Introduction to Crowd Management

Claudio Feliciani · Kenichiro Shimura ·
Katsuhiro Nishinari

Introduction to Crowd Management

Managing Crowds in the Digital Era: Theory and Practice

Springer

Claudio Feliciani
Research Center for Advanced Science and Technology
The University of Tokyo
Meguro, Tokyo, Japan

Katsuhiro Nishinari
Research Center for Advanced Science and Technology
The University of Tokyo
Meguro, Tokyo, Japan

Kenichiro Shimura
Industrial Research Institute for Japan Ltd.
Chiyoda, Tokyo, Japan

ISBN 978-3-030-90011-3 ISBN 978-3-030-90012-0 (eBook)
https://doi.org/10.1007/978-3-030-90012-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book is dedicated to our parents who, despite being different in culture and customs, all helped us growing up and choose the right path unconsciously leading to the publication of this book.

Foreword

All of us participate in traffic, every day. It has become so natural that we usually do not even think about it. Therefore, one would expect that we know very well how traffic works. While this is (arguably) true for vehicular traffic, the situation is rather different for pedestrian and crowd dynamics.

So why—despite its relevance for everyday life—are several aspects of pedestrian dynamics not yet fully understood, especially on a quantitative level (compared to vehicular traffic)? And what could be done to change this?

Of course there are good reasons behind the gaps in our understanding. In contrast to vehicular traffic, pedestrian motion is truly two-dimensional with people moving in arbitrary directions. It is also much less restricted by legal rules whereas cars have to use streets, in a given direction, stay in lanes, and obey regulations, e.g., at intersections. There is also an important difference from a physics point of view. The motion of cars is very much restricted by inertia which plays little role in pedestrian motion. Pedestrians are able to accelerate, change the direction of motion, etc. almost instantaneously. Therefore, their motion is less controlled by physics, but more by psychological effects. Depending on their goals, desires, emotions, etc., pedestrians can change their state of motion very quickly, e.g., to follow the quickest path to their destination. Pedestrians are able to learn and their behavior will be influenced by previous experiences in similar situations. This makes their movement much less predictable than the motion of cars which well described by rather simple physical theories due to limited acceleration capability and the legal rules that restrict the motion.

Despite these difficulties, new techniques and approaches have allowed to make substantial progress in our understanding of pedestrian motion and crowd dynamics in recent years. Using laboratory experiments, the behavior of pedestrians could be studied in some detail, at least in relatively simple, but well-defined scenarios. Sophisticated modeling approaches, like multi-agent models, allow to incorporate much more details that are relevant for crowd motion. Last but not least, the ever-increasing capabilities of computers have made it possible to perform simulations of large crowds faster than real time thus making predictions (forecasts) possible, at least in principle.

There are other potential differences between different modes of traffic related to safety. Usually, we are aware about its risks, e.g., in cars and planes. But what about the risks in large crowds? Usually we feel rather safe, although sometimes uncomfortable. Nevertheless, we more and more hear of crowd disasters on the news, often with many injuries and even casualties. To address the problems associated, e.g., with large-scale public events, crowd control and risk management have become increasingly important. Using modern techniques both in planning and surveillance of crowd events, it has become possible to reduce the risk for participants in large crowd gatherings.

What exactly is "crowd management"? It is not just "tell people what to do, where to go", etc. Instead, it is a scientific discipline that requires an ingenious combination of very different fields in a truly interdisciplinary way. Crowds are different from pure physical systems which are similar in certain aspects as e.g. granular media. Crowds involve different persons who have their own will, goals, etc. Thus, understanding its dynamics requires the inclusion of social and psychological aspects.

In this book, the authors give a comprehensive review of the state of the art of every aspect of pedestrian dynamics and crowd motion, starting from empirical techniques for data acquisition to sophisticated modeling approaches. They put the latest scientific insights into perspective of applications, thus reducing the gap between scientists and stakeholders. Practitioners are interested in the identification and analysis of risks and methods to make crowd dynamics safer and more comfortable. They will find valuable introductions to information management, methods of crowd control and risk management which are essential tools in the planning of large events and mass gatherings.

The authors are renowned experts and have made seminal contributions to the field, ranging from theory to experiments and practical applications. Through the "Crowd Management Research Center" founded by Prof. Nishinari, they are engaged in close collaborations with practitioners in the context of crowd management. Their expertise has made them sought after advisors, e.g., for the 2020 Tokyo Olympic and Paralympic Games. Their track record makes them perfectly suited to write an insightful and wide-ranging overview of all relevant aspects of crowd dynamics and crowd management. I have learned a lot from this book, and I am sure other readers will as well!

Cologne, Germany Andreas Schadschneider
August 2021

Preface

On May 2017, Prof. Katsuhiro Nishinari founded the "Crowd Management Research Center" with the aim to reinforce collaboration between academics and stakeholders involved in crowd management. In the three-year project, a number of meetings, workshops, site visits, and symposiums have been hold with our partner private companies. From our side, we tried to teach them the theory behind crowd dynamics and allow them to discover the latest technological trends in the discipline. At the same time, we took the opportunity to understand what are the most common problematics in the frame of crowd management and what are the solutions most typically used on a daily basis from people dealing with pedestrian traffic and crowds on-site.

