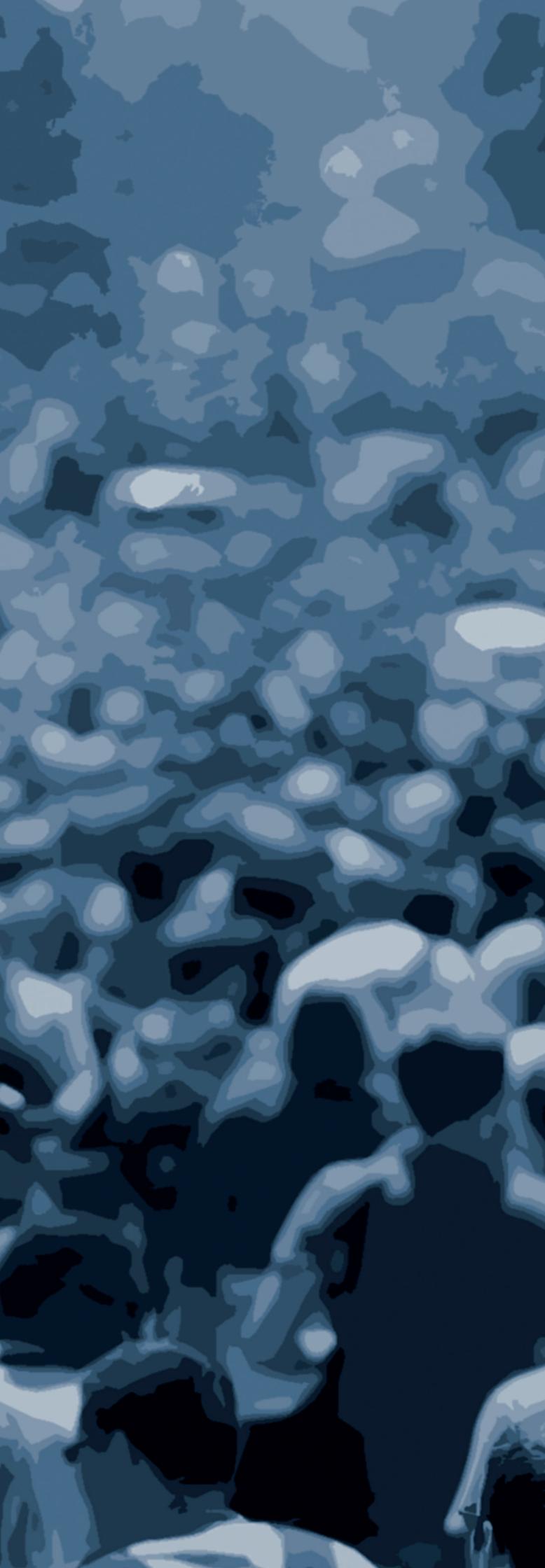


# SAFETY IN NUMBERS

*There are few people on earth who haven't at some point been part of a crowd. But while the saying goes that there's safety in numbers, this only applies if someone has done the sums, as Kirstie Pelling found out when she met mathematician and crowd modeller **Keith Still***



Crowd Dynamics expert Professor Keith Still had his 'lightbulb' moment in a queue for a Freddie Mercury Aids Awareness concert in 1992. Although he'd been modelling crowds for some time, it was only in that moment that his understanding crystalised. Since then he's built a career calculating, modelling and simulating groups of people in indoor and outdoor spaces, while advising some of the world's most prolific event organisers on how to get people in, around and out of events in normal and emergency situations.

Today, in his Harley Davidson shirt, Still looks more biker than professor, and as he welcomes delegates to the Crowd Dynamics workshop in Easingwold, Yorkshire, his relaxed Scottish manner gives away few of his credentials. Still is a Fellow of the Institute of Mathematics and its Applications and a Visiting Professor at Bucks New University, as well as having an international reputation in making crowds count. Through a series of equations, models and simulation tools his consultancy company provides a systematic blueprint for the industry, while his workshops teach others to understand the theory of Crowd Dynamics, and apply it to real events. And the police officers, venue owners and safety officials gathered before him today know just how 'real' things can get. The recent 20th anniversary of Hillsborough provides a sobering reminder of how devastating it can be when crowd safety is compromised.

