ARTICLE

HOW DO WE SOLVE WICKED PROBLEMS? EFFECTIVE CROWD MANAGEMENT

Andrew Tatrai

When modern visualisation techniques are used to depict real-time changes in crowd behaviour, their movement resembles the dancing landscapes of complex adaptive environments. Researcher Andrew Tatrai describes the exciting possibilities offered by new monitoring technologies to improve crowd management.

INTRODUCTION

The science of emergence, the mechanics of complexity and the links to the understanding and building robust artificial intelligence are increasing at an accelerated rate. So much so, there is a need to prescribe some generally accepted techniques to solve the multidisciplinary problems or define an approach for previously unsolvable situations. The community of practice and Second Track processes are designed to consider these broader views beyond traditional science silos to create new knowledge on complexity, social and intelligence horizons.[1]

Wicked problems built on causal relationships are partly ignored due to the dominance of statistics that summarise data but do not interpret it. The issue with wicked problems is that we can understand the causal inference by tinkering (in the words of Judea Pearl) with the factors that affect the result but cannot build the mathematically explicit models required to emulate the solutions to these common and recognisable problems.[2]

1. Massingham et al., 2020
2. Pearl and Mackenzie, 2018

The application of complexity theory and complex adaptive systems has provided insight; however, the traditional metrics cannot often model change. Advances in technology offer new tools to view the complexity lens. This research reviews a wicked problem of crowd management and applies the methodology to define, model and solve crowd management intervention technics based on new views, new metrics and modern technology. A multidisciplinary approach was taken, drawing on psychology, sociology, mathematics and computer science.

As the world becomes crowded, effective crowd management is essential for every organisation responsible for safety, yet the literature is fragmented in theory and practice for solutions across the broad range of crowd behaviours. This paper introduces concepts that improve our understanding of crowd behaviour and new tools to improve the management of crowds.

THE NATURE OF CROWDS

The origins of crowd theory can be traced back to the late 1800s when psychology and psychologists played a leading role in developing models of human behaviour. Friedrich Nietzsche wrote, touching on some of the vagaries of crowd observations, '[i] n individuals, insanity is rare; but in groups, parties, nations and epochs, it is the rule'.[3] There are two philosophical pathways of thought. Type 1 suggests that the presence and interaction of people in crowds develop a group mind, separate from and overruling individual rationale. This has become the leading paradigm in foundation theory, despite some sociologists arguing that it lacks the nuanced approach to consider both aspects of irrationality and other influences that align with behavioural theory. Type 2 suggests that individuals in the crowd develop, share and proliferate their traits to form the crowd. These twin theories provided the foundations for academic exploration of thought.

In the last six decades, crowd theory was influenced by general management theory. Smelser, in 1962 provided an alternative view of the ability of a crowd to apply rational decision making.[4] This prompted a wave of research from scholars such as McPhail, who wrote about 'the myth of the maddening crowd'.[5] The idea of the crowd as a rational group gave rise to directional and informative crowd control techniques that include simple rules such as informing crowds of limits, issues, ethics and required behaviours. These concepts have been applied in practice, for example, by British police to look at crowd eruptions as responses to socioeconomic problems and how dialogue and negotiation can keep the peace.[6] Consistent with crowd behaviour, not all situations aligned with this theory; Gorringe and Rosie point to the failure of this strategy in the 2011 London riots. These advances have been unable to explain why crowd behaviour can present as disproportionate or erratic outputs.

The complexity approach is based on recognising that crowd behaviour is emergent, as interacting factors and conditions and interrelationships between various influences can produce various responses. Crowd behaviour is a complex situation that requires a systems-oriented approach, and managing crowds requires an understanding of changes in the emergent behaviour and the factors that influence those changes.

3. Nietzsche and Faber, 1998
4. Smelser, 2013
5. Smelser, 2013; McPhail, 1991
6. Gorringe and Rosie, 2011

COMPLEX ADAPTIVE SYSTEMS AND WICKED PROBLEMS

Emergent behaviour is an advancement of systems thinking that replicates how nature develops changes and new forms emerge. Changes, agents, rules and the environment all affect the result or output. The emergent behaviour concept fits crowds because the behaviour of a system emerges from the structure of its parts, and a crowd's behaviour cannot easily be predicted or extrapolated from the behaviour of those individual parts. Emergent behaviour refers to how complex systems and patterns arise out of a multiplicity of relatively simple interactions, and thus, it cannot be predicted by linear or inflexible theory. Emergent behaviour looks remarkably like crowd structures, with bottom-up changes driving adaptive responses.