This book is the result of this three-year project. On one side, we tried to summarize the theoretical knowledge accumulated in over 20 years of research on crowd dynamics based on research performed by researchers throughout the world while also including the contributions of the authors themselves. On the other side, we tried to relate this theoretical background with practical aspects involved in the daily activity of crowd management to allow readers understanding how theory can be used for practical applications. The result is a book that we hope can be of interest for people working in the field of crowd management, but also a good starting point for researchers or students approaching the field of crowd dynamics and wishing to get an overall view on this complex, interdisciplinary, and fascinating topic.

As such, this book addresses methods and technologies used in managing and controlling crowds in busy places (train stations, airports, shopping malls, exhibition halls, etc.) and during events like concerts and sport competitions by addressing fundamental aspects related to crowd management using simple concepts requiring little or no knowledge of mathematics or engineering. A large number of images and tables have been used to clearly illustrate the most important points. In addition, we structured the book in way in which theoretical notions are presented first and practical advices are given at the end to allow understanding the link between both parts.

Although this book has been conceived over this three-year project by continuous discussions between the authors, each of us took different roles in writing it. Below,

the contributions of each author are listed along with a short description on their background.

Claudio Feliciani received his Ph.D. from The University of Tokyo in 2017, and he is currently working in the same institution as Project Associate Professor. Although having a background in engineering, he has always had a profound interest on social sciences. As a consequence, his research path has naturally drawn him to pedestrian traffic and crowd management where he made use of his knowledge on physics and mathematics to create new methods to assess crowd condition and develop new models for simulation. He has authored or co-authored numerous works mostly relating to crowd dynamics and traffic, but also covering animal behavior and social issues. In 2021, he shared the Ig Nobel Prize in kinetics (with Katsuhiro Nishinari among others) for having helped in the discovery that distracted pedestrians are more likely to bump into others. Beside academic research, he has also been active as a volunteer firefighter in his hometown in Switzerland for several years. In the frame of this book, he has been the main responsible in composing Chaps. 2, 4, 5 and 6. In addition, he has also been working to unify the writing style and presentation throughout the book, has helped extending the accidents accounted in the Appendix, and has prepared most of the final figures of this book.

Kenichiro Shimura is the Representative Director of Industrial Research Institute for Japan, Ltd. and is the Visiting Research Fellow at The University of Tokyo since April 2021, followed by being the Project Lecturer from 2017. He has extensive research experience in the field of crowd dynamics and safety management of crowd control for over a decade. He specializes in crowd control, simulation and safety analysis. He received a bachelor's degree (Aerospace) from The University of Glasgow, UK in 1995 and a master's degree (Automatic Control and Systems Engineering) from The University of Sheffield, UK in 1998. He then received his Ph.D. in Quantum Engineering and Systems Science from The University of Tokyo in 2003. He has been involved in various areas such as, nuclear engineering, materials science and hydrogen energy, researching the modelling and simulation by the use of Cellular Automata since then. In this book he introduces the analytical methods to assess crowd accidents, developed by him in order to help readers design appropriate planning and control of crowds to prevent crowd accident in the future. The details can be found in the academic papers published by Shimura. Chapter 3 is written by Shimura, with reflection of comments by Claudio Feliciani, who has contributed to increase the statistical samples of past accidents.

Katsuhiro Nishinari received his Ph.D. from The University of Tokyo in 1995, and he has been holding a Full Professor position in the same institution since 2009. His research interests include "jamology", which is an interdisciplinary field related to transportation and jamming phenomena including vehicular traffic, pedestrian motion, queuing networks, and supply chain by means of applied mathematics, fluid dynamics, and statistical physics. He has authored over 150 scientific publications and written several books on a variety of subjects. He his also active in cooperating with private institutions and has been a consultant for over 100 companies while

also being an external advisor for the 2020 Tokyo Olympic and Paralympic Games organizing committee. For this book, he has written the original texts for Chaps. 1, 7, 8 and 9. In addition, he found the financial means to support this project and has overseen the whole work.

To summarize in a simpler form, the contributions of the single authors within this book can be listed as follows:

Chapter 1	Katsuhiro Nishinari
Chapter 2	Claudio Feliciani
Chapter 3	Kenichiro Shimura (with contributions from Claudio Feliciani and Katsuhiro Nishinari)
Chapter 4	Claudio Feliciani
Chapter 5	Claudio Feliciani
Chapter 6	Claudio Feliciani (with contributions from Katsuhiro Nishinari)
Chapter 7	Katsuhiro Nishinari (with contributions from Claudio Feliciani and Kenichiro Shimura)
Chapter 8	Katsuhiro Nishinari (with contributions from Claudio Feliciani)
Chapter 9	Katsuhiro Nishinari

Tokyo, Japan
August 2021

Claudio Feliciani

Acknowledgements

This book has been written in the frame of a project involving a close cooperation between the authors and industrial/private partners. The authors are therefore grateful to the nine companies involved in the project and would like to thank them for the precious discussions, which helped us to understand the crowd management problem from the point of view of institutions having to deal with it on a daily basis and thus allowing us to create a book combining theoretical and practical expertise. The companies taking part in the "Crowd Management Research Center" (active between 2017 and 2020) are listed as follows (in alphabetical order): ANA Holdings Inc., East Japan Railway Company, Goodfellows Co., Ltd, Kajima Corporation, Mitsubishi Electric Corporation, Narita International Airport Corporation, SECOM Co., Ltd, Tokyo Dome Corporation, and Tokyo Metro Co., Ltd.

