A review of entropy-based studies on crowd behavior and risk analysis

Kiran Naik[1], Gayathri Harihara Subramanian[2] and Ashish Verma[3]

[1] MTech Student, Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India
[2] Postdoctoral Research Fellow, accu:rate GmbH, Munich 80331, Germany
[3]Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India
ashishv@iisc.ac.in

Abstract. Understanding crowd behavior has become imperative as the number of mass gatherings is increasing. Many factors, such as overcrowding, venue deficiencies, rumors, accidents (such as fires, etc.), and inadequate crowd management practices, can lead to serious crowd-related severe that have resulted in injuries and fatalities. Several studies have been conducted to understand crowd behavior and predict risk conditions using different methods. The methods used to detect the crowd anomaly behavior can be classified into two general categories; Implicit Method (relies on expert opinions on several factors and needs human intervention in the model) and Explicit Method (Assessment of crowd risk situations done by the model itself, requires less human intervention in the model). Entropy, one of such explicit methods, has been widely adopted to analyze crowd behavior and predict crowd risk situations in recent years. The purpose of this study is to review the existing literature on entropy-based crowd risk prediction models and identify research gaps so that more in-depth studies on crowd management and risk assessment can be conducted.

Keywords: Entropy, Crowd-risk Analysis, Crowd Behaviour, Explicit Models.

1 Introduction

In recent years, the number of crowd gatherings at public transport stations, religious places, stadiums, shopping malls, political rallies, etc., is increasing due to urbanization, transportation convenience, social media exposure, etc. Sometimes, there might be a risk or dangerous situation due to unavoidable circumstances. Between 1980 and 2022, there were at least 440 human stampedes, resulting in roughly 13,700 fatalities and 27,000 injuries. [1]. So, it becomes essential to study crowd behavior and the factors that affect it. Crowd risk prediction is a highly relevant study area because it has practical applications in many settings, including public events, sporting events, and emergencies. Understanding how crowds behave makes it possible to identify potential risks and take steps to mitigate them. It can help reduce the likelihood of accidents, injuries, and other adverse outcomes and improve public safety in general. In addition, studying crowd risk prediction can provide insight into human behavior and decision-making, which can be helpful in fields such as psychology, sociology, and economics. By understanding why people behave the way they do in crowds, it is possible to design

K. R. Rao et al. (eds.), *Traffic and Granular Flow '22* , Lecture Notes in Civil Engineering 443, https://doi.org/10.1007/978-981-99-7976-9_7

interventions and strategies to encourage safe and positive outcomes. This paper tries to understand the following:

1. Different causes of crowd risk situations.
2. Explicit and implicit methods of crowd risk prediction.
3. Parameters used to evaluate crowd risk.
4. Entropy, different applications of Entropy, and why and how is entropy used to understand crowd behavior?
5. Identified research gaps and future trends in crowd risk prediction.

1.1 Causes of Crowd risk

There are several causes of crowd risk situations, including overcrowding, physical barriers, unfamiliar surroundings, excitement or agitation, poor lighting or visibility, and poor communication.

1.2 Parameters used to evaluate crowd risk

Several parameters can be used to evaluate crowd risk, including density, velocity, pressure, direction, composition, and behavior.[1] has extensively reviewed methods based on risk characterization parameters such as density, velocity, and pressure and mentioned other parameters like crowd energy and entropy.
This study tries to review different applications of entropy parameter in crowd behavior and crowd risk assessment.

1.3 Methods used in crowd risk prediction

Risk prediction systems can help authorities and event organizers take proactive measures to ensure public safety by analyzing crowd density, movement patterns, and social interactions. Several methods are used in crowd risk prediction, including crowd density estimation, trajectory analysis, social network analysis, machine learning, simulation, human behavioral models, physical models, statistical models, and entropy-based approaches. Many risk prediction systems combine multiple methods which are not mutually exclusive.

2 Explicit and Implicit methods of crowd risk prediction

The methods used to detect crowd anomaly behavior can be classified into the following two general categories[2]:
Implicit Method: This method involves expert opinion and human intervention to assess factors such as population density, environmental and behavioral factors. It is up to the engineer to interpret the outcome of the analysis of crush conditions.
Explicit Method: This method incorporates an assessment of crush into the model itself and therefore requires less human analysis than the implicit approach. This methodology can be used in the Social Forces Model, which calculates forces acting in the crowd.

Explicit methods are better as:

a) They are not dependent upon human perception, as it may vary from expert to expert.

b) Objectivity in predicting crowd crushes.

c) Results are based solely on force calculations in the crowd, instantaneous maximum speed, velocity correction, velocity smoothing, simulation, etc.

d) It may be possible to quantify the danger that individuals may face in a crowd crush.