At its most basic, Crowd Dynamics is a series of equations, numbers plotted on grids, and simple hand drawn models of relevant stadiums or green field sites. Few of the delegates attending this workshop at Easingwold's UK Cabinet office Emergency Planning College have a science or maths background, so the challenge is to engage them in the kind of 'sums' they might not have done since school. Still says he's done a good job when his students don't just understand the maths but know exactly how to apply it. "A police officer might come on the course saying 'I don't do maths.' But you often find that by the end of the third day he's tapping away at his mobile phone confident that he can calculate safe levels of crowd density, and hold his own with an event organiser or consultant."

But delegates aren't thrown in at the deep end. In the early stages of the course they learn simple calculations and diagrams: calculating crowd density, exploring the effects of density on groups of people in limited spaces, working out upper safety limits and discussing the implications for assessing them. They are given cardboard cut-out figures and a grid, and told that 47 persons per 10 square metres is the recommended guidance for standing crowds at sports venues, a figure that they then break down further (see diagram to right).

Then it's a question of working out safe upper limits for different sizes and types of venue. "The first cut principle is if you can do a simple calculation and show that if it doesn't work then it doesn't work. If you do simple calculation and the numbers *do work* then you may then need to drill in more detail, but the basic foundations are there. Of course we then go on to break it down into more maths than that." ►

# Safety in numbers

**T**he delegates are then encouraged to mark out a one metre square grid on the floor, turning the exercise into a social experiment. The four smallest people in the room are selected to stand in the grid. Then the largest. They are asked how it feels to be part of that group in that particular space. Then extra delegates are moved into the square metre, to explore the sensation and find out at which point they start to feel uncomfortable. When up to ten people are packed into the square, one of the delegates on the periphery is given a slight push, and the group feels the sensation of a shock wave passing through them (like Newton's Cradle – but with people). Still then asks them to visualise this square multiplied dozens of times in a confined space in an emergency situation.

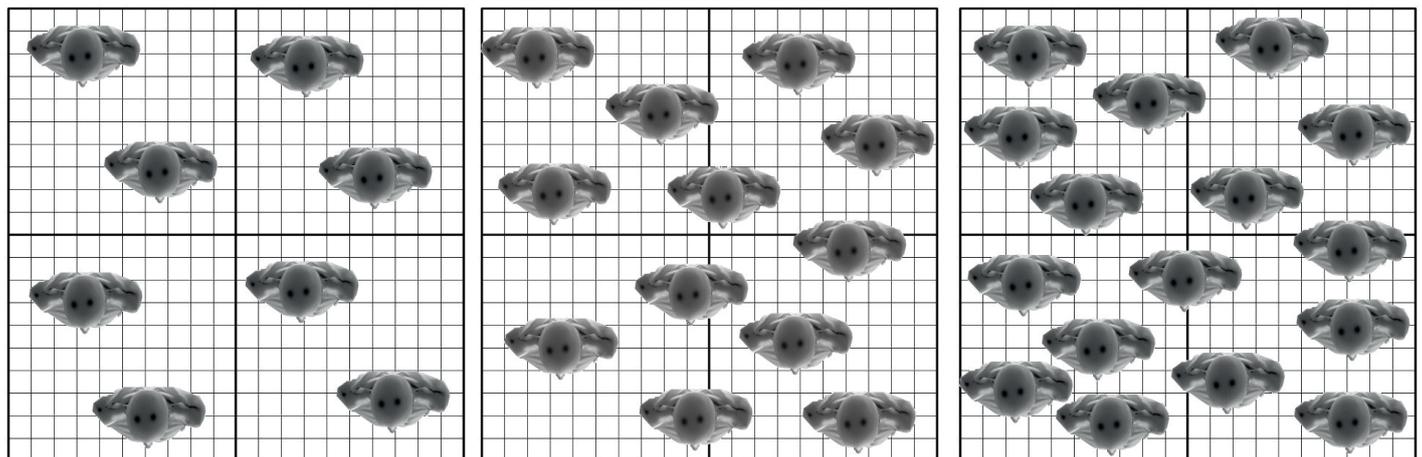
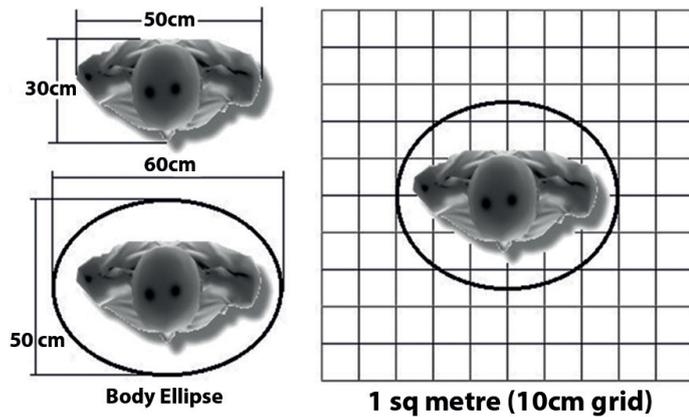
Then the group looks at the effects of moving away from this congested space en masse. To calculate emergency egress (exit) time, they need to work out the correct speed/density relationship. "A sustainable high density crowd flow at four people per metre is something they have to learn to manage, monitor and control," Still explains. "And then by examining what happens if the density builds and flow rates slow down, they are prompted to reconsider design systems or emergency planning measures, for example putting in more egress gates."