In addition to the companies listed above, part of the research behind some contents presented in this book was also founded by the JST-Mirai Program Grant Number JPMJMI17D4 and JPMJMI20D1 and the JSPS KAKENHI Grant Number 20K14992. The authors wish to express their gratitude to the institutions that founded us and allowed us to perform the research need to better grasp important aspects of crowd motion making this publication not only possible but also more complete and accurate.

The authors would also like to acknowledge the help from the members of the Nishinari laboratory, who helped to better shape minor, but still relevant, parts of this book. In particular we would like to thank Hisashi Murakami, Xiaolu Jia, Sakurako Tanida, Daichi Yanagisawa, Takahiro Ezaki, and Satori Tsuzuki, who constantly provided feedback, support, and encouragement to the authors, allowing us to stay focused on this book. Among them a special thanks to Hisashi Murakami, who, by winning the Ig Nobel Prize (shared with Yuta Nishiyama and two authors of this book) helped spreading the awareness on crowd research to a wider audience.

We are also very grateful to our secretaries: Yuko Tsumori, En Fujimoto, Isako Tanaka, Yuriko Yokoyama, and Erika Shihara, who, not only provided administrative support, but also kept us in good spirits. In addition, we would like to thank all the students who have been part of the Nishinari laboratory during the three-years

period in which the book was written for having helped organizing a number of experiments that are used as content in this book. Among them a special thanks to Akihiro Fujita and Fumitaka Sumiyama who often instructed participants to our experiments, allowing us to focus on the observation of crowd behavior. The acknowledgment is also extended to previous students, whose research topics have been of inspiration in the writing of this book, and to Enago (www.enago.jp) for the English language review of parts of this book.

Finally, we would like to thank colleagues throughout the world that helped us finding the right point of view through discussions and joint research. In particular, we are grateful to Andrea Gorrini, Andreas Schadschneider, Francesco Zanlungo, Zeynep Yücel, Luca Crociani, Akihito Nagahama, Masahiro Furukawa, Shuqi Xue, Xiaomeng Shi, Iker Zuriguel, Angel Garcimartin, Maik Boltes, Alessandro Corbetta, Jasmin Thurau, Giuseppe Vizzari, Stefania Bandini, Bastien Chopard, Leonel Aguilar, Armin Seyfried, Mohcine Chraibi, Milad Haghani, Ruggiero Lovreglio, Yu-Li Tsai, Dražen Brščic, Agnes Grisoglio, Catherine Henot, and Heinrich Marti (while also, obviously, including the people we forgot).

Contents

Acronyms

AI	Artificial intelligence
API	Application program interface
BIM	Building information modeling
BLE	Bluetooth low energy
BPM	Beat per minute
CA	Cellular automata
CAD	Computer-aided Design
CCTV	Closed circuit television
CPU	Central processing unit
DRC	Democratic Republic of the Congo
ESIM	Elaborated social identity model
GPS	Global Positioning System
HD	High definition
ISO	International Organization for Standardization
IT	Information technology
LADAR	Laser radar
LIDAR	Laser imaging detection and ranging
LOS	Level of service
LSO	Landing Signal Officer
MAC	Media access control
OD	Origin destination
RFID	Radio frequency identification
SDK	Software Development Kit
TBD	To be determined
UK	United Kingdom
USA	United States of America
USSR	Union of Soviet Socialist Republics
UUID	Universally Unique Identifier
VIP	Very important person

Chapter 1
What Is Crowd Management?

Abstract Crowds of people have been studied for more than a century, but their behavior has not been (and may possibly never be) fully understood. Nonetheless, the presence of crowds of people is becoming a dominant part of our modern civilization, and it is therefore important to find efficient ways to manage them in order to guarantee safety and comfort for people living in increasingly urbanized areas. This chapter introduces the definition of crowd management and explains the differences between managing and controlling crowds. Crowd management strategies are discussed in regard to safety and comfort, explaining how it is possible to keep a balance between both contrasting goals. In addition, the role of the stakeholders involved in crowd management is also discussed putting an emphasis on the importance of their cooperation and information sharing. In fact, success is guaranteed in crowd events or user experience maximized in large facilities (to consider some examples) only when all stakeholders work together toward a common goal. In this regard, an official responsible for crowd management, which we define as "crowd manager," should be instructed to have sufficient knowledge on crowd behavior and dynamics and act as a mediator between stakeholders to advice them on policies related to crowd management and control.

1.1 Introduction

The social nature of humans has always led to gatherings of people and crowds have been observed from the early times of civilization. In some ways, humans can be considered as social animals, which possess an individual cognition but change into a collective behavior while in group. Although understanding the collective behavior observed in animal swarms is already a difficult and challenging task, the complex social structure of humans and their abstract psychological thinking makes understanding and predicting behavior of human crowds even more difficult.

However, the need to understand crowd behavior or at least grasp some of its fundamental features has grown with the progresses of human civilization. Although crowds used to be sporadic appearances to be seen only during special occasions or in the few urbanized cities in the old times, the exploding urbanization occurring in the

C. Feliciani et al., *Introduction to Crowd Management*,
https://doi.org/10.1007/978-3-030-90012-0_1

nineteenth and twentieth centuries has radically changed people's living conditions. Nowadays, crowds of people can be seen daily in train stations, airports, or other large infrastructures, and religions gatherings in densely populated areas can attract millions of people in only few days. Mobility has also seen a dramatic increase, thus adding to crowds a remarkably dynamic feature.

