Introduction to Crowd Science

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Introduction

> Experience is one thing you can't get for nothing.
>
> Oscar Wilde

> The only source of knowledge is experience.
>
> Albert Einstein

We have spent the last two decades developing computer simulations, software systems, tools, techniques and methodologies relating to crowd risk analysis and safety engineering. This effort has not been an academic exercise; the tools have been applied to many of the worlds' largest and most challenging events. These include design aspects of the Jamarat Bridge (the stoning of the devil ritual, part of the annual pilgrimage to Mecca), the 2011 Royal Wedding, London New Year events and as expert witness on a number of high-profile cases (Love Parade, Germany).

Realising, over a decade ago, that computer simulations were only a small part of our consulting projects, we began to focus more of our time towards teaching and training programmes. The bulk of our work is now aimed at developing better techniques for crowd risk analysis and safety engineering. We do this through educational material and university courses, Foundation degree and BA (Hons) courses.

For over 20 years we have reviewed events, accident and incidents, best practices, things that came close to failure, near misses, and we have integrated that information back into the teaching and training programmes. That experience is integral to the materials we are developing in several short courses and an MSc (masters) course as eLearning systems. These are not theoretical courses for academics—these are courses for practitioners. They cover real-world, practical techniques and methodologies, grounded and aimed towards the operational side of crowd safety. There are two objectives to these courses: the first is to raise awareness of crowd risks in built and complex environments, and the second is to provide simple pragmatic, low-cost and easy-to-apply techniques in order to improve crowd safety.

Making available our experience over a wide spectrum of events is the purpose of this book; to pass that knowledge and information to a wider audience. We look at the ways in which events can be made to work well, how they can—and do—fail, and how they are often dangerously close to failure. For over a decade, we have run workshops around the world on crowd risk analysis and safety engineering. At the start of the crowd safety workshops, we usually ask the delegates this question:

> Show of hands—how many people in this room have, at the end of an event, thought: Phew! We were lucky that time?

The day nobody raises a hand will be the time to stop teaching.

Preface

> 'Safety First' is 'Safety Always'.
>
> Charles M. Hayes

> The safety of the people shall be the highest law.
>
> Marcus Tullius Cicero

In this book, we* demonstrate how crowd accidents and incidents—specifically mass fatalities in crowded spaces—can occur, and how they can be avoided using simple, practical and low-cost analysis techniques. We explore the underlying causes of accidents and incidents and provide the reader with a comprehensive set of tools for crowd risk analysis and crowd safety engineering. These tools, methods and worked examples come from over two decades of consulting on major crowd projects.

We have also been teaching, training and developing applications around the world for over 10 years; these methods have been applied to many major events in the United Kingdom, the United States and elsewhere. We demonstrate real-world case studies from a range of event sites and illustrate how we managed risk in some complex sites.

Throughout this book, we focus on the practical elements of developing the crowd risk analysis and crowd safety aspects of an event plan, with consideration to places of public assembly, major events and large-scale urban environments. We define a range of modelling techniques, including line diagrams that represent crowd flow, calculations of the speed at which a space can fill, and of the time it takes for that space to reach critical and then crush density. We define a method of understanding, during the event planning and approval (licensing/permitting) phases,

* Over the years, a variety of associates have worked with the author, in the field, on operational research, development and teaching activities described throughout the book. Their names are listed in the acknowledgements. Although we are using the academic convention throughout this book, 'we' refers to the author's opinions and experience, shaped by decades of working in the field of crowd risk analysis and crowd safety.

crowd conditions that are hazardous to life and limb using tools, techniques and methods are all low-cost, easy to understand, easy to implement and simple to apply.

We hope you find this book both interesting and useful in applying a modelling approach to your own events and environments and that as a result of reading it you can be sure that it can, and will, make a difference to your crowd, to your event and to your peace of mind.

Acknowledgements

Before beginning, plan carefully.

