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Intelligent Evacuation Management Systems: A Review

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Crowd and evacuation management have been active areas of research and study in the recent past. Various developments continue to take place in the process of efficient evacuation of crowds in mass gatherings. This article is intended to provide a review of intelligent evacuation management systems covering the aspects of crowd monitoring, crowd disaster prediction, evacuation modelling and evacuation path guidelines. Soft computing approaches play a vital role in the design and deployment of intelligent evacuation applications pertaining to crowd control management. While the review deals with video and non-video based aspects of crowd monitoring and crowd disaster prediction, evacuation techniques are reviewed via the theme of soft computing, along with a short review on the evacuation navigation path. We believe that this review will assist researchers in developing reliable automated evacuation systems that will help in ensuring the safety of the evacuees especially during emergency evacuation scenarios.

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General Terms: Theory, Management

Additional Key Words and Phrases: Crowd monitoring, prediction of crowd disaster, evacuation modelling, evacuation path guidelines, crowd management

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1. INTRODUCTION

Various research developments have been proposed in the process of safe and efficient evacuation of human crowd during large-scale events like Hajj pilgrimage, mega festivals, sporting events as well as regular pedestrian crowded public places such as shopping areas, underground subways and so on. While such evacuation processes serve as a routine activity in certain planned events, crowd management authorities are also expected to take immediate evacuation steps during emergency situations such as unexpected fire accidents, bomb blasts, stampedes due to crowd panic, incidents of violence, collapse of buildings, natural calamities like earthquakes and so on.

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Blockage conditions amidst an emergency evacuation cause a great challenge for any evacuation management system. Traffic and blockage during emergency evacuation occur when the demand for travel exceeds the available path. Varaiya [1993] points out that Intelligent Vehicle / Highway System (IVHS) as an integration of the control, communication and computing technologies, placed on the highway and on the vehicle, could assist drivers' effective decisions in their routes. Similarly, Kachroo et al. [2008] also claimed that proper integration of control, communication and computing technologies in an Intelligent Evacuation System (IES), may assist evacuees to make smart and amicable decisions. Indeed, an appropriate combination of these aspects of control, communication and computing technologies in an IES might enable the development of better automated evacuation system ensuring the safety of the evacuees, especially during emergency evacuation scenarios.

The prevailing evacuation management systems depend mainly on the human power to assist the evacuees during an emergency evacuation scenario. However, absence of information, especially pertaining to crowds, such as the location, the seriousness of the disaster and safer evacuation exits may worsen a crowd calamity circumstance, thus rendering the job of safe evacuation difficult. At the point when confronting such instability, it is significant to have an Intelligent Evacuation Management System (IEMS) that can adapt to these and different sorts of crowd muddling, and ultimately prevent serious misfortunes of human lives. Hence, this review work on analysis of the IEMS is vital to provide insight which could aid in developing better automated evacuation system in order to aid safe dispersal of evacuees even during emergency situations.

Several review works that intend to assist researchers on modelling the crowd and evacuation system are available. Gwynne et al. [1999] reviewed 22 evacuation models that are based on one of three main evacuation methodologies viz. optimization, simulation and risk assessment. They used a fine network or coarse network approach in order to represent the evacuation enclosure. Zhan et al. [2008] presented a review of crowd analysis based on visual surveillance perspectives in terms of extraction of crowd data and modelling the crowd by vision and non-vision approaches. Jacques Junior et al. [2010] provided a review of crowd analysis also based on computer vision perspectives in terms of crowd tracking, crowd density inference, event detection, validation and simulation. In Zheng et al. [2009], the authors discussed benefits and drawbacks of seven methodological approaches in modelling crowd evacuation of a building, namely, cellular automata models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game theory models, besides experimental methods using animals. Other works related to review of crowd and evacuation system can be found in Santos and Aguirre [2004], Kobes et al. [2010] and Zhou et al. [2010].