Research is still ongoing to understand how people behave while inside a crowd, how the crowd itself moves as a whole and which psychological state is formed by the collective bonds formed between strangers within a packed group of people. To completely understand and predict crowds, we first need to fully understand individuals, and therefore, there is still a long way to have a full understanding (and we may never have a perfect model/theory describing them). Nonetheless, human behavior in crowds has been studied for several decades (if not centuries) now and, while we do not know everything, lot has been understood through scientific research, by learning from previous tragedies and thank to a continuous feedback from people directly dealing with masses of people on a daily basis (security personnel, station staff, police, etc.). It is therefore possible to describe common phenomena and behaviors observed in crowds and, based on these, set up guidelines on how to deal with crowds and possibly control them.

This book aims at summarizing what we have learned about crowds and propose methods which can be useful to improve safety and comfort in locations experiencing congestion or related problems. Since technology increasingly plays an important role in crowd management, we gave a particular attention to technical solutions also because we believe a general understanding of technological solutions will benefit people involved with crowd management in the near future. Nonetheless, aspects related to crowd psychology and classical human intervention are also discussed, because, without neglecting the usefulness of technical solutions, crowds are unpredictable at times and, in that case, humans are usually the ones coming up with the best approaches. Also, it is very likely, that, regardless of technological improvements, at least in the near future, crowd management will be never fully automatized, thus requiring the assistance of human personnel, which, for this reason, must have an adequate understanding and preparation to be able to act in the right way.

Needless to say, this book cannot cover every aspect of crowd management since this is a multidisciplinary discipline, and there are already excellent texts considering specific aspects such as mass psychology, emergency route planning, crowd simulation, wayfinding or coping with emergencies. This book should be seen (as clearly stated in the title) as an introduction providing a sufficient and yet complete overview on all aspects involved with crowd management. People professionally involved in this area, facility managers, researchers, or interested readers may take this book as a starting point. Based on what learned here, some reader may find the need to explore more in detail one or more specific aspects discussed in this book and, in that case, specialized literature will become fundamental on the scope.

1.2 Objectives of This Chapter

This chapter aims at introducing the most fundamental principles related to crowd management, the actors involved in it, and present the general structure of this book. In particular, it is important that the reader understands how to keep a balance between safety and comfort and feels when a change in strategy is required. On that purpose, throughout the book, we will present methods to predict and control crowds' motion. While the same method may be used to achieve both the goal of safety *and* comfort, most methods are more appropriate to achieve only one goal. Thus, it is important to read this book while keeping in mind the theoretical principles introduced in this chapter on the balance between safety and comfort and understand when, how, and to which extend the focus must be gradually changed from one goal to the other.

This chapter will also outline the most relevant actors in regard to crowd management. In the same way, we will remind through the book that crowd management is never successful if conducted alone by a single person/institution and it is a team work indeed. Therefore, each of the methods presented in this book (e.g., crowd prediction/simulation and crowd control) need to be seen as a task that several actors will carry out together. In this sense, this chapter should form the foundation to construct a successful crowd management framework with the following chapters only providing the building blocks which constitute that framework. While the principles introduced in this chapter are simple and may seem even obvious, they are also easy to forget, and therefore, it is necessary to consider this chapter as the glue keeping the book (or the elements of that framework) together.

1.3 Definitions and Fundamental Principles of This Book

Let us begin by establishing the concepts behind crowd management. For the purposes of this book, crowd management is defined in the following way:

> Proactive security activities that bring safety and comfort to individuals by facilitating efficient movement of crowds

Various characteristics of crowds are discussed in the following chapters, and the term is used in the broadest possible sense of the word. Both "casual" crowds, such as those encountered when commuting, and "occasional" crowds, such as those found at events, are included in the scope of the following discussion on crowd management. In addition to moving crowds, which are more common and generally more difficult to manage, static regular crowds are often seen when people stop moving to watch sport events, during public viewing or when they line up at service counters to pass through immigration control, to check-in at airports or, again, to

perform procedures at administrative offices. These types of static, accumulated gatherings are also subject to crowd management.

The topic of management being discussed regards, of course, the assembly and movement of groups of people in crowds, but this should not be considered from a simple, narrow perspective where every aspect of crowds is considered separately, but should instead be generally seen as part of a wider problem where several elements interact with each other's. Crowd management could result in deliberately restricting the movements of some groups of people in order to minimize risk and improve the overall efficiency and comfort, such as when crowds are made to leave large stadiums by seating block rather than exiting at will. To explain how this relates with the previous statement concerning the need for a wide perspective, we should note that, if each seating block is considered separately and not part of a larger structure, a simultaneous swift egress would seem as the optimal solution, but when the stadium is seen as a whole more complex and interconnected network, then benefits behind the strategy presented earlier become evident. For some people, it may take longer to leave, but congestion is reduced in the stadium, thus resulting in an overall benefit for the whole crowd.

The goal of crowd management is to ensure safety and comfort of its constituents. Avoiding stagnation and hazardous situations involving high densities of people by enabling a smooth movement of crowds helps to prevent risks. Furthermore, making movement more efficient helps to reduce wasted time, which can have great social significance. Efficient time use also increases individual comfort and enables a space to be used by more users over a single day, which is of benefit to the stakeholders involved too. Ultimately, it is important that a combination of safety and comfort is always ensured for individuals who make up a crowd, and from here on, we will examine the role of security and efficiency as necessary mechanisms for achieving this goal. Since there are many different types of crowds and because future evolution of events can be uncertain, we must be flexible in our approach.