Some examples of explicit methods are entropy, mutual information, and order parameter-based methods. Using mutual information, Harding et al. detected crush conditions in crowd evacuation and incorporated the social force model (FDS+Evac model) to calculate the forces acting in the crowd, later validated this model using a case study of station nightclub (Rhode Island, USA) fire incident [3]. Y. Zhao et al. conducted a study to detect ordered-disordered behavior, crowd mutation, and bi-directional ordered behavior of simulated pedestrian data using an order parameter[4]. The order parameter can take values between 0 and 1, with closer to 1 indicating more ordered movement. In most cases, explicit methods provide values as outputs, which are then used to analyze the crowd risk based on specific thresholds of the parameters. This makes the analysis much more objective.

3 Entropy

Entropy, a fundamental thermodynamic concept, can be loosely defined as a "measure of the amount of disorder" in a system[5]. According to Boltzmann, thermodynamic entropy is proportional to the logarithmic of the number of microstates in a system [6]

$$Entropy = K_B \ln(W) \tag{1}$$

Where, K_B is a Boltzmann constant and W is the thermodynamic probability.
Later, C.G. Chakrabarti et al. rephrased this as [7]

$$Entropy = k \ln(Disorder) \tag{2}$$

In 1948, Claude Shannon formulated entropy in the context of information theory[8] as

$$Entropy = -K \sum_{i=1}^{n} p_i \, log(p_i) \tag{3}$$

Where, K is a positive constant (merely amounts to a choice of unit of measure)

Gibbs gave an equation of entropy as [9]

$$Entropy = -K_B \sum_{i=1}^{n} p_i \, log(p_i) \tag{4}$$

Where, K_B is a Boltzmann constant.
Entropy has applications in various fields like urban systems, cyber security, industrial engineering, finance, software risk assessment, construction-agent system risk assessment, crowd behavior, and risk analysis.

Applications of Entropy in Crowd behavior and risk prediction

Entropy-based crowd risk prediction refers to the use of entropy, a measure of disorder or randomness, to forecast the likelihood of risky situations occurring in crowds.

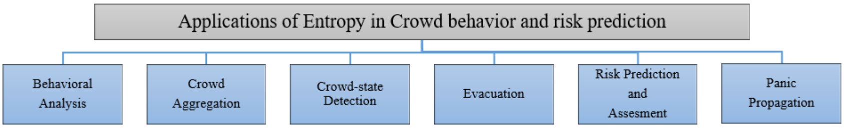

Fig. 1. Applications of Entropy in the field of crowd behavior and risk prediction

This approach has gained significant attention in recent years due to the increasing prevalence of large-scale public events and the associated risks of crowd disasters. Figure 1 illustrates various applications of entropy in crowd behavior and risk prediction.

- **Behavioral Analysis**: Researchers have used entropy-based methods to analyze the behavior of individuals within a crowd, such as identifying leaders and followers, and recognizing behaviors like seeking, exiting, and avoiding collisions.
  X. Gu et al. proposed a novel approach to represent crowd distribution information using Particle entropy[10]. Gaussian Mixture Model (GMM) was used to predict anomalies in crowd behavior and validated the study using a publicly available gathering and dispersion events dataset. Also, the experiments conducted on the public UMN dataset demonstrate the proposed model has excellent performance. Zheyi Fan et al. used an improved statistical global optical flow entropy for identifying abnormal behavior and describing the degree of chaos in the crowd based on the abnormality judgment formula[11]. The optical flow entropy is modified using concepts of information entropy and boltzmann entropy. The behavior entropy model was introduced by Wei-Ya Ren et al. for detecting and localizing abnormalities in crowds. The behavior certainty concept is used to estimate the behavior entropy of each pixel[12]. Pathan et al. introduced a new concept of social entropy to measure uncertainty in flow and used Support Vector Machine (SVM) to train and classify the flow vectors as normal and abnormal[13]. Zhang et al. compared the heat motion of basic particles with crowd motion and used boltzmann entropy to detect abnormal collective behaviors in CCTV surveillance videos[14].
- **Crowd Aggregation**: Entropy can be used to identify and describe the microstates present in a system. This can help in identifying the local aggregation in a crowd.
  Hui Guo et al. used a crowd entropy-based model to identify the local aggregation in a group depending on the difference and fluctuation in entropy values[15].
- **Crowd-state detection**: Crowd-state detection refers to the process of identifying the characteristics of a crowd, such as density, movement patterns, mutation, and congestion. By using entropy as a parameter, researchers have developed algorithms that can automatically detect different crowd states based on the level of entropy.
  Comparing theoretical entropy and actual entropy of the crowd system of an area occupied by the different crowd states, Zhao et al. developed a model to judge a high-density crowd state[16]. Behera et al. proposed the entropy-energy model to