The objective of this article is to provide a review of IEMS (example of an IEMS is shown in Figure 1), consisting of a combination of the following key aspects:

- I. *Relevant crowd monitoring techniques*
- II. *The prediction techniques that could foresee the occurrence of crowd disasters*
- III. *Computing technologies relevant to evacuation modelling*
- IV. *Models that provide guidelines and info on efficient evacuation pathways*

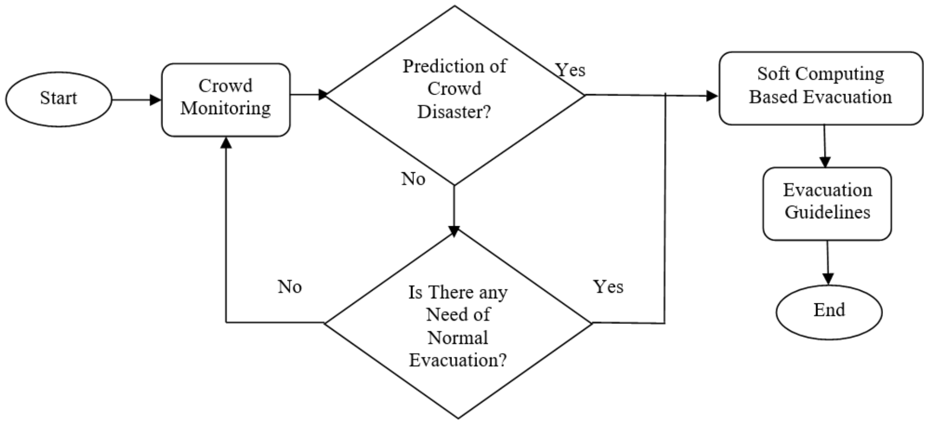

Fig. 1. Flowchart of a typical IEMS

Main contributions of this work can be summarized as follows:

- A review of IEMS as an amalgamation of several aspects which are crowd monitoring, anticipation of crowd disaster, evacuation modelling and evacuation guidelines navigation paths
- A brief review of crowd monitoring techniques via video and non-video based mechanisms
- State-of-the-art of prediction of crowd disaster, video and non-video based and the overview of critical crowd conditions
- An up-to-date review of soft computing techniques pertaining to evacuation models
- A number of useful tables (Table I - V) is presented indicating current developments, advantages, disadvantages, and overview of the aspects of IEMS
- Possible future trends for development of an IEMS are presented at the end of the paper

The paper is organized as follows. Section 2 describes work pertaining to crowd monitoring, while section 3 discusses prediction of crowd disaster. Section 4 and 5 provide reviews on evacuation models and evacuation path guidelines respectively. Finally, in section 6, each aspect of IEMS is dealt with in detail and the paper is concluded pointing out possible future research.

2. CROWD MONITORING

In order to monitor the activities of a crowd, two essential steps to be done are locating the crowd and tracking the crowd. Prior to doing the latter task, it is important to extract information on crowd such as the location and estimated number of the people in the crowd. There are a number of technologies that can be utilized to achieve the exact location of the crowd such as Global Positioning System (GPS), Assisted GPS (AGPS), IR Infrared, broadband satellite network, Radio Frequency Identification (RFID), Bluetooth sensor and Wireless Local Area Networks (WLAN). Visual intelligence based detection has also been employed by researchers in order to estimate the number in the crowd by estimating the density of the crowd. A widely used method proposed by Seidler et al. [1976], has estimated has suggested certain crowd density metrics by analysing aerial photography as: loose crowd: 1 person/m^2, solid crowd: 2 persons/m^2, and very dense crowd: 4 persons/m^2.

When a crowd is detected, the next step is to continuously track the crowd. Several crowd tracking technologies have been proposed, as shown in Figure 2, by different researchers. Interestingly, the information extraction or location based technologies are also being used for tracking purposes. There are several sensors being used as a result of the growing adoption of positioning technologies on smartphones, such as Bluetooth and Global Positioning System (GPS), which are also being used to determine the location of the phone. Computer vision based tracking techniques have also been utilized to track and reconstruct individual trajectories as reported by Marrón-Romera et al. [2010]. However, many challenges in tracking the crowds using computer vision techniques are due to the presence of many people cluttering the scene, especially in monitoring large-scale gatherings. Besides these, Radio Frequency Identification (RFID) and Infrared (IR) receiver and transmitter technology are also currently being utilized by researchers for the purposes of locating and tracking crowds.