Complex adaptive systems embrace the self-organising feature common in nature and society. The mathematical foundations of complex adaptive systems are credited to John Holland, working in genetic algorithms. Other scholars such as Axelrod[7] showed that complexity could be applied to social science issues such as developing a culture in organisations. Complex systems are systems made of many microscopic components interacting with each other in nontrivial ways. Characteristics of complexity are noted as interdependent and diverse entities that can adapt and respond to their local and larger environment. Complex systems have broad and non-scientific descriptors to illustrate changes over time. Page[8] presents dynamic and fluid reactions of complex systems as dancing landscapes changing over time. Crowd behaviour is portrayed to adapt and move over time. Crowd behaviour is characterised by constant change, self-organisation and feedback loops that cause non-linear responses. Like other complex systems, crowds are unpredictable and can produce significant disproportionate responses (e.g., crowd panic in reaction to a gunshot or during crowd evacuation). Complex systems produce bottom-up phenomena, in which the actions of the individual members become the group's actions. The adaptive response of crowds to agents and actors points to emergent behaviour.

The essential purpose of crowd management is to ensure that crowds stay safe and in a neutral or positive mood and to achieve this, emergent behaviour needs to be kept within the boundaries that are acceptable and desirable in the given situation. At one end of the scale, this may be about maximising the experience for an audience, and at the other, about the containment of disruptive or dangerous behaviour. To control emergent behaviour is to direct the development of a complex adaptive system, which simplifies complexity, which is a wicked problem by definition. As Webb[9] notes, 'wicked problems … [are made up of]… interrelated components of organised complexity … [which] cannot be solved in isolation from each other'. They are found when a single theory or paradigm does not identify the nature of complexity; its difficulty and length have defined complexity to describe and model the relationships between components. While some systems can be modelled sufficiently, social sciences can still not quantify and identify the many influencing factors within complex adaptive systems, hence stalling the modelling applications until new techniques became available. Research needs to provide quantitative data for crowds as a social system by utilising the latest advances in digital technology to collect and analyse that data.

7. Axelrod, 1997
8. Page, 2015
9. Webb, 2006

CROWD MANAGEMENT

There are two aspects to crowd management – structural and dynamic – and both apply whether the crowd is in a stadium, shopping mall, music festival, conference, railway station, or any other place where people congregate in large numbers. The structural aspect covers the physical situation – the capacity, layout, entrances and exits, pathways, focal points – as well as the temporal dimension – the schedule of activities within that space. A good design and plan, adequately funded and carefully implemented, is the first essential step in effective crowd management. The more significant difficulties lie in the dynamics of the moment, for the mood and behaviour of a crowd will change over time and may change rapidly, producing a dangerous situation. A crowd is not a simple unit that will behave predictably but an aggregate of individuals and groups of individuals, who will act, react and interact in an infinite variety of ways. A crowd is a complex adaptive system, and as we have noted, the effective management of complexity is intrinsically a wicked problem.

Several practitioners have supported the psychological approach. One of the most practical guides for crowd management comes from UK psychologists who developed a series of guides and supporting evidence for understanding crowd behaviour.[10] Given that psychology includes definitions of a person's mental characteristics or attitude, its rise to dominance, in theory, is not surprising. While psychology continues to dominate the study of crowd theory, other disciplines bring their unique perspectives to the field. For example, Brewer and Wollman[11] argue: 'It is sociology as a discipline that best understands crowd behaviour', noting that 'crowd behaviour is dynamic in unpredictable ways, and reason and motive disappear when crowds move unpredictably'.

A multidisciplinary approach suggested by Challenger et al.[12] acknowledges the role of other disciplines in crowd management, highlighting that real-time systematic observations and expert knowledge are vital to an effective stimulation model, as most simulation tools are not based sufficiently on research literature, and proposes that future simulation tools need to include groups of people within groups, individuals' emotions, and the interface between people and traffic.[13]

DETERMINANTS OF CROWD BEHAVIOUR: DENSITY AND MOVEMENT

Crowd behaviour is affected by many factors: actors, agents, external environmental factors such as light, sound, signage and intoxication, and internal drivers of grouping and mindset, to name a few. On the theme of starting with superficial causal relationships that can be measured, this research uses two well-researched metrics of crowd density and flow rate as inputs having a causal relationship on the crowd behaviour output of mood. The three are interlinked, and each is subject to a range of externalities and human pressures. Effective crowd management relies upon a quick assessment of and response to these factors. Crowd management practice has remained fundamentally unchanged for some years. It relies essentially on the experience of crowd managers and the robustness of their teams. Crucial to this is the experience of the crowd managers and the surveillance they have over the crowd: they must assess density, velocity and mood. Making these assessments have improved over time, and the industry is taking great strides forward at present.