characterize the dense crowd state in sociocultural gatherings[17]. Gibbs entropy is used to calculate the average frame entropy in videos and represents the crowd state based on these entropy values. Velocity entropy which represents motion magnitude and direction distribution, was used by Chen et al. for detecting the crowd behavior macro state[4], crowd motion phase transition[18], and congestion in crowd. The model [19] was trained using simulation data based on AnyLogic software and then tested on video recordings of the love parade disaster. The results show that this method can detect the abnormal crowd state without recognizing and tracking individual pedestrians in real time.

- **Evacuation**: Crowd evacuation refers to safely and efficiently moving a large group out of a building or other enclosed space. A higher entropy in an evacuation scenario would indicate a higher degree of disorder, such as people moving in different directions or getting stuck in bottlenecks. In comparison, a lower entropy would mean a more orderly evacuation. Wang et al. used statistical characteristics like crowd velocity, movement frequency, and crowd entropy to analyze the crowd evacuation behavior during terrorist attack event in China[20]. The novel evacuation model ECEM[21] based on agent simulation was proposed by Chen et al. The unique individual behavior called seeking behavior was incorporated into this model, and the disorder level in the crowd was estimated using Boltzmann entropy. Later, the ECBM model[22] included combined behaviors of individuals to study the relationship between different crowd behaviors during evacuation. An evacuation experiment study was done to identify the effect of small-group behavioral patterns on crowd evacuation using evacuation entropy[23].
- **Risk Prediction and assessment**: Crowd risk prediction and assessment using entropy is a research area that aims to use entropy as a metric to assess the risk of crowd-related incidents like stampedes and other emergency situations.

Using individuals' velocity and related probability, Zhao et al. proposed an entropy model to measure the crowd security level[24]. Zhang et al. used boltzmann entropy calculated from the histogram of clips to distinguish the abnormal behaviors in emergencies from their normal behaviors[25]. The entropy algorithms can be used to detect crowd anomalies using social media locations[26]. The Fuzzy system[27] has been used to pre-evaluate the crowd's safety state based on the number of pedestrians and distribution entropy. Cob-Parro et al. used optical flow entropy extracted from images for real-time stampede detection[28] in low and medium crowd scenarios.

The HCRA model[29] and improved crowd-flow model were proposed by Zhao et al., incorporating internal energy and information entropy for dynamic crowd accident risk assessment.

- **Panic Propagation**: Panic propagation in a crowd refers to the spread of panic from one person or group to others in public. As panic spreads through a crowd, it can lead to an increase in entropy or disorder.

Zhang et al. used the entropy of the enthalpy distribution for the motion field of pedestrians to detect the crowd panic state [30]. The novel approach of panic entropy based on information entropy and the Aw-Rascle model[31] was used to study the panic propagation dynamics in a highly dense crowd. Later, by including psychological factors and Shannon's entropy, the dynamic model was developed to study the escape panic propagation during the COVID-19 epidemic situation[32].

4 Future trends

Currently, machine learning algorithms are being used to improve the accuracy and efficiency of crowd risk prediction based on entropy. As a result of these algorithms, large quantities of data can be analyzed, and patterns identified that might not be apparent to humans allow more accurate predictions of crowd dangers.

Using macrostate parameters like speed, flow, density and geometrical parameters, along with Entropy, may provide better information about the crowd state and help predict the risk more efficiently.

In the future, entropy-based approaches will likely be integrated with other types of risk prediction methods, such as simulation models or physical models, to provide a more comprehensive and accurate understanding of crowd risks. Additionally, data analytics and artificial intelligence may continue to play a more significant role in crowd risk prediction, allowing for real-time analysis and response to potential risks. Using real-life data for research will help build a much more realistic model, and results obtained from it can easily be applied in the field.

There may also be a shift towards using predictive analytics and proactive measures to prevent crowd risks rather than simply reacting to incidents as they occur. This may involve using data-driven decision-making and proactive risk management strategies to prevent incidents before they occur.

5 Conclusion

This review study has highlighted the potential of entropy-based methods for analyzing and predicting crowd behavior and associated risks. These methods, based on the concept of entropy, are effective in capturing the complexity and diversity of crowd dynamics. They have been successfully applied in various settings, including crowd control, evacuation planning, and security management. However, further research is needed to realize the potential of these methods fully and to address the limitations that have been identified. Overall, this review suggests that entropy-based methods are promising for analyzing and predicting crowd behavior and risks and warrant further investigation.