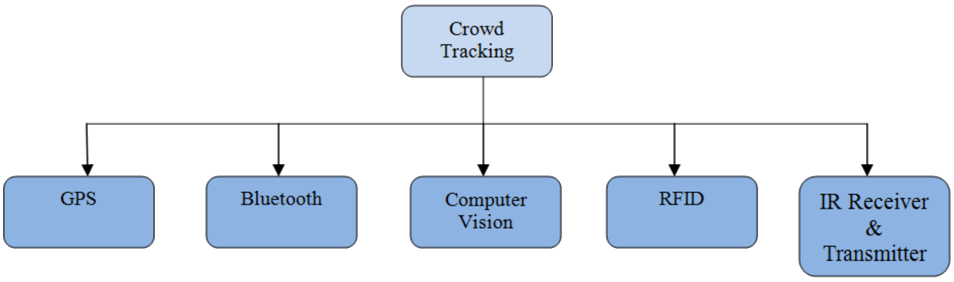

Fig. 2. Different Types of Crowd Tracking Technologies

2.1 GPS Based Tracking

Global Positioning System (GPS) allows the tracking of various types of devices and gives their actual positions continuously [Yu et. 2014]. It is reported by Allan [1997] that the accuracy of GPS time receivers are 14 nanoseconds. The GPS satellite transmits GPS signals via radio waves in order to provide the actual location of the device in terms of latitude and longitude and also time position irrespective of any given time and weather conditions. The location of smartphone or any other GPS device can easily be provided by GPS satellite due to the growing adoption of GPS technology in smartphones and other devices as well.

The deployment of smartphones for crowd monitoring has been increasing recently, mainly because of the fact that smartphones are embedded with GPS receivers. Blanke et al. [2014] monitored the crowd behaviour by tracking the location of attendees' smartphones. In order to collect the attendees' location, it is important to have a dedicated application installed by users on their smartphones. Here, the authors built an official application (app) for Zuri Fascht 2013 town festival in Switzerland, which is attended by hundreds of thousands of people and is said to provide fun and entertainment for all generations and tastes. The app was built for Apple iOS and Android platform and is able to gather 25 million GPS data during the three day festival. Since the deployed app needs the user's cooperation, the data collection was performed after getting the user's consent.

Natural disasters could lead to several hazardous effects to countries, thus, Rahman et al. [2012] developed a system for evacuation preparation purposes during disasters, especially in Bangladesh. In the event of a user being in any calamity zone, the application utilizes GPS to recognize the user's present position and sends this information to the system for evacuation . Likewise, Soni et al. [2014] proposed a location based early disaster warning using Google Maps and GPS technology.

Meanwhile, Koshak and Fouda [2008] analysed pilgrims' movement during Hajj Tawaf of 1424 H (2004 in the Georgian Calendar) by utilizing GPS and Geographic Information Systems (GIS). Here, the GPS devices are used to fetch the location of the movement of pilgrims at intervals of 15 seconds. The other related works in crowd monitoring via GPS devices can be found in Zheng et al. [2010] and Maneesha et al. [2012]. Since the research on GPS based crowd monitoring is increasing recently, there is a great possibility in monitoring crowds by tracking the attendees' smartphone or by using any other GPS devices.

2.2 Bluetooth Based Tracking

Bluetooth is a low power, short range and open protocol wireless technology for exchanging data over short distances by using short wavelengths. It works using the Industrial, Scientific and Medical (ISM) frequency band of 2.4 GHz. Bluetooth technology has progressively been recommended as a basic and minimal cost for the recreation of spatial behaviour. Since numerous individuals have Bluetooth transceivers in their smartphones, laptops and personal digital assistants (PDA) in the discoverable mode as default setting, Bluetooth technology is currently being researched for the purpose of crowd monitoring.

Versichele et al. [2012] utilized Bluetooth technology to track the crowd at the Ghent Festivities in Belgium which is a 10-day cultural and theatre festival. They placed the static Bluetooth scanning devices in the related bounded area to extract the information of the attendees. They were able to track 152,487 trajectories generated by 80,828 detected attendees. Versichele et al. [2012] also presented a technique that aided in the mobile mapping of spectators along the track of a road cycling race during the tour of a road cycling race using Bluetooth sensors, during 'the tour of Flanders', which is a large sporting event, a road cycling race held yearly in Flanders, Belgium. Here, they utilized a vehicle furnished with two Bluetooth sensors that moved along the track, searching Bluetooth gadgets passing by them in order to map the attendees.

Recently, Weppner and Lukowicz [2013] monitored the crowd by scanning the Bluetooth devices using smartphones. They discovered the crowd density in an area of $2500m^2$ by integrating the information from several mobile phones carried by different stationary and dynamic users. They extracted the crowd density information by analysing the collaborative features based on the ratio between values observed by different devices with a granularity of 40 seconds. The system was tested during the European soccer championship public viewing event in Kaiserslautern and the system is reported to achieve more than 75% of recognition accuracy. Another related work can be found in O'Neill et al. [2006], in which they proposed people counting techniques by utilizing the Bluetooth scanning gadget. They fixed the Bluetooth scanning device near a narrow exit or gate in order to find the cumulative crowd density in a bounded area.