10. Challenger et al., 2009
11. Brewer and Wollman, 2011
12. Challenger et al., 2009
13. Challenger et al., 2009

The basic approach to real-time data collection and measurement of crowds is crowd counting. This started with subjective estimates for event attendance, which was developed by combining data relating to density and space from photos with knowledge of geographical areas multiplied across sectors and layers.[14] These methods come from the desire to confirm event attendance at, for example, protests and marches but are viewed as inaccurate, the primary flaw being that the angle from which a photograph is taken has a significant bearing on the estimate. Some researchers have tried to adapt old methods to modern applications, using drones to estimate event attendance with the Jacobs method.[15] Subjective measures have been accepted for practical applications until better techniques were developed.

Crowd counting expanded into planning guides for safe crowd density and capacity calculations. Practical guides became the foundation for event planning capacities. The *British Guide to Safety at Sports Grounds*, also known as the *Green Guide*, assists crowd managers to reference and calculate safe capacities. The 2018 *Green Guide* mentions density (as a function of capacity) 23 times without providing a measurement method other than estimation.[16] These guides are widely used in pre-event planning and post-event or incident analysis but are not applied to dynamic moving crowds. Simple changes, such as entrance gateways becoming reduced, cannot be anticipated in pre-event planning. Stationary pre-planning guides cannot anticipate the multiple scenarios real crowds produce.

Data collection for crowds also comes from observations of, and interviews with, actual participants. These studies provide background to the issues and concerns of attendees but fail to explain the interaction of the agents in a crowd or how the behaviour can be consistently modelled. Authors such as Boghossian and Velastin[17] note the inefficiency of human observations of crowds for study purposes, citing inaccuracies and the inability to compute multiple variances. Whilst human observation can reiterate situations frequently, cognitive limits point to the necessity of machine data collection.

The design of smart cities has increased crowd management research applications. For example, the need to increase pedestrian signal road crossing times when large crowds are present can be detected and actioned by camera analysis. This method uses visual shape recognition for individuals tracked by using a Kalman or particle filter. Advances in image and vision computing to measure crowd density and template-based tracking include the work of Idrees et al.,[18] who analyse instant crowd flow and density calculations without prior contextual training of instrumentation required. This is an example of management leading technology advances.

DETERMINANTS OF CROWD BEHAVIOUR: MOOD

The mood is rarely mentioned in crowd management literature, though as crowd management practitioner Bob Quintella of the Oakland Coliseum notes, 'to keep management from crossing over into crowd control, one of the most important things to do is correctly assess the mood of the crowd'.[19] Recently, these lines of thought were restricted as there was no method

14. Jacobs, 1967
15. Choi-Fitzpatrick and Juskauskas, 2015
16. Department of National Heritage, 2018
17. Boghossian and Velastin, 1999
18. Idrees et al., 2014
19. Waddell, 1997

'to assess the crowd's mood'. Crowd mood research has been restrained by designing large-scale research projects without mood measurement devices.

The mood is hard to define, and its complexity is created by the multiple influences of external and internal stimuli. Lazarus describes the mood as 'a transient reaction to specific encounters with the environment, one that comes and goes depending on particular conditions'.[20] Moods are subtle and often not self-recognised as an impact on self-behaviour.[21]

Crowd mood definitions reflect the uncertainty of mood understanding. Barsade and Gibson[22] suggest that although group emotion has no standard definition, the ebb and flow of emotion affect crowds both from the individual to the group and from the individual.[23] Their model shows that group emotion causes a feedback loop that affects individual moods, which in turn rebalance the developing group mood; this appears similar to the influences of emergent behaviour. It has only been in the last three-five years that quantitative mood and emotion analysis has been possible.[24]

Crowd mood measurement and research have yet to receive significant academic attention. The literature reflects the lack of research to sanction mood measurement or the use of facial expressions as an accurate representation of mood. This may be because the mood is viewed as layered complexity, or techniques have not been developed to measure facial features for mood comparison. Despite broad reading in mood research, Skinner's behavioural approach provides a vague link to mood and facial expression by epistemic interpretation. Skinner's philosophy on behaviourism suggests to only measure what can be proved. Hence facial features such as smiles and frowns are valid substance. Behaviourism also supports the concept that the environmental factors received by the crowd affect the mood of the crowd.[25] If we can simplify mood to what can be inferred from observed facial features, it can be measured using the currently available technology.