Notoriously, a difficult problem that we face here is finding the correct balance between safety and efficiency. There is often too much emphasis placed on efficiency with the aim to improve visitors' experience, having as a result that systems that are put in place can be overwhelmed by crowds under specific conditions, which, in turn, will compromise security. Accordingly, efficiency can be considered in low-risk situations, but it is important that management systems prioritize safety when risk is high. In short, a flexible approach is necessary, in which people are able to freely move in low-risk situations, but methods and protocols are ready to be put in force when safety is under risk.

The various activities that help to achieve this flexible approach are referred to as crowd control, and this forms the core of crowd management. This topic will also be discussed in more detail in later chapters, but the key concept behind crowd control relies on accident prevention through risk management. Preventive safety measures are extremely important when trying to safeguard human lives, and obtaining a clear image on crowd's condition/state is essential when attempting to foresee and evaluate risks. If a risk is deemed to be high, it is important to use preventive crowd control in a timely manner to lower the risk level. A variety of methods of control can be

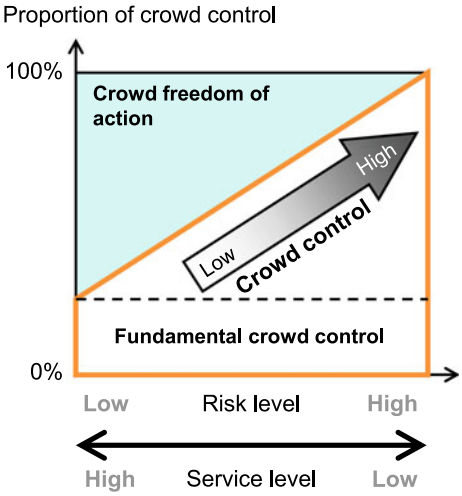

Fig. 1.1 Crowd control in response to risk and service levels

considered depending on the level of risk, from the simple information provision employing a mix of media, to compulsory guidance imposed by security staff. Furthermore, it is important to consider not only risk but also to look at the situation from the perspective of efficiency. As an example, when the number of people waiting in a line increases beyond a certain level, it is important to reduce waiting times and improve the level of service by dynamically increasing the number of service counters that are available in response. When no alternatives are available, adopting conservative measures is imperative to ensure safety, but, if enough resources are accessible, then using them straightaway in a less conservative manner is suggested since that would allow to lower risk by also ensuring an adequate level of comfort.

Figure 1.1 illustrates the general principles presented above.

In this diagram, the horizontal axis represents both risk levels and service levels, and the vertical axis represents the degree of crowd control. When risk level is low or service level is high, there is no need for special crowd control measures except, of course, for basic information provision (guidance is still required even in an almost empty building or people may get lost). This minimum and fundamental amount of crowd control is shown as the base level in the diagram. In other words, information provision should always be in place as a foundation for further crowd control, in a similar fashion to road signs (drivers could easily miss an highway exit if signs are not given and car navigation not used). When the risk level becomes elevated as the density of the crowd becomes higher, it is necessary to deploy additional crowd control measures in appropriate order. In this respect, individual freedom of behavior may need to be restricted and/or service levels reduced as necessary steps in ensuring the overall safety of the crowd.

Additionally, in emergencies such as accidents, the worst-case scenario must be assumed and consequently considered in advance. In this regard, another important part of crowd management is the prior planning that is needed to minimize damage,

through such measures as ensuring that evacuation routes are secure and sufficient in number. Furthermore, during emergencies, on-site personnel need to be prepared and specifically formed to communicate with the crowd and necessary information must be provided in an efficient manner to external or third-party emergency services.

Every successful crowd management strategy should account not only for on-site, real-time crowd management but also for off-site crowd management and advance planning. In this book, we try to cover all these aspects. The concepts that we have touched upon here (including preventive flow design to identify and eliminate risks) will be described in more detail in the following chapters.

1.4 Stakeholders and Crowd Information

As already briefly stated, the key element in successful crowd management is ensuring that information is properly shared, and activities are coordinated among relevant stakeholders. There are many stakeholders when it comes to crowds; the following examples apply when organizing an event.

> Attendees, organizers, sponsors, media, firefighters, security staff, police, government officials, facility staff, transportation companies, travel agencies, local residents, etc.

From here on, we will mostly consider crowds attending an event and discuss all aspects related to their management. This choice is related to the fact that events typically involve a lot of stakeholders and attract a lot of people over a short period of time, thus representing the most complex case of crowd management. However, the concepts introduced here for the case of an event also hold true for a train station or an airport, with the exception that crowd management strategies can be improved over time by observing and analyzing crowd behavior on a daily basis (which does not eliminate the need for planning).

Coming back to the list highlighted above, we can see from this example that there are several types of stakeholder involved in crowd management. If coordination among the stakeholders does not exist, even if individual organizations are aware of their roles and come up with optimized plans, the overall plan will be only partially optimized, and it is unlikely that the individual plans will form a coherently optimized whole. If the whole plan is divided into areas of individual responsibility, it may lead to incidents involving the crowd, as we will discuss later. It is therefore important that stakeholders share information and coordinate, both during the planning stages and during the actual event. Considering the various aspects of the event as a whole allows proper decision-making about crowd management and in turn allows visitors to enjoy the event in safety and comfort.