2.3 Computer Vision Based Tracking

Detection of humans [Shafie et al. 2014; Azhar et al. 2012] in any crowd scenario is the first relevant step of information extraction in video based systems. However, detecting humans in the video is a difficult task because of the intricacies inherent on dynamic human motions, the formulation of a robust feature set that can clearly discriminate human shapes and to perform human detection in cluttered backgrounds under various illumination changes [Qing Jun and Ru Bo 2008]. Dalal and Triggs [2005] also suggested that detecting humans has proven to be a challenging task because of the wide variability in appearance due to clothing, partial occlusion and illumination conditions.

Dynamic object tracking is essential in automated surveillance systems. Tracking each individual object becomes a difficult job, especially when multiple tracked objects merge into groups with different complexities of occlusion. One of the most crucial criteria for the intelligent evacuation system is to track multiple objects over time in occluded scenes and to keep a consistent identity for each target object. This is due to the fact that it can give important information about human interactions, relationships between objects of interest, and human behaviours [Li et al. 2008]. Examples of video based crowd monitoring can be found in Helbing et al. [2007], Johansson et al. [2008] and Ali and Shah [2008]. In addition, reviews on moving object detection and tracking via computer vision approach can be found in Xi et al. [2013], Zhan et al. [2008], Azhar et al. [2013] and Jacques Junior et al. [2010].

2.4 RFID

RFID standing for Radio-Frequency Identification, is a small electronic device that consists of a small chip and an antenna. The RFID device does not need to be positioned relative to the scanner. In contrast, an RFID device can operate within a range of a few feet of the scanner. Recently, RFID is being used for coordinating universal computing and physical objects such as products, vehicles and people. RFID framework comprises of four principal components: RFID tags, RFID readers, antennas and a computer network used to connect the readers. The antennas connect the readers to the tags in such a way that the readers can transfer the RF signals to the tags and listen for responses. Next, the reader sends the information to a computer system so that the information can be processed [Garfinkel and Holtzman 2006]. In recent times, the RFID system has been proposed and utilized to monitor crowds because of the technical difficulty in monitoring large gathering of crowd via other sensors or technology.

Mitchell et al. [2013] tracks the pilgrims during Hajj via RFID technology. They proposed that each of the pilgrims is given a RFID tag. Then, the RFID readers are divided into a number of regions and placed around the Hajj area. When a pilgrim passes near an RFID reader, the pilgrim's tag will be read and sent to the system in order to update the pilgrim's location. Here, the authors used software that runs the Rafidi framework in order to interface the RFID reader and the main system. Similarly, Nair and Daniel [2014] also tracked pilgrims during Hajj using RFID system. However, here, the authors include a microcontroller and Zigbee transceiver together with RFID readers in transmitting section. In addition, they proposed a heartbeat monitoring system in which they detect the heartbeat of each pilgrim in order to monitor the medical condition of the pilgrims.

The extended version of RFID, which is Wireless Identification and Sensing Platform (WISP) is presented by Mowafi et al. [2013] in order to track the crowd during large-scale gatherings. WISP extends the RFID technology by including sensing power, computing power and enabling the storage of identity and contact information. During large-scale events, WISP readers and writers are placed in several places to collect data of crowd mobility. Other related works of implementing crowd tracking via RFID technology can be found in Yamin et al. [2008], Yamin and Ades [2009], Mohandes [2010] and Ravi et al. [2012]. However, several disadvantages of using RFID technology for crowd tracking are as follows: the technolgy is less reliable, RFID tags are application specific, the technology has less memory power and is expensive.

2.5 IR Transmitter and Receiver

Recently, Shelke et al. [2014] presented a novel idea of monitoring crowds via an IR transmitter and receiver. The proposed system which contains an infrared transmitter and receiver illustrates a crowd control system via infrared communication. First, they detect crowds using IR transmitter and receiver. Then, they track the crowd at several places and continuously update the system. They implemented the system for crowd control on the road, especially at four way junctions. However, crowd monitoring via an IR transmitter and receiver is still in the early stage and has not yet been researched for crowd monitoring at mass gatherings.