THE TECHNOLOGY

This investigation uses new technology to measure density, flow and mood in a crowd simultaneously, and it is the measurement and analysis of all three factors, together, in real time that makes this approach uniquely valuable as a tool for crowd management. The software developed by Dynamic Crowd Measurement Pty Ltd combines programs to record all three metrics, working from data collected by CCTV[26] cameras. Dynamic Crowd Measurement (DCM) is a Sydney-based technology start-up that has developed commercial software to measure crowd characteristics and model crowd data. The software visualises the interrelationship between density, flow and mood as a three-dimensional regression model in near real-time, showing the phase changes and tipping points as well as the effect of intervention or crowd management.

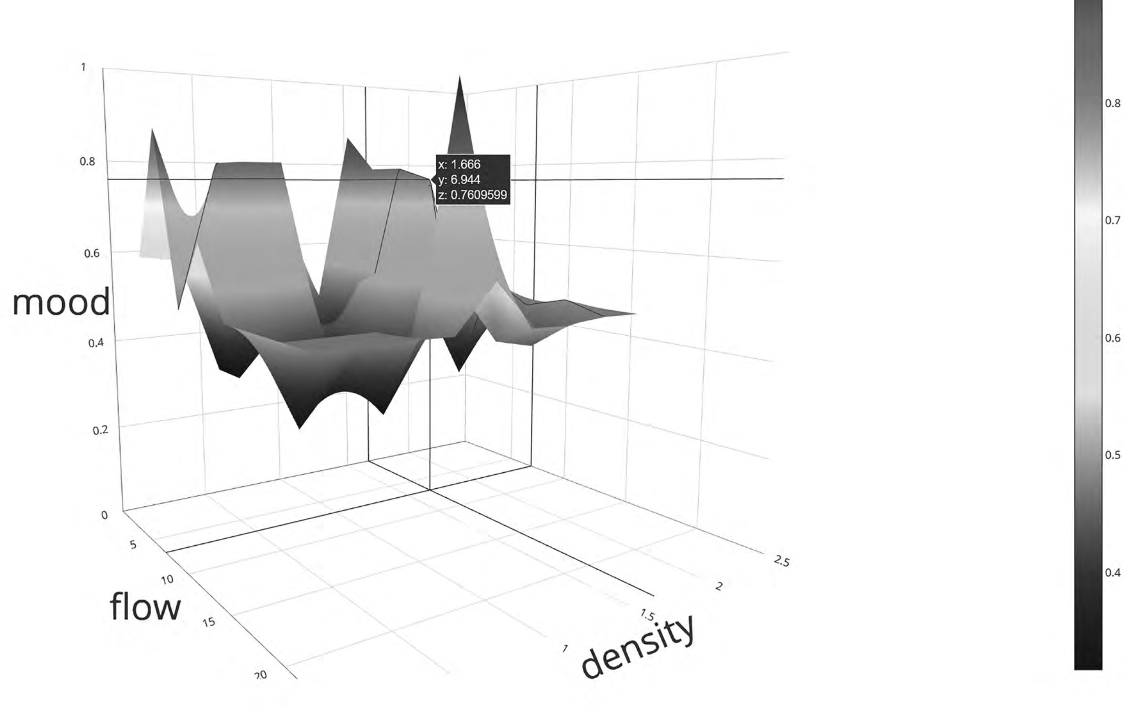
Headcount, density, flow and mood were measured, then analysed and presented in various formats. The operational managers on the ground required a condensed and visual interpretation of the data. The three metrics of Density, Flow and Mood (DFM) are modelled in a data visualisation technique called a fitness landscape, which effectively maps the complexity of the DFM relationship.

20. Lazarus, 1991, p.47
21. Forgas, 1992
22. Barsade and Gibson, 2012
23. Barsade et al., 2018
24. Barsade et al., 2018
25. Catania and Harnad, 1988
26. Closed-circuit television (CCTV), also known as video surveillance

The image below displays density in the X-axis, flow in the Y-axis and mood as the vertical axis, with colour gradients to show the increase in negativity climbing towards value 1. After consultation with crowd managers, this orientation was chosen to recognise the red colour, and the high peak symbolised the escalating seriousness of the situation. The blue or cool colours denote positive mood as valleys below 0.5 or neutral mood score.