If we look in more depth at stakeholder relationships, we can see that the general image and approach described so far is getting even more complex. For example, the primary target for crowd management at events is visitors, but local residents also have significant connections to the event since their normal routine is being affected. In this context, when scheduling an event, the traffic of visitors need to be set up so that it causes the minimum possible disruption to the daily lives of local residents. It is, however, almost impossible for an event to have no local impact at all, which means that it is necessary to establish dialog with residents and make adjustments to take their needs into account. In order to be beneficial and ensure a long-standing relationship, this communication must be a two-sided. If local residents are allowed to gain information from organizers about upcoming local events, they may be able to come up with ideas such as local festivals, flea markets or side events, adding value to the main event. However, a continuous dialogue is needed between both parties. For instance, if side events are organized by local residents without informing organizers of the main event, congestion may occur on access routes and in the worst-case emergency vehicles may not be able to enter the facility in case of accidents. To avoid such a situation and ensure that daily routine traffic, gatherings of local residents, and the flow of visitors mix in a planned, optimal, and safe way, this kind of communication and two-way information sharing is thus extremely important.

Furthermore, those who contribute financially to the organization of an event, such as investors and sponsors, are likely to have strong opinions about the planning of the event. However, single-mindedly pursuing commercial goals risks compromising crowd safety. It is of course necessary to listen to police guidance and pay attention to the law but, even if that is the case, the pursuit of profit tends to lead to underestimations of risk. If an event is held with unreasonably low margins for safety, it becomes impossible to respond to unexpected situations.

Additionally, if there are multiple organizers, the decision-making process can become unduly complicated, eventually making unclear who is responsible if something goes wrong. Accordingly, it is important for stakeholders to properly discuss the planning in advance and to establish consensus, so that each stakeholder fully understands the scope of their own responsibilities. It is essential that everyone who is involved shares the same goal, resulting in the creation of unified protocols for command and control combining all parties resources, thus eventually leading to a unified response to any expected or unexpected event. As already mentioned, it is particularly important to reach an agreement and a common vision by those stakeholders whose goal lie on both extremes in relation to safety and comfort (e.g., sponsors/investors and police/firefighters).

Next, let us look at the information that is required for proper crowd management. As shown in Table 1.1, each stakeholder has a variety of information at their disposal and will sometimes need to quickly communicate the information that they have to those who are on-site at the event. There have been many cases in which a failure to convey information to those who need it in a timely manner has led to accidents involving crowds as we will see in Chap. 3.

However, sharing this kind of information often has privacy implications, and it is important that there are rules in place for information sharing. Information that is

Table 1.1 Stakeholders and crowd information

Stakeholder	Crowd information
Visitors	Personal information (age, gender, etc.), destination, group size, scheduled arrival and travel times, etc.
Organizers	Venue information, event schedule, ticket sales, etc.
Private security companies	Location of security personnel, response protocols, CCTV locations, etc.
Police	Traffic information, data about criminal activity, etc.
Transportation companies	Timetables, transport capacity, number of vehicles, etc.
Facility operating company	Detailed facility map, venue capacity, toilet/locker locations, shop opening hours, etc.
Government	Legal regulations, data about related companies, relevant historical material, etc.
Fire and ambulance service	Evacuation sites, number of fire trucks and ambulance available, number of hospitals open, number of doctors on call, etc.
Local residents	Local events, members of residents' committees, etc.

relevant to the life and safety of those in the crowd should be shared to the maximum extent possible, but information for which prior consent for disclosure has not been obtained should be safeguarded. As it is difficult to strike a balance between security and privacy, stakeholders need to discuss the issues thoroughly and establish ground rules before a crisis occurs. At the same time, it is important to remember that it is not always possible to obtain complete information. In these instances, it is necessary to be able to manage the crowd using only the information that is available at the time and/or consider alternative methods to obtain the missing information, maybe only in part or in a summarized format.

Standardization and digitalization are needed to ensure the smooth sharing of information. Most of the times, digitization of information is particularly lacking or is available in a format that is not universally recognized and therefore not understandable by other stakeholders. Also considering that crowd control is rapidly moving toward a digitized and partially automated approach, it is therefore essential to put efforts into digital crowd information, so that communication between stakeholders is facilitated. Eventually, platforms can and should be developed to enhance crowd management in the future (possibly by also sharing part of the information with the crowd itself as we will discuss in Chap. 6).

CAD and Building Information Modeling (BIM) data are increasingly playing an important role in crowd management as they represent the starting point for simulations (as we will see in Chap. 5). Although this information is often confidential,

since it reveals some vulnerable details related to venues' security, it is fundamental that at least a simplified version roughly representing the areas in which people move should be made available to organizers or related stakeholders. Such kind of data (in particularly BIM) can also help companies operating facilities to plan and schedule maintenance and identify optimal locations for security cameras and/or sensors (more in Chap. 4), thus enabling good crowd management strategies from multiple perspectives.

1.5 The Crowd Manager

Crowd management involves a variety of stakeholders who each have access to different information, and it is important that there is a central individual or organization who can make top-down adjustments in order to optimize the whole management system. Presently, this often takes the form of a person (typically in a managerial position) within the organization/company hosting the event. However, managing a crowd is a specialized job that requires extensive knowledge and experience, and it can have many implications for the lives of those who make up the crowd. Looking into the future, there is a need for certified specialists to fulfill this role. We believe that such a role should be taken by a so-called crowd manager who specializes in crowd management and makes use of her/his knowledge to act as coordinator between stakeholders to help identify lacks during planning. To some extent, this book can be taken as an effort to summarize the required knowledge for crowd managers and is intended to be used as a reference guide for the development of human resources devoted to crowd management.