References

[1] W. Weng, J. Wang, L. Shen, and Y. Song, "Review of analyses on crowd-gathering risk and its evaluation methods," *J. Saf. Sci. Resil.*, vol. 4, no. 1, pp. 93–107, 2023, doi: 10.1016/j.jnlssr.2022.10.004.

[2] P. J. Harding, M. Amos, and S. Gwynne, "Prediction and Mitigation of Crush Conditions in Emergency Evacuations," *Pedestr. Evacuation Dyn. 2008*, pp. 10–11,

2010, doi: 10.1007/978-3-642-04504-2 18.

[3] P. Harding, S. Gwynne, and M. Amos, "Mutual information for the detection of crush," *PLoS One*, vol. 6, no. 12, 2011, doi: 10.1371/journal.pone.0028747.

[4] Y. Zhao, M. Yuan, G. Su, and T. Chen, "Crowd macro state detection using entropy model," *Phys. A Stat. Mech. its Appl.*, vol. 431, pp. 84–93, 2015, doi: 10.1016/j.physa.2015.02.068.

[5] D. C. Marinescu and G. M. Marinescu, *Classical and Quantum Information Theory*. 2012. doi: 10.1016/b978-0-12-383874-2.00003-5.

[6] S. G. B. Ludwig Boltzmann, "Lectures on Gas Theory : University of California." https://archive.org/details/lectures-on-gas-theory-ludwig-boltzmann/page/n143/mode/2up (accessed Jan. 13, 2023).

[7] C. G. Chakrabarti and I. Chakrabarty, "Boltzmann Entropy : Probability and Information," *Entropy*, vol. 52, no. 1, pp. 5–7, 2007, [Online]. Available: http://arxiv.org/abs/0705.2850

[8] C. E. Shannon, "A Mathematical Theory of Communication," *Bell Syst. Tech. J.*, vol. 27, no. 4, pp. 623–656, 1948, doi: 10.1002/j.1538-7305.1948.tb00917.x.

[9] M. E. Popović, "Research in entropy wonderland: A review of the entropy concept," *Therm. Sci.*, vol. 22, no. 2, pp. 1163–1178, 2018, doi: 10.2298/TSCI180115012P.

[10] X. Gu, J. Cui, and Q. Zhu, "Abnormal crowd behavior detection by using the particle entropy," *Optik (Stuttg).*, vol. 125, no. 14, pp. 3428–3433, 2014, doi: 10.1016/j.ijleo.2014.01.041.

[11] Z. Fan, W. Li, Z. He, and Z. Liu, "Abnormal Crowd Behavior Detection Based on the Entropy of Optical Flow," *J. Beijing Inst. Technol. (English Ed.*, vol. 28, no. 4, pp. 756–763, 2019, doi: 10.15918/j.jbit1004-0579.18098.

[12] W. Y. Ren, G. H. Li, J. Chen, and H. Z. Liang, "Abnormal crowd behavior detection using behavior entropy model," *Int. Conf. Wavelet Anal. Pattern Recognit.*, pp. 212–221, 2012, doi: 10.1109/ICWAPR.2012.6294781.

[13] S. S. Pathan, A. Al-Hamadi, and B. Michaelis, "Incorporating social entropy for crowd behavior detection using SVM," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 6453 LNCS, no. PART 1, pp. 153–162, 2010, doi: 10.1007/978-3-642-17289-2_15.

[14] X. Zhang, S. Yang, Y. Y. Tang, and W. Zhang, "Crowd motion monitoring with thermodynamics-inspired feature," *Proc. Natl. Conf. Artif. Intell.*, vol. 6, no. 61472087, pp. 4300–4301, 2015, doi: 10.1609/aaai.v29i1.9270.

[15] H. Guo, X. Guo, W. Lv, and Y. Song, "Investigation of crowd's aggregation measurement based on an entropy model," *Saf. Sci.*, vol. 127, no. March 2018, p. 104714, 2020, doi: 10.1016/j.ssci.2020.104714.

[16] G. Zhao, C. Li, G. Xu, F. He, and J. Zhang, "A high-density crowd state judgment model based on entropy theory," *PLoS One*, vol. 16, no. September, pp. 1–15, 2021, doi: 10.1371/journal.pone.0255468.

[17] S. Behera, D. P. Dogra, and P. P. Roy, *Characterization of dense crowd using gibbs entropy*, vol. 704. Springer Singapore, 2018. doi: 10.1007/978-981-10-7898-9_24.