Management action could modify the crowd mood, and intervention was conducted. The test was designed as a controlled situation to accentuate the visual results and connect the action on the ground with the timestamps on the data frames. Typically, if density increases and the flow reduces, the mood should be negative, so access to the pavilion was deliberately reduced. Over repeated sequences, the width of the door entries was reduced from 8 metres (fully open) to approximately 2 metres. The constriction caused an increase in density and a reduction of crowd flow. Correspondingly, and with a very short lag in response, the measurement device noted changes in crowd mood, shifting to

IMAGE 1: FITNESS LANDSCAPE VISUALISATION OF DENSITY FLOW AND MOOD DATA FROM THE SHOW BAG PAVILION[27]



27. From the Show Bag pavilion, 19 April 2019. The display can be rotated in 3D, and magnified as needed so that all parts of the model can be examined. Image credit assistance from Ruoxiang Wen, DCM data scientist. https://dcmtenant.s3-ap-southeast-2.amazonaws.com/10000000-0000-0000-0000-000000000000/dcm-dfm-data-plotting/version1/test_data_3d.html

negative. This demonstrated the sensitivity that the measuring device was able to provide. When the access ways were reopened to their full width, allowing density to reduce and flow to increase, the mood plateaued (as noted in Image 6) and relaxed back to a neutral than positive position. The real-world response was that people were happy they could enter without restrictions and congestion, and therefore the crowd mood changed.

In summary, the pilot data sampling at the Royal Easter Show confirmed the concept that crowd mood can be managed by controlling density and flow. It shows that the relationship between density, flow and mood is dynamic and non-linear despite the repeatability of the situations and outcomes. The variance of the influences is a symptom of complexity. Complexity theory explains this relationship more accurately than traditional management theories.[28]

A further test was applied to crowd management practice to test the validity of the DCM data measurement instrument. The next phase was data collection and management in a more complex environment.

PILOT STUDY 2: METHODS AND RESULTS

Wicked problems are known for their complexity, so a second real-life study was designed to explicitly test if crowd management could make changes in density and flow to manipulate mood in a public crowd. The hypothesis provided was, 'When do pedestrians become a crowd, and when does a crowd need crowd management?'. A statement like this is more relevant for wicked real-world problems and reflects the objectives of the crowd management practitioners.

Pilot study 2 was at the VIVID Sydney Light Walk 2019. This Destination NSW (DNSW) event attracted over 2.3 million patrons in 2019. It stimulates the Sydney night-time economy and promotes the iconic Sydney Harbour, Opera House and Sydney Harbour Bridge. DNSW makes a substantial investment in overseas marketing to attract visitors to Sydney for the event in mid-winter. It wants visitors to have a pleasant experience at VIVID because this increases the value of the overseas marketing spend by supporting it with positive word-of-mouth referrals and comments.

VIVID Sydney Light Walk has a complicated event footprint, with artist installations straddling the Rocks Precinct and Circular Quay and stretching to the Royal Botanic Gardens. The walking route conflicts with patrons and commuters arriving at the Circular Quay transport hub. Crowd management difficulties include urban infrastructure and buildings that create bottlenecks and construction projects. As the event is free and un-ticketed over 23 days, predicting crowds based on past attendance is difficult. This uncertainty has required high levels of crowd staffing to cope with worst-case numbers on numerous event days, which has a financial impact.

This stage of the testing did not include any deliberate modification as prompted in the pilot study test but used the 'natural' variation in the arrival and circulation flows of the crowds. This is referred to as 'in the wild', signifying non-modified and non-laboratory conditions in standard terminology. It was, therefore, a test for management application. Travis Semmens, an experienced associate and the crowd security manager for the VIVID event, supported the technology and security guidance and response implementation. Cameras and observers were placed at the bottleneck points at West Circular Quay, East Circular Quay, and the Rocks' Cutaway. The aim was to monitor changes that cause negative mood impacts and use this information to allow crowd managers to deploy crowd calming techniques. Once management response scenarios

28. Goulielmos, 2002

IMAGE 2: TESTING BOXING IDENTIFICATION WEST CIRCULAR QUAY SYDNEY DURING VIVID 2019

were devised and staff were briefed, the mood levels were calibrated to match the concern of the consulting, and the measuring instrument started.

Initial observations noted the novelty of the information to crowd managers. It was apparent that the technology is far more sensitive than human assessment, requiring crowd managers to build trust in the measurements before they could start to believe and react to the measurement advice. Consultation with crowd management and police noted that the technical data, while interesting, was not easily understood. A quick reference guide was required to reduce the information provided to focus on actionable areas, and a dashboard was developed with simplified colour codes and heat mapping to reflect real-time changes in mood for rapid responses.

USING NEW METRICS TO SOLVE WICKED PROBLEMS

This research, and the broad and general research question describing a wicked problem, has identified mood measurement as a basis for practical crowd management purposes. Crowd behaviour has been linked to mood in practice before measuring and visualising the changes. The scientific evidence that management intervention to change crowd density and flow affects mood provides a quantitative base for management decision support. Once mood can be measured, consistent, repeatable and large-scale crowd management decisions can be developed.