It is worth noting that qualified crowd managers already exist in some countries, and their required training is substantial. In the USA, for example, any location where large numbers of people gather is required to have a crowd manager in place. As an example of this, venues such as dance halls and bars in which large crowds are common must have one crowd manager for every 250 people, and owners who violate this rule face potential jail time [1]. However, the main job for this kind of crowd manager is to guide evacuation in the event of a fire, and state fire departments provide the necessary training courses. The manager is also expected to check fire protection equipment, make sure that the venue does not exceed its capacity, and make announcements when a crisis occurs. In some countries, there are similar positions related to fire safety which partially cover these responsibilities, but it should be noted that they are slightly different to the role of crowd managers that is detailed here, and typically, only aspects related with fire prevention/extinction are covered with the "crowd" part missing in the training. In addition, venue security and police also perform many activities that are linked to the role of crowd managers although they not always possess specific knowledge on the subject (for instance police is typically trained for riots or violent scenarios, which, on the other side, are not typically within the responsibilities of crowd managers and not part of their training).

This book summarizes the knowledge that is required for successful crowd management, incorporating the latest theories and technical knowledge on the subject from academia, experience gained on-site and relevant crowd security sources from around the world.

1.6 Structure of This Book

This book covers almost all of the knowledge that is required for crowd management, and its contents and the relationship between each part are shown in Fig. 1.2. Firstly, this initial chapter defined the concept of crowd management and provided an overview of the topic.

In Chap. 2, we will learn about the characteristics of crowds and discuss various aspects of crowd psychology and crowd behavior. A deep understanding of crowds' nature forms the initial foundation for learning about crowd management.

Chapter 3 looks at historical incidents involving crowds from around the world, with particular emphasis on summarizing and classifying serious incidents that resulted in fatalities or left many people wounded. Learning about the causes of past accidents enables us to learn about common mistakes made in crowd management and helps us to consider ways to prevent the same errors being repeated.

Chapter 4 summarizes methods that can be used to detect the presence of people and thus "measure" crowds. There are many ways to do this, each with their own advantages and disadvantages. New technologies are currently being developed to help with this process and the state of the art will be reviewed as widely as possible. In doing this, we tried to explain the most important aspects avoiding details which may be difficult to understand by people without a technical background.

Chapter 5 looks at various simulation methods that have been developed in recent years as a means of attempting to predict crowd behavior. The behavior of crowds is not based on natural principles such as physics, which means that there is no unified method for predicting their actions, and various models have been proposed. These range from micro to macroapproaches, and many models are applied in real life cases around the world. It should be noted, however, that no universal almighty simulator

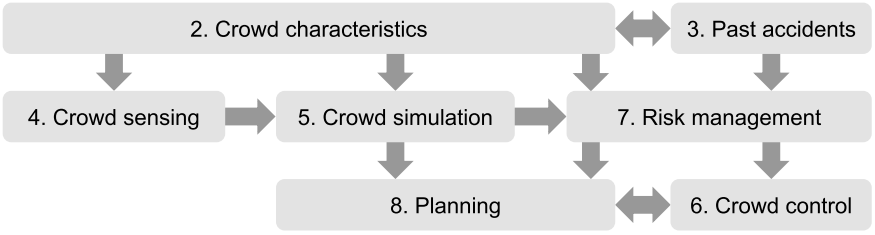

Fig. 1.2 The contents of each chapter and their relationships to each other

exists, and comparison and examination of each method/product show that they each have their own advantages and disadvantages. Also in this chapter, we tried to present the most fundamental aspects required to understand how a crowd simulator work leaving to interested readers the possibility to deepen the subject by themselves if needed.

Chapter 6 examines methods that can be used to control crowds and looks at various techniques and theories that aim to control crowd behavior according to levels of risk. When risk levels are low, techniques that range from the installation of simple, static signs to the use of dynamic signage can be implemented. Higher levels of risk require more compelling forms of crowd guidance, such as barricades. The latest research on the subject pays particular attention to using the so-called nudge theory to take a soft approach to guidance, and this chapter will summarize the various control methods that are available when aiming to minimize risk.

Chapter 7 looks at risk assessment and describes methods for assessing and classifying risk to avoid incidents when dealing with crowds. Risk assessment will be presented taking into consideration the possibilities offered by crowd simulation and sensing as described in the previous chapters.

Chapter 8 acts as a comprehensive summary of the planning topics considered so far with a particular emphasis on events that are to be planned in a short time but require a lot of attention in regard to crowd management . At the event planning stage, it is important to anticipate various sources of risk and to take steps to reduce their potential impact. It is particularly important that dangerous areas are identified and that steps are taken to plan the flow of visitors. There are also various operational constraints to consider (cost, time, safety and service level, etc.) and it is important that these factors are taken into account when designing crowd management systems.

Finally, Chap. 9 summarizes the content of this book in seven important rules (labeled the “seven knows”) that should act as the fundamental principles to every crowd manager.