Before long, delegates are being marched down corridors calculating minute-by-minute flow rates as the group bunches up and disperses. Corners are added and pinch points considered. The

## NO ROOM TO MOVE

**Top: Two different-sized body profiles (left). A crowd exhibits a marked speed reduction when the space around a person is less than one square metre (right)**

**Bottom (left to right): Two people per square metre, three people per square metre, four people per square metre**



# Crowds have collective reason but they don't have collective behaviour

'little old lady factor' is identified (crowds moving at the pace of the slowest member). "They're then encouraged to imagine about 50,000 people in a corridor and it suddenly becomes relevant," says Still. "The density, speed and movement – the dynamics if you like – suddenly come to life. Whereas before they might have said 'Well I have so much egress and width, it looks about right,' now they can work with the appropriate calculations. You challenge their perceptions and misconceptions, and then go on to apply the maths to a site they're familiar with."

**B**ut Still stresses that Crowd Dynamics is about more than just sums. It involves elements of risk assessment, emergency planning, information systems, human psychology and spatial awareness. Delegates go on to consider the three ways a crowd can be influenced (design, information and management), plotting them against the three different phases of behaviour (coming in, circulating and going out), for both normal and emergency situations. The model, known as DIM ICE, is a matrix of nine boxes each standing for one of these influences and phases (see above right). The delegates then consider the same matrix – but for emergency situations – what is the same, what will be different?

With each practical application of the DIM ICE matrix, Still teaches delegates to recognise and assess how small changes can cause big ripple effects; for example the placing of a police car or impromptu signage that can push crowds into an unforeseen direction. He also dispels myths surrounding crowd behaviour in emergencies: "There is very little evidence of panic as you would see in Hollywood movies with people screaming like headless chickens. Crowds have a collective reaction but they don't have collective behaviour. An example of collective reaction is when a bus stops and the crowd moves towards it; or its group survival instinct is triggered by a sense of danger. People don't suddenly take on group-think, in fact at the first sign of danger they often help each other

	INGRESS	CIRCULATION	EGRESS
DESIGN	Elements of the design influence the crowd during entrance (e.g. barriers, local geometry, route widths, paths and stairs, entrances, turnstiles)	Elements of the design influence the crowd during 'mid-event' moving around (e.g. route widths, stairs, layout and facilities management)	Elements of the design influence the crowd during exit (e.g. egress capacity, route complexity, geometry)
INFORMATION	Many factors prior to the event can influence the crowd behaviour (e.g. advance notification, media coverage, tickets and posters, previous event history, weather forecasts)	Mid-event there can be a lot of conflicting information that influences the crowd (e.g. the performance, signage, PA announcements, stewards and information points)	Signage and PA announcements for departure influence not only the direction but also the distribution of the crowd
MANAGEMENT	Stewards, security and police can divert the crowd to the most appropriate areas, but they also influence the crowd's behaviour	During the event the stewards can actively manage queues and crowd movements	During egress departing crowds can be actively managed to prevent a free-for-all dash for the exit

out and pick up the little old lady rather than trample over her.” Still quotes a study by psychological profiler David Canter which found that in the initial stages of fire only 25% of people tried to leave, while 25% moved towards the danger to try and do something to tackle the situation, and 50% did nothing at all.