[18] Y. Zhao, M. Yuan, G. Su, and T. Chen, "Entropy and Dynamics Analysis of Crowd Motions Phase Transition," 2015, doi: 10.15242/iie.e0115006.

[19] L. Huang, T. Chen, Y. Wang, and H. Yuan, "Congestion detection of pedestrians using

the velocity entropy: A case study of Love Parade 2010 disaster," *Phys. A Stat. Mech. its Appl.*, vol. 440, pp. 200–209, 2015, doi: 10.1016/j.physa.2015.08.013.

[20] J. Wang, S. Ni, S. Shen, and S. Li, "Empirical study of crowd dynamic in public gathering places during a terrorist attack event," *Phys. A Stat. Mech. its Appl.*, vol. 523, no. July 2016, pp. 1–9, 2019, doi: 10.1016/j.physa.2019.01.120.

[21] X. Chen and J. Wang, "Entropy-Based Crowd Evacuation Modeling with Seeking Behavior of Social Groups," *IEEE Access*, vol. 9, pp. 4653–4664, 2021, doi: 10.1109/ACCESS.2020.3048054.

[22] X. Chen and J. Wang, "An Entropy-Based Combined Behavior Model for Crowd Evacuation," *Entropy*, vol. 24, no. 10, 2022, doi: 10.3390/e24101479.

[23] J. Ren, Z. Mao, D. Zhang, M. Gong, and S. Zuo, "Experimental study of crowd evacuation dynamics considering small group behavioral patterns," *Int. J. Disaster Risk Reduct.*, vol. 80, no. August, p. 103228, 2022, doi: 10.1016/j.ijdrr.2022.103228.

[24] Y. Zhao, M. Yuan, G. Su, and T. Chen, "Crowd security detection based on entropy model," *ISCRAM 2015 Conf. Proc. - 12th Int. Conf. Inf. Syst. Cris. Response Manag.*, vol. 2015-Janua, pp. 24–33, 2015.

[25] X. Zhang, S. Yang, Y. Y. Tang, and W. Zhang, "A thermodynamics-inspired feature for anomaly detection on crowd motions in surveillance videos," *Multimed. Tools Appl.*, vol. 75, no. 14, pp. 8799–8826, 2016, doi: 10.1007/s11042-015-3101-8.

[26] C. Garcia-Rubio, R. P. D. Redondo, C. Campo, and A. F. Vilas, "Using entropy of social media location data for the detection of crowd dynamics anomalies," *Electron.*, vol. 7, no. 12, pp. 1–15, 2018, doi: 10.3390/electronics7120380.

[27] X. Zhang, Q. Yu, and Y. Wang, "Fuzzy evaluation of crowd safety based on pedestrians' number and distribution entropy," *Entropy*, vol. 22, no. 8, 2020, doi: 10.3390/E22080832.

[28] A. C. Cob-Parro, C. Losada-Gutiérrez, M. Marrón-Romera, A. Gardel-Vicente, I. Bravo-Muñoz, and M. I. Sarker, "A Proposal on Stampede Detection in Real Environments," *CEUR Workshop Proc.*, vol. 3097, 2021.

[29] R. Zhao *et al.*, "Dynamic Crowd Accident-Risk Assessment Based on Internal Energy and Information Entropy for Large-Scale Crowd Flow Considering COVID-19 Epidemic," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 10, pp. 17466–17478, 2022, doi: 10.1109/TITS.2022.3156922.

[30] X. Zhang, X. Shu, and Z. He, "Crowd panic state detection using entropy of the distribution of enthalpy," *Phys. A Stat. Mech. its Appl.*, vol. 525, pp. 935–945, 2019, doi: 10.1016/j.physa.2019.04.033.

[31] R. Zhao, Q. Hu, Q. Liu, C. Li, D. Dong, and Y. Ma, "Panic Propagation Dynamics of High-Density Crowd Based on Information Entropy and Aw-Rascle Model," *IEEE Trans. Intell. Transp. Syst.*, vol. 21, no. 10, pp. 4425–4434, 2020, doi: 10.1109/TITS.2019.2953357.

[32] R. Zhao, P. Jia, Y. Wang, C. Li, Y. Ma, and Z. Zhang, "Dynamic propagation model of crowd panic based on Shanoon's entropy theory under COVID-19 epidemic situation," *IAEAC 2021 - IEEE 5th Adv. Inf. Technol. Electron. Autom. Control Conf.*, vol. 2021, pp. 1720–1724, 2021, doi: 10.1109/IAEAC50856.2021.9391003.