3. PREDICTION OF CROWD DISASTER

For crowd safety, it is very important to study the critical conditions of the crowd and anticipate the crowd disaster as early as possible. At present, a large volume of research concentrates on crowd simulation tools which are implemented prior to the gathering of a large crowd to enable the mitigation of crowd disaster by identifying the critical locations [Johansson et al. 2012] where possible congestion, clogging and crowd disaster may occurs. It is vital to predict the area where the crowd congestion may occur during any particular event in order to provide safety measures [Helbing et al. 2007]. Clogging, counter flow, narrow path and congestion may lead to crowd disaster such as stampede [Helbing et al. 2007]. Although the organizers of large gatherings might have done the necessary preparation, it is difficult to anticipate the behaviour of a crowd during an event that may lead to possible crowd disaster. Hence, it is essential to examine the condition, movement and behaviour of the crowd in order to anticipate the crowd disaster as early as possible during any mass event. Early mitigation of crowd disaster could open the way for the authorities to direct and provide a safe evacuation path for the crowd. For example, late evacuation is one of the reasons for the crowd disaster of the Love Parade 2010 in Duisburg, Germany where 21 visitors died in a stampede. It is reported that the first attempt by the police to direct the crowd for safe evacuation during the crowd disaster of Love Parade 2010 started around 16:40, while crowd turbulence has already started at least at 16:34 [Helbing and Mukerji 2012].

Critical conditions of the crowd can be characterised using three main attributes, namely, density, speed and flow of the crowd [Johansson et al. 2008]. Smith [1995] has investigated the relationship between these three characteristics in the context of large crowds and concluded that higher density will reduce the walking speed of the crowd and vice versa. Meanwhile, flow rate is a product of density and velocity. Hence, the intermediate values of density and walking speed will result in an optimum flow rate of the crowd [Smith 1995]. Density estimation of the crowd is one of the important characteristics to anticipate critical crowd conditions. Wirz et al. [2013] suggested that it is crucial to understand the density and behaviour or situation of the crowd. For instance, higher density of the counter-flow crowd is more critical than higher density of the uni-flow crowd [Au et al. 1993; Nicholson et al. 1995; Wirz et al. 2012]. Table I indicates the relationship between density, pedestrian walking speed and their behaviour. At present, prediction of crowd disaster has been done by researchers using video based and non-video based techniques.

Table I. Relationship between density, walking speed and behaviour with reference to literature

Density (person/m^2)	**Walking speed (m/s)**	**Behaviour**	**Reference**
0.8	1.4	Free Walking	Smith [1995]
1.8	0.8	Non-contact walking	Smith [1995]
<2	1.0	Walking speed when the pedestrian is close to exit door	Chizari et al. [2013]
<2	2.0	Walking speed when the pedestrian is far from the exit door	Chizari et al. [2013]
2 - 5	0.5 - 0.75	Walking speed when the pedestrian is close to exit door	Chizari et al. [2013]
2 - 5	1.0 - 1.5	Walking speed when the pedestrian is far from the exit door	Chizari et al. [2013]
4	0.4	Contact walking among people and stagnation occurs	Smith [1995]

5	n/a	Limited movement, even when sufficient space is available	Oberhagemann [2012]
>5	0.38	Walking speed when the pedestrian is close to exit door	Chizari et al. [2013]
>5	0.75	Walking speed when the pedestrian is far from the exit door	Chizari et al. [2013]
5.55	n/a	Possible crowd forces begin to occur	Fruin [1981]
6 – 6.2	n/a	Critical crowd density for moving. Able to move slowly by exerting forces on each other	Oberhagemann [2012]
7.1	n/a	Maximum crowd density while standing	Fruin [1981]
8 – 8.2	n/a	Critical crowd density while standing. Possible when external pressure is exerted onpeople	Oberhagemann [2012]
10	n/a	Nearly the crowd tend to be static. This is a critical crowd density state that can lead to crowd crushing	Lee and Hughes [2005]
11	n/a	Based on the projected area of human bodies	Still [2000]

3.1 Video based crowd disaster prediction

Johansson [2008] has analysed video recordings of the crowd disaster that was encountered on the 12th January 2006 at Mina during the last day of the Hajj, where 363 pilgrims lost their lives. In their work, they revealed two transitions in flow, which resulted from increased crowd density and dynamic crowd behaviour. When the crowd density was increasing, two sudden transitions were found: from smooth (laminar) flow to stop-and-go-flow, and further to crowd turbulence. When the crowd density was high enough, smooth flow gets broken down into dynamic stop-and-go waves. For even higher crowd densities, there was a second transition in which motion becomes turbulent and got characterized by blocks of pedestrians being moved around the crowd in an unpredictable way.