Depending on the location and the type of facility representing each reader’s focus, one chapter may be more relevant than others. For example, when it comes to real-time, on-site crowd management, crowd sensing plays a vital role in understanding a crowd’s situation, and ideally crowd behavior must be modeled in real time, using simulations that are based on this information. In such places, it is usually possible to put a certain emphasis on comfort as number of occupants is typically stable, occupants often familiar with the place and staff well acknowledged with emergency procedures. In this sense, readers interested in developing a state-of-the-art system to keep crowds under control 24-h a day all-year round may find Chaps. 4 and 5 particularly relevant on this task.

On the other side, when it comes to off-site planning (e.g., for events that takes place only for a short time, but requires extensive preparation), behavior must be predicted by using such information as the total number of expected visitors, and the estimated length of their visit. This kind of modeling can be difficult, but predictions are easier when there are a fixed number of seats available, such as stadium or ticket-based events. In this context, planning and risk assessment play the utmost important role, and flexible approaches are required in which crowd control may have to be

enforced using the stricter measures. In this regard, readers who are working or focusing on such a scenario may find Chaps. 6, 7 and 8 particularly useful to them.

The above outline gives the structure of the discussion on crowd management related aspects in this book. Since each chapter is basically independent from the others, the reader may jump to the chapters that address her/his learning objectives, although following the structure of the book chapter after chapter may help to build a gradual understanding on the subject.

Reference

1. International Code Council, Inc.: International fire code (2015)

Chapter 2
Crowd Properties and Characteristics

Abstract The definition of "crowd" has been the subject of several disputes, let alone the description of its behavior and properties. Although there is no universal way to classify and describe crowds, there are some qualitative properties that can help profiling a specific crowd and manage it accordingly. In addition, there are also characteristic patterns observed when people move in large groups. Knowing them and be able to recognize them can help predicting the way people move in a given environment. Moreover, in more than a century of research on mass psychology and related fields, several theories have emerged to explain how people switch from an individual identity to a shared one when inside a crowd. Although this sort of theories had been originally developed spurred by scientific/academic interest, a number of applications have been developed and are rapidly emerging based on these theories. Understanding them can therefore help in managing crowds and the most important ones will be presented in this chapter. Nonetheless, without neglecting the importance to understand crowds qualitatively, technological development is pushing toward the need to define crowds in a numerical, quantitative way. We will therefore discuss how crowds can be measured and what are the most important quantities used in crowd management. Density, speed, and flow which represent the foundation of quantitative crowd management will be presented and discussed in detail along with the related fundamental diagram and Level of Service (LOS).

2.1 Introduction

The concept of "crowd" has always fascinated intellectuals and general public. In particular, researchers have been trying to understand how a simple, large group of people can turn into a crowd behaving with their own dynamics and when the members of a crowd "lose" their individuality in favor of a collective mindset. Crowds have also become an important topic of research after the historical events of the twentieth century, when leaders employed increasingly large crowds as a weapon to strengthen their power (with the opposite situation when crowds have challenged established leadership being also true) [1]. As research on crowds progressed, it became evident that defining a crowd and its properties is essential for a critical and

C. Feliciani et al., *Introduction to Crowd Management*,
https://doi.org/10.1007/978-3-030-90012-0_2

structured approach. The earliest definitions of crowd were very theoretical but later definition took into account the more practical aspects.

Many crowd theories have been proposed over the years. However, no single theory can explain the phenomena observed during crowd events (and no such theory may be established in the foreseeable future). More than a hundred years of discussion and research on the topic have helped clarify the need to analyze and manage crowds and the cognitive processes transforming individuals once inside a large group of people.

The study of crowds has also been considerably influenced by historical events and technological improvements. In the '60s, when the memory of the large wars of the 20th century was still alive and globalization was an emerging phenomenon, people were mostly interested in the sociological aspects of crowds: How and why does an individual transition to a collective mindset when people gather in large groups? Why is this phenomenon particularly strong in some crowds compared to others? Moreover, with regard to tragic events, how does panic spread across escaping crowds (currently, it is believed that panic does not occur or that it occurs only in rare cases, as will be discussed later)? At the same time, more practical problematics emerged in increasingly congested cities. As mass transportation evolved with the construction of metro, tram, and bus lines, people started to move around cities in large numbers. As a consequence, more practical questions arose: How to design transportation facilities from the perspective of pedestrian users? How to define building criteria that can ensure both comfort and safety?

Because of the technological limitations and the historical context, the initial research (in the early twentieth century) on crowds mainly adopted a qualitative perspective, with some simple numerical norms appearing in the late '50s and early '60s. However, with the rapid improvements in computer technology and the decreasing costs of video components, collecting numerical data on pedestrian and crowd movements became easier. Nowadays, in the digital era where a large amount of data is available, research on crowd has taken a predominantly quantitative approach. Because of the ease of counting people, tracking their positions, and more recently, even measuring their emotional states as well as the possibility of employing machine learning approaches to analyze data, a quantitative approach is better suited.

However, the rapid development toward a quantitative approach has led to a partial neglect of crowd theories and qualitative aspects. While crowd management definitely requires quantitative data that can help performing automated tasks, crowd managers also need to be familiar with qualitative aspects to understand how the crowd theory concepts are turned into numbers. In addition, qualitative aspects related to crowd management, such as sociological theories, are an important tool to help understand crowds in new situations going beyond previous experiences or to prepare for something new.

To partially reflect the historical approach of crowd research and management and to enable a better understanding of the topics presented, this chapter will start with the discussion of the qualitative aspects of crowd behavior and then delve into the quantitative aspects.