Marcus Tullius Cicero (106BC–43BC)

We have had the pleasure of working with many people over the years, from stewards to senior police officers, from students to government ministers. They have all contributed, in one way or another, to this work. To name them all would be a very long list of acknowledgements. Some who have been outstanding in their support and assistance are: John Parkinson, Ron Woodham, Jon Wort, John Webster, Nick Eade, Annie Chebib, Eric Alexander, Kat Steinberg, Mick Upton, Simon Ancliffe, Prof. Ian Stewart, Clifford Stott, John Drury, Chris Cocking, Owen Grainger-Jones, Hani Al Nabulsi, Brad Spies, Beverly Griffiths, Eric Stuart, Stuart Cornish, Roger Gomm, Andrew McQuillan, Andy Hollinson, William John Herriot, Lukasz J. Nalewaj, Martin Hoube, Ralf Zimme, Clayton McKenzie, Chris Kemp, Morten J. Therkildsen, all the students and cohorts at Bucks New University (you feature in the string experiment—thanks), by the way, everyone who has helped in reading the early drafts, we are still waiting for your input (just kidding). Many thanks to Tony Moore and Kathryn Everett at Taylor & Francis Group for their patience and understanding during the development of this book—their support and assistance are greatly appreciated. Special thanks to Georgia at Laval Editing for her input during the first edit process. I know I have missed a great many names off this list, you know who you are and my deepest thanks extend to everyone who has helped in the process.

This book is dedicated to my wife (Val) and children (Harry and Erin) who are reason enough to try and make the world a safer place. Thanks for your support guys, I could not have done this without you.

Author

G. Keith Still teaches crowd science at several UK universities. He has lectured at the UK Cabinet Office Emergency Planning College since 1999 and developed the EPC's Crowd Dynamics and Crowd Science materials and workshops as well as contributing to several other safety-related courses. He is a fellow of the Institute of Mathematics and its Applications, a fellow of the Institute of Civil Protection and Emergency Management and a specialist fellow of the international institute of risk and safety management.

Keith's mathematical, human behaviour modelling and simulation tools have led to the development of a systematic blueprint for the crowd safety industry. His tools (Legion, Paramics UAF, Myriad, Shepard, Tawaf, DWELL, Progressive Crowd Collapse and Crowd Pressure simulations) have been used for the analysis of crowds in complex and built spaces for over a decade. He has also worked as a safety coordinator, safety advisor and expert witness on many of the world's most dangerous and challenging events. He has developed educational workshops teaching the theory and applications of crowd science, which he has applied directly to major events around the world

Although he has developed and used some of the most sophisticated crowd modelling and simulation tools, his work remains true to the principles of his original research: to develop a model of crowds specifically aimed at improving crowd safety. To this aim his teaching and training programmes do not use computer simulations to model complex sites.

Chapter 1

Introduction

> Someone who builds a mathematical model can get carried away with all the clever things that can be done with it. The model becomes a safe little world, free from anxiety, free from office politics, rewarding in its own right. This often results in a very clever model that has little to do with reality.
>
> Sam L. Savage, author of *INSIGHT.xla: Business Analysis Software for Microsoft Excel*

This is not a book about the clever things you can do with a computer. Nor is this book about deep scientific discussion and argument, complex mathematical techniques, simulations or computer technology. In fact, we argue that crowd simulations must be used with extreme caution when applied to major events—particularly if they relate to crowd safety.

This *is* a book about how to apply simple, practical techniques to help you understand crowd risks. Specifically, this is a book in which we outline *how* to apply a range of tools and techniques to help you plan for crowds in places of public assembly at your event.

We outline case studies where these tools have improved our understanding of event risk analysis and made a significant improvement to crowd safety around the world. We explore the underlying causes that can lead to mass fatalities, and provide the reader with a comprehensive, methodical, systematic approach to crowd risk analysis and safety engineering. The aim of this book is simple: to improve your understanding of crowd risks; to help you plan for, and manage, your crowds safely.

WHY DO WE NEED THIS?

Around the world, event organisers are planning increasingly large, challenging events while also trying to minimise expenditure, recoup costs and maximise profits. With larger events comes the potential for larger incidents, and, sadly, we are seeing an increase in crowd-related incidents around the world.

Crowd injuries—such as overcrowding and crushing—can be avoided through the application of foresight, planning and simple risk analysis techniques. Although crowds are just one element of an event plan, they are an element in which safety cannot be compromised.

The event process, from conception to delivery, consists of three distinct phases: planning, approval* and operations. During the *planning phase,* the event organiser should define the event in a document that should include a safety concept and crowd management plan. This document will describe the event, its location and duration, and crowd capacity. It should detail the necessary emergency, contingency and safety plans, and it should include a comprehensive risk assessment that identifies various potential risks or hazards associated with the event.

The event may require some form of approval (e.g. a licence or permit); during the *approval phase* the plan and risk assessment should be checked. If the plan and safety concept are deemed feasible, a licence or permit may be granted. This phase of the event is a quality assurance process and needs to be performed by a competent person. That person, or persons, must understand events and the associated crowd risks to ensure the plan is 'fit for purpose'; that the risks have been identified and will be managed safely. The event will then run (the *operations phase*) in accordance with the event plan.

