the belief that the situation was real. For example the response to a fire alarm sounding was different to the response when smoke is visible. (It was humorously suggested that perhaps fire alarms should belch out smoke rather than noise.) The speaker then asked whether wheel chairs could be coped with. Martin Band confirmed that profiles taken on London Underground included all types including wheel chairs. The simulation has to be enhanced for mobility impairment. Professor Muir admitted that airplanes were poor in dealing with wheel chairs, it comes down to who pays for the extra space as stated before.

Legion was then asked how they modelled hand luggage and those trolley cases which crowds always seemed to have when on railway stations or at airports? Again the answer was measurement and validation. If such hand baggage is expected in the environment being measured then the measurements will account for it. Validation later will confirm the accuracy
of the measurements and simulation. Obviously as more measurements are taken and stored in the data then the more accurate become the simulations.

Another questioner returned to an earlier question to Professor Muir. If injuries during research could happen how does she handle ethics and liability? Professor Muir explained that they have their own ethics committee who are experts. In effect it comes down to making sure that there is a good understanding of the problems by the participants. One explains to them without giving too much away and thereby invalidating the results, that there will be a certain amount of pushing and pulling, etc. Those who are uncomfortable with this just don’t take part.

A further question to Legion re the Sydney Olympic Experience. The ‘People Care’ was immense in Sydney, was this modelled or was it a bonus afterwards? In response Legion confirmed that there were large numbers of helpers on the site and this was known and included in the model.

How is Panic simulated in the model? It isn’t. This is not an area for Legion, contention areas and misbehaviour is outside the Legion remit.

The Chairman thanked the questioners and the presenters for their enthusiastic contributions. He remarked that, as a past regulator, he was interested in the concept that in 3-5 years time safety cases should include crowd control and would watch with interest. The meeting closed at 19.25pm.