This research proves mood can be monitored and measured. Technology to measure mood changes is far more efficient than subjective human cognition. When mood changes are visualised as peaks and valleys, crowd managers can see the objective of crowd management rather than interpret and 'feel' the mood changes. It becomes positive guidance. The ability to measure these characteristics advances crowd management understanding and causality.

The data can visualise the phase changes and tipping points in crowd mood. Pilot study 1 provided crowd managers with evidence of mood escalation to estimate causality and instigate intervention to manage mood. The predictive capability of crowd managers was enhanced by near real-time information flow. This is a significant advancement from traditional crowd management; however, it became apparent that a mathematically explicit model could use the slope angles and formula of mood visualisation to extrapolate or predict mood change, tipping points and phase changes. Pilot study 2, in a less controlled environment, provided the opportunity for crowd managers to practise using the technology and respond within a timeframe to maintain crowd mood. In addition, the use of technology dashboards allowed crowd analytical information to be disseminated to event organisers, police, transport authorities and other stakeholders. Potentially, even attendees could receive a heat map of crowd congestion at events by logging into an app or portal to allow self-organisation, depending on their tolerance and desire to avoid crowded areas. This is a considerable advancement for crowd and event management.

Data visualisation identifies forms. The most exciting discovery from the research is the visualisation of the changing crowd data from pilot studies 1 and 2. The moving data in real time resembles the dancing landscapes of complex adaptive environments described by Page.[29] The crowd mood visualisation parallels many features of complex adaptive systems. Dramatic peaks grow, move and sink into valleys as emergent behaviour, represented by mood, is influenced by changes to density and flow.

Real-time visualisation shows the efficiency of computer detection and mapping. The pilot studies showed how machine computation amplified changes beyond experienced crowd managers' ability. The technology was significantly more sensitive than human observation. The mood measurement can be applied to classify all crowds, from simple crowds of pedestrians or spectators to diverse and complex crowds at gatherings to the chaos of riots and disorder. At the extremes (e.g., stable pedestrian crowds and riotous disorder), the mood is measurable and assists in the identification. However, it is the area that Page[30] notes as 'he interesting in-between', described as complex, or on the edge of chaos, that benefits the most from mood measurement. This research focuses on complex crowds where the dynamic features of complexity and the dancing landscapes leap into life with the new data collection technology. Mood measurement has opened significant volumes of academic research on complexity and complex adaptive systems that can now be applied to crowd management.

29. Page, 2011
30. Ibid.

The similarities between complex adaptive systems and crowds are extensive. Complexity theory is still nascent, so caution is applied in labelling this as a perfect description for crowd science. However, there have been a small number of focused applications of complexity theory in crowd science. Goulielmos[31] claims complexity theory 'describes life better than the hitherto available theories, as it deals more effectively with dynamic, non-linear and cyclical phenomena'. It follows that once the measurement has allowed the complexity of the relationship to present itself, a management framework can be selected and applied.

A NEW DEFINITION OF CROWD MANAGEMENT BASED ON MOOD MEASUREMENT

Wicked problems require new definitions. The diversity of crowd theory has led to various definitions and practices, and similarly, crowd management practice is poorly defined. Single academic theories do not extend to crowd management definitions, and definitions from practitioners vary extensively.

To solve wicked and practical problems, a solution needs to define all aspects of the practice clearly. These are the definitions that arise from the research.

1. **Strategic definition:** 'Crowd Management is the observation and modification of crowd mood to meet meet the event's objectives or place managers'.
2. **Tactical definition:** 'Crowd management maintains crowds in a neutral or positive mood'.
3. **Operational definition:** 'Crowd management modifies external environmental factors such as density and flow to balance the crowd's mood for the objectives desired. Crowd density, flow and mood are influenced by external environmental conditions, including available space, information, numbers, light, sound, weather, the presence of actors and agents (police, security, crowd marshals or stewards), internal factors such as groups' emotions, and the effect of alcohol or drugs. Ultimately the final measurable output is the averaged crowd mood. If crowd mood is prevented from becoming negative, then crowd management is a success.'

USING THE FINDINGS TO IDENTIFY A MANAGEMENT FRAMEWORK

For a solution to be considered valid in the real world, the last piece of the jigsaw puzzle should fit an existing management framework. Complexity theory can be coupled with the ordered and unordered states of crowd behaviour. The data from this research has been able to offer a delineation between ordered and unordered states. An ordered state is aligned with a neutral mood, while an unordered state can be found at the extremes of both a negative or a positive mood.