The process varies from country to country, but the principles are the same: planning, approval and operations are three phases of the event process where risk analysis techniques must be both understood and rigorously applied in order to be effective. Sadly, this is not always the case. There are many events where there are neither approval processes nor competent persons checking event safety. Furthermore, many events are unlicensed and remain outside of both scrutiny and sanction, with officials therefore unable to enforce safety changes. Some of these may be significant crowd events, such as Christmas markets, air shows, fêtes, bonfires, street processions and victory parades, charity events, Christmas lights switch-on, book-signing, celebrity guest appearances and so on. As a result the approval process—a critical part of the safety model—may be neglected.

Are simulations the answer?

Over the last 25 years, we have developed a wide range of crowd simulation systems and applied them to crowd safety and risk analysis for many of the world's largest and most challenging events. During the earlier years of our research, crowd simulations were essential tools. They helped us to develop an understanding of crowd risks, and they enabled us to experiment with a wide range of behavioural assumptions. You can experiment with crowds

* Various terms are used around the world; here, we will use the term 'approval' to cover all terms associated with licensing or permitting an event.

in a computer-generated environment in a way that is simply not possible in real time (for obvious safety reasons). This proved to be essential in understanding the interactions between crowds and their environment. With crowd simulations, we could understand how risks develop into incidents and how incidents can escalate into disasters, but the simulation approach was both expensive and time consuming.

Embedded within the computer simulation, there is a mathematical model; this is a numerical recipe describing the crowd dynamics, the interactions and the way individuals behave in a range of situations. The crowd simulation is limited by the assumptions built into the mathematical model; the simulation process will not improve on an incorrect or unsuitable set of assumptions. As the saying goes, 'Garbage in, garbage out'.

In the original PhD research, we stated that a computer simulation would assist in both the event planning and the event approval processes. There were significant obstacles to achieving that goal. As we stated in the thesis (http://www.gkstill.com/CV/PhD/Chapter9.html):

> There were three objectives to this research: Firstly, to understand the nature of crowd dynamics with respect to crowd safety; secondly, to develop a more appropriate risk analysis methodology for the design and management of places where crowds may develop. Finally, to create a tool that allows others to understand the nature, problems and necessary components of crowds and crowd dynamics.
>
> G. Keith Still, PhD thesis: *Crowd Dynamics*, 2000

What we know

We know more about crowds now than we did 25 years ago, but we may never know *everything* about crowds. There are many things we do not yet fully understand about the human condition. For example, how and why people react under normal and emergency situations; their decision-making process as individuals, as groups, as families and so forth. There are many elements we simply cannot measure, such as emotion, anger and aggression levels. We do not know exactly how a wide range of internal or external factors—such as mood and weather, aggression and music—influence crowds. There is a long list of unknowns. We have to make assumptions about human behaviour for our mathematical models.

Crowd simulations can help us to explore these assumptions and build better mathematical models. They are useful tools for exploring the theoretical relationships between internal and external factors on the crowd, and there are many research applications for these types of simulations. Our focus is on crowd risk analysis and safety engineering, our concern being whether or not crowd simulation can make a significant improvement to the event planning process.

Uses of a crowd simulation

Some (not all) crowd analysis projects require complex computer simulations merely in order to develop an understanding of the complexity and degree of crowd interactions of people in spaces over time. For example, as a special advisor for crowd safety in Saudi Arabia, we worked on the design of the Jamarat Bridge (Mina Valley), where 3 million pilgrims perform the 'stoning of the devil' ritual every day during Hajj (the annual pilgrimage to Mecca). This project involved a wide area where millions of pilgrims would be moving on five different levels, in multiple directions, completing complex rituals. Computer simulation was an important research tool in understanding the overall crowd dynamics across such a wide space and on so many levels of a complex structure. However, it was not the *only* tool we used to model, and understand the complexity of the site.

Site mapping

To understand crowd movements on the proposed new Jamarat Bridge, we started by mapping out the site on a drawing board using a series of overlays: transparent sheets of drafting film, placed on top of the site plan. We drew the routes the crowds would take under normal and emergency situations, and checked dimensions such as travel distance and minimum width along those routes. In this way we could separate crowd flow, directions, congestion, risk and most/least used spaces. It was an essential step in understanding the complexity of the site.

We applied the same type of analysis to each of the five levels of the new bridge design and worked methodically, area-by-area, section-by-section, through the whole system. We dissected the site to help us build a clearer model of the overall crowd dynamic. Only when we had a complete construction of the crowd flow paths and areas of potential risk were we able to code those parameters into the computer simulation. This process of site analysis was key to understanding the large-scale complex environments where millions of pilgrims live, move, pray and perform the various rituals of Hajj.