It is perhaps ironic that a man named Still has spent his life modelling dynamics – things that move. And just as crowds never stay still, neither can the science. His company is currently developing a groundbreaking software package combining pedestrian based spatial analysis and traffic micro-simulation which leaves the simple maths far behind. In the past few years he has advised on events worldwide from New

### THE DIM ICE MATRIX

This 9x9 matrix summarises the ways a crowd may be influenced

Year events in Aberdeen to the annual pilgrimage to Mecca. And following his work for Beijing and Sydney, Still and his team are advisers for the London Olympics.

But he says managing crowds for events of national or global interest gets harder all the time; with the global threat of terrorism, the rise of huge, multi-purpose urban venues, and the recessionary pressures for owners to pack more people into spaces in order to recoup costs. Then there's media pressure to get it right; in the UK recently the spotlight has been on police treatment of crowds with both the G20 protests and the Hillsborough anniversary. Added to this the 2007 corporate manslaughter act means anyone organising an event is now held liable for accidents and incidents, “Certainly ▶

## PROFILE: Professor G. Keith Still

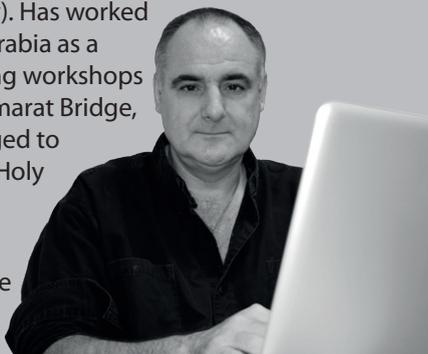
**Born:** 7 January 1959

**Education:** BSc in Physical Sciences at Robert Gordons Institute of Technology (Aberdeen), PhD in Interdisciplinary Mathematics at Warwick University (under the supervision of Professor Ian Stewart).

**Research interests:** Crowd simulations, complexity theory, queueing theory, chaos, self-organised systems, crowd and traffic optimisation, cellular automata...

**Career highlights:** Founded Crowd Dynamics Ltd, an international consultancy business advising on crowd dynamics during normal and emergency situations. Was made a Fellow of the Institute of Mathematics and its applications (FIMA) in late 2007 and is a Professor at the Centre for Crowd Management and Security Studies (Bucks New University). Has worked extensively in Saudi Arabia as a special advisor, running workshops and modelling the Jamarat Bridge, and is currently engaged to model Al-Haram (the Holy Mosque in Mecca).

**Hobbies:** Motorbikes, golf, puzzles, playing the saxophone



## THE MATHEMATICS OF CROWDS

Keith Still has developed simulations of crowd movement that use *cellular automata* to model individuals or 'agents'. Cellular automata are discrete mathematical models where each cell in a grid can take one of a finite number of states. As time advances, the system evolves according to a set of rules that determine the new state of each cell in terms of the states of neighbouring cells on the grid.

In Still's cellular automata crowd model, these 'rules' state that each individual will try to move to a desired endpoint, maintain an optimum velocity and keep a minimum distance between themselves and surrounding objects. There is also a delay in an individual's response to changes in the environment (due to the time taken for the brain to assimilate information). A *least effort* algorithm is applied to model the dynamics of the system according to these rules. This algorithm looks for the easiest route (i.e. the route which involves the individual travelling the shortest distance at the fastest pace).

An agent model such as this is typically combined with spatial and network analysis of the area in which the crowd is moving. The overall crowd behaviour is an *emergent* phenomenon, which means that complex patterns arise from simple interactions between the system's parts.

# Safety in numbers

“Over the last few years we’re finding our work is defining the safety aspects of crowds a lot more,” he says.