The established Cynefin Management Framework has a good fit for crowd management and has shown practical applications in strategic police management, where a range of situations present the need for a measured approach based on the complexity of the response.[32]

31. Goulielmos, 2002
32. Snowden and Boone, 2007

TABLE 1: COMPARING SNOWDEN'S COMPLEX ADAPTIVE ENVIRONMENT TO CROWD SITUATIONS[33]

FROM SNOWDEN AND BOONE (SNOWDEN & BOONE 2007)	OBSERVATIONS OF CROWDS (TATRAI 2010-2020)
It involves a large number of interacting elements	Individual and groups as agents, previous past experiences, motivation, density, crowd flow and mood and psychology, size, numbers and groups, light sound, control forces, weather
The interactions are nonlinear, and minor changes can produce disproportionately significant consequences)	Some inputs can cause panic, reaction to peer influence or police violence. Barriers or blockages cause crush, music and alcohol can exaggerate behaviour
The system is dynamic, referred to as emergent	Crowd behaviour can develop quickly and expectantly with the right catalysts
The system has a history, past integrated with the present	People humans have intentionality, identities and can change the system (rebel against guidance/force) create self-generating leadership for internal groups
May appear ordered, but hindsight does not lead to foresight, because conditions continually change	Precisely as crowds seem at times, event mass movements appear ordered until a blockage, a noise, a scare sets the crowd off in a disordered pattern
In complex systems agents and the system constrain each other	Crowd management, crowd control, signage, lighting, other people in the crowd groups and police and external authorities all interact to influence the end output or result

KEY POINTS THAT PROVIDED A MEASURED SOLUTION TO A PREVIOUSLY WICKED PROBLEM

Advances in technology have allowed crowd features to be observed, measured and modelled in real time, and the measurement assists in understanding patterns of changes and influences. When the new data is visualised in a graphical display, the crowd scenes present the dancing landscapes typical of complex adaptive systems. Once the modelling shows phase changes and tipping points, a new perspective on management is possible. Refining and aligning a management framework to the new data is the solution for a problem, formerly only solved by human experience. If it is accepted that crowd management has been previously a wicked problem, new technology, new data, new views, and new applications is the process flow to find a new solution. This research identifies the potential link from measurement to management, and in doing so, creates a new era in crowd management that will provide transparent goals and objectives.

33. O'Toole et al., 2020

REFERENCES

Axelrod, R. (1997), *The complexity of cooperation: Agent-based models of competition and collaboration*, Princeton University Press

Barsade, S.G., Coutifaris, C.G. and Pillemer, J. (2018), Emotional contagion in organisational life. *Research in Organisational Behavior*, 38, 137–151

Barsade, S.G. and Gibson, D.E. (2012), Group affect: Its influence on individual and group outcomes. *Current Directions in Psychological Science*, 21, 119-123

Boghossian, B,A., Velastin, S.A. (1999), Motion-based machine vision techniques for the management of large crowds. Proceedings of the 6th IEEE International Conference on Electronics, Circuits and Systems ICECS, 1999. 961–964

Brewer, J. and Wollman, H. (2011), Sociologists' offer to unravel the riots', Letter to *The Guardian*.

Catania, A. and Harnad, S.E. (1988), *The selection of behavior: The operant behaviorism of BF Skinner: Comments and consequences*, Cambridge University Press

Challenger, W., Clegg, W. and Robinson, A. (2009), Understanding crowd behaviours: Guidance and lessons identified. *UK Cabinet Office*, 11–13

Choi-Fitzpatrick, A. and Juskauskas, T. (2015), Up in the Air: Applying the Jacobs Crowd Formula to Drone Imagery. *Procedia Engineering*

Department of National Heritage (2018), *Guide to Safety at Sports Grounds 6th ed.*, London, Sports Ground Safety Authority (SGSA)

Forgas, J.P. (1992), On mood and peculiar people: Affect and person typicality in impression formation. *Journal of Personality and Social Psychology*, 62, 863–875

Gorringe, H. and Rosie, M. (2011), King mob: perceptions, prescriptions and presumptions about the policing of England's riots. *Sociological Research Online*, 16, 1–6

Goulielmos, A.M. (2002), Complexity theory applied to management of shipping companies. *Maritime Policy and Management*, 29, 375–391.