We were working with a range of site engineers and crowd safety operations managers during this process, asking them key questions about management techniques, infrastructure, systems integration, design constraints, information and communications systems. This was a very complex site and there were a lot of different groups working together to manage the area. We had to develop a systematic approach to collecting all the information relevant to normal and emergency processes and procedures. Capturing that information was challenging given the language differences, and we had to develop techniques of structuring the information for later analysis. These processes—mapping the site, identifying crowd movements and

areas of risk—were tools that helped us collect and collate information for later analysis.

Workshops

Closer to home, we have worked with the crowd management teams for the wedding of Prince William and Kate Middleton (2011); London New Year events (2006–2012); and the London Olympics (2012). For these projects a combination of computer models, real-time data analysis, meta-models and the principles and applications of crowd science were fundamental to the event planning, risk analysis and safe management of the events. Typically, projects begin with a workshop where the various groups meet to outline their concerns, and resolutions are discussed and agreed.

In addition to working on major projects, we have run teaching and training programmes to help delegates understand the key issues around crowd risks and safety engineering principles. Out of these, two courses developed: Introduction to Crowd Science (a foundation degree course) and Applied Crowd Science, BA (Hons). We have run 30–40 of these courses every year, around the world, where delegates bring their concerns to the workshop and we help them through the risk and safety analysis applications.

Teaching and training

Since early 2000, we have been teaching practical methods for crowd modelling, focussing on 'simple to apply' and 'simple to understand' techniques for assessing crowd risks and evaluating crowd safety strategies. We developed a workshop approach to problem solving that was similar to what we were using in our consulting projects—to identify and catalogue the key information for crowd risk analysis. We teach the same methods as we use on major projects.

Workshops had proven to be a successful means of understanding site-related issues while teaching delegates how to understand the fundamentals of crowd-related risks for major events. Delegates were typically crowd safety operations managers—the people who plan and operate events—so there was a wealth of practical experience to draw upon for our development projects, and good general understanding of the key issues related to crowd risks. Workshops have helped us develop better mathematical models of crowd behaviour and improve our understanding of crowd risks; specifically, they have helped us develop more appropriate crowd-modelling tools for crowd safety.

As a result of running safety workshops for over 15 years, the teaching techniques and modelling tools we have developed are not academic or theoretical exercises: they are based on real-world situations. They are practical and applicable tools, techniques and methodologies. Those tools are the subject of this book.

CROWD MODELLING

During these workshops we noted that there were many unreported crowd risks at major events. Specifically the delegates' concerns were about safeguarding against the risks of major incidents. As our focus is crowd safety, we developed methods to help the delegates to understand those risks and how to apply that understanding to their own events. We show delegates how to model crowd movement and how to map areas of potential risk. This helps the delegates transfer experience onto paper, and records the nature of those risks for further analysis.

All of our projects start with the same fundamental modelling method of route and risk mapping. We have developed and used a wide range of site modelling tools to assist in this process. Sometimes it is more appropriate to use commercially available tools such as Google Earth and a variety of distance/route/area mapping software. Sometimes, a simple map, sketch or diagram of the site is sufficient to identify key areas of crowd risk. We use all of these tools to help delegates investigate a site, its transportation infrastructure, and available spaces for the crowds. This process helps the delegates build a model of how the crowd may move under both normal and emergency situations.

Crowd safety projects

We consult on major projects around the world, and every project begins by collecting information and collating it into a form we can analyse. Every analysis begins in a similar manner, with crowd flow diagrams and site sketches. This is the same fundamental process that we teach in the workshops: simple line drawings to understand the crowd flow and potential risks, area and flow mapping and flow calculations.

Common to every project, we found that crowd risks could be identified through the collection and collation of event information. For complex sites, where the use of crowd simulation may have been necessary, we still had to collect the same type of information and map out the site before coding the computer. We use that information to code the computer simulation, but the fundamentals of crowd risks are already apparent in the data collection and collation process. We asked ourselves the question, 'What did the computer simulation tell us that we could not readily discover using the event information, the crowd flow and routing diagrams, the area and route mapping, risk analysis and mapping techniques?'

The answer was very little—and it took a long time to realise this.

Developing a crowd simulation took years; producing a good event simulation for a major project took weeks, sometimes months. Testing an event simulation took days and validating the crowd and event simulation also took time. Inevitably this led us to question our simulation approach. Did