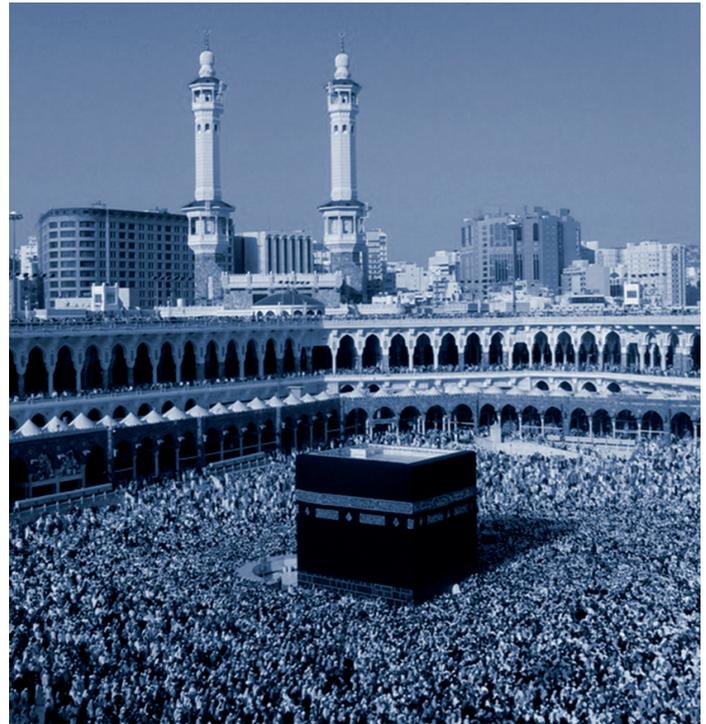
Police are now filtering through the workshops for London 2012, where venues will hold in excess of 80,000 people. And while the stadiums are built with Olympic usage in mind, much of the infrastructure around them, like the London Underground, was designed in a different era. And Still also worries about people’s safety in other stadiums around the UK that haven’t changed in terms of design concept and geometry since Roman times. He says they operate with the modern risks of heavily urbanised environments, a mismatch between arrival routes and pinch points of entry and exit, and a very different crowd from those they were designed to house. “A football crowd in a football stadium has a totally different dynamic from pop fans attending a concert in a football stadium, in terms of culture and demographics, arrival times, how they get there, where they are placed in the venue and how they are policed.”

**A**s we wind up our interview, Keith Still returns to the podium to demonstrate Ellsberg’s paradox with two thousand balls and two buckets. It’s a demonstration of maths versus psychology; the audience are briefed that in one bucket there are 500 red and 500 black balls, while in the second, with 1,000 balls red and black, the percentage is unknown. Simple mathematics would tell his delegates that the probability of picking a red ball is the same in both buckets. But Still alters the risk reward perceptions by telling a member of the audience he’ll give them £10,000 for picking a red ball, while they must give him the same amount if they pick a black one. In nearly every workshop the chosen delegate picks a ball from the 50:50% bucket that they believe has a quantifiable and safer feel to it. Their decision making thus ignores the maths while drawing on perception of risk. He then asks the audience and, in general, more than 80% of the audience also picks the 50:50% bucket.

Still compares the outcome of this exercise to an emergency situation where people are confronted with two exit routes. Despite the fact that one door might have ‘emergency exit’ signs all over it, many people choose to go out through the door they came in by, while the other door is perceived as too risky. “It’s all to do with the known vs. the unknown – it’s not £10,000 now, it’s their life at risk and the choice is based on the perception of that risk – ‘I know this route, I don’t know that route’. But the architect is likely to have designed the building with the assumption that all exits will be used in equal proportion.”

Minimising risk and understanding and predicting a crowd’s perception of it is what Still is all about. But his mission now is to educate others to use the science to keep people safe. “It’s vital to teach people how to do this stuff. Maybe not to the extent they

.....  
**Many stadiums around the UK haven’t changed in terms of their design concept and geometry since Roman times**  
.....



## CROWDS AT MECCA

Keith Still is involved in modelling crowd dynamics at the annual pilgrimage to Mecca, where many fatal stampedes have occurred

can go and consult with the Saudi government or do design work signing off on the safety of 1.2 billion dollars worth of concrete. But to be able to look at the environment and see the risks and say ‘if we did the following simple things we could make it much safer.’ At the start of his workshops he always asks how many people have come to the end of an event and said “Phew! We were lucky that time.” The response is always overwhelming. But Professor Still’s hope is that one day the room will stay silent, because luck is the last thing that Crowd Dynamics should be about. ■

## FIND OUT MORE

**Crowd Dynamics Ltd**

[www.crowddynamics.com](http://www.crowddynamics.com), [www.crowddynamics.co.uk](http://www.crowddynamics.co.uk)

## ABOUT THE AUTHOR



Kirstie Pelling is a writer and journalist living and working in Cumbria. She writes columns and features for a wide range of magazines, has also written for stage and radio, and spent several years working as a promotions producer for BBC radio and TV. She edits a website on family adventure

([www.familyadventureproject.org](http://www.familyadventureproject.org)) and blogs regularly about adventurous family travel and environmental issues.