Idrees, H., Warner, N. and Shah, M. (2014), Tracking in dense crowds using prominence and neighborhood motion concurrence. *Image and Vision Computing*, 32, 14–26

Jacobs, H. (1967), To count a crowd. *Columbia Journalism Review*, 6, 36–40

Lazarus, R.S. (1991), *Emotion and adaptation*, Oxford University Press on Demand

Massingham, P., Fritz-Kalish, C. and McAuley, I. (2020), Emergent communities of practice: A complexity theory lens. *Journal of Behavioural Economics and Social Systems*, 2, 17–36

McPhail, C. (1991), The Myth ofthe Madding Crowd. New York: Aldine de Gruyter

Nietzsche, F.W. and Faber, M. (1998), *Beyond good and evil: prelude to a philosophy of the future*, Oxford, Oxford University Press

O'Toole, W., Luke, S., Semmens, T., Brown, J. and Tatrai, A. (2020), *Crowd Management. Risk, security and health*, Goodfellow Publishers

Page, S.E. (2011), *Diversity and complexity*, Princeton, NJ, Princeton University Press

Page, S.E. (2015), What sociologists should know about complexity. *Annual Review of Sociology*, 41, 21–41.

Pearl, J. and Mackenzie, D. (2018), *The book of why: the new science of cause and effect*, Hachette UK

Smelser, N.J. (2013), *Theory Collectve Behav Ils* 258, Routledge

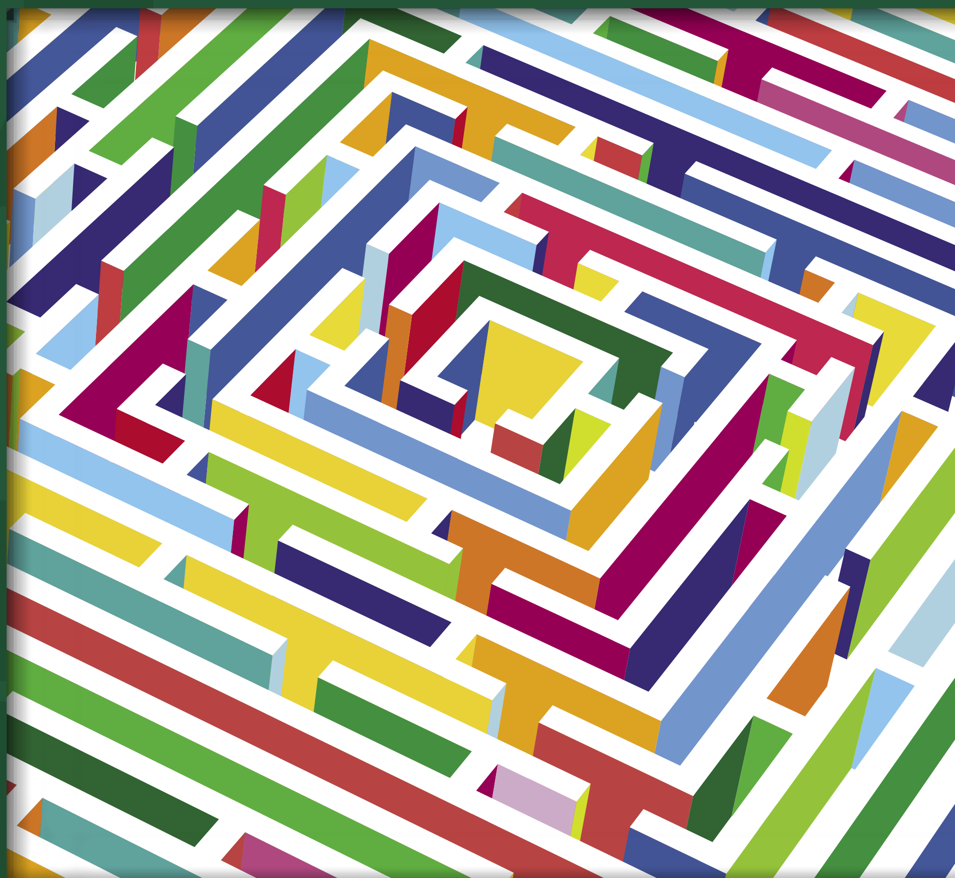
Snowden, D.J. and Boone, M.E. (2007), A leader's framework for decision making, *Harvard business review*, 85, 68–149

Waddell, R. (1997). Quintella talks crowd management: Director Bob Quintella of Oakland Coliseum, California [Online], BPI Communications

Webb, S.A. (2006), *Social work in a risk society: Social and political perspectives*, Macmillan International Higher Education

JOURNAL OF BEHAVIOURAL ECONOMICS AND SOCIAL SYSTEMS

Volume 3, Number 1, 2021



gap | TCG