He has proposed a measure called crowd pressure which can be seen as an early warning sign for critical crowd situations. Crowd pressure is computed as a product of local velocity variance and local crowd density as defined in Equation (1),

$$P(\vec{r},t) = \rho(\vec{r},t)Var_{\vec{r},t}(\vec{V}) \tag{1}$$

where$\rho(\vec{r},t)$ is the local density measured at place $\vec{r}(x,y)$ and time, t and $Var_{\vec{r},t}(\vec{V})$ is local velocity variance. In order to find a suitable measure that will identify crowd turbulence and crowd disaster, at first, Johansson [2008] tested using the local density $\rho(\vec{r},t)$, the curl operator on the velocity curl $(\vec{V})$ and the negative velocity divergence $-div(V)$. However, the results was negative since the risky irregular movement of the crowd cannot be identified. In contrast, using crowd pressure gives satisfying results that the pressure is high when both local density and local velocity variance are high, indicating the dangerous irregular movement of the congested crowd. Thus, it is suggested that crowd pressure can be used to identify critical crowd conditions. However, it is preferred if possible, to find a measure that can identify crowd conditions when the stop-and-go waves appear in order to give sufficient time for the authorities to reduce crowd inflow and if needed, to provide a safe evacuation path for the crowd.

Besides that, Krausz and Bauckhage [2012] have proposed a method using optical flow computations that can be used as an early warning sign for critical crowd situations during large-scale events. They claimed that their method is in real-time and avoid the privacy of the person monitored. Since tracking of each individual using computer vision techniques during mass events is often impossible due to limitations of camera view and fully occluded scene, they proposed this method of using optical flow computations to avoid the need for tracking each individual. First, they find dense optical flow and compute equivalent histograms. Then they average the histogram over short time intervals and detect critical crowd conditions by measuring the mirror symmetry of an optical flow histogram since a high degree of symmetry in a histogram reflects the congested area. Mirror symmetry of an optical flow histogram can be computed by summing up the absolute differences between optical flow histogram and its flipped version. Mirror symmetry of an optical flow histogram is defined as,

$$sym_{t,c} = \sum_{dir,mag} \left| \widehat{H}_{t,c}(dir, mag) - H_{t,c}(dir, mag) \right| \quad (2)$$

where $H_{t,c}(dir, mag)$is the two dimensional histogram of direction and magnitude of cell c at time t, while $\widehat{H}_{t,c}(dir, mag)$is a flipped version of it. The proposed method is used to identify crowd turbulence by detecting overcrowding area and it is implemented using video recordings of Love Parade 2010 at Duisburg, Germany. However, in our view, detecting overcrowding area alone for the purpose of identifying critical crowd conditions often might not be enough for detecting unsafe irregular movement of the congested crowd that is likely to lead to crowd disaster.

Wu et al. [2009] predicted the abnormal status crowd via multi resolution density cells. During the calibration stage, the image has been divided into 21 cells and crowd density is estimated at each cell. The total error of crowd number estimation is less than 12%. Then, regression was used to estimate the crowd density information. They tracked the changes in density distribution in order to detect crowd abnormalities which are overcrowdedness and overemptyness. However, it is normal that overcrowding occurs in any large-scale gathering of a crowd which makes the method not suitable to predict crowd disasters.

Very recently, the crowd behaviour entropy model was presented in order to mitigate crowd disasters by using the crowd individual velocity and its probability [Zhao et al. 2015]. The crowd behaviour entropy model is defined as in Equation (3) and Equation (4),

$$S(\omega) = -\sum_{i=1}^{\|\mathbb{A}\|} P(Q_i) \ln[P(Q_i)] \quad (3)$$

$$P(Q_i) = \frac{H(x,y)}{N} \quad (4)$$

Where S denotes the crowd behaviour entropy, $P(Q_i)$ is the probability function of crowd in the state i, $\omega = \{Q_i; i = 1,2,.., \|\mathbb{A}\|\}$, is the whole state space matrix, Q_i denotes the state of I, $\|\mathbb{A}\|$ denotes the total number of states, $H(x, y)$ is the counts of pedestrians with velocity in the partition x of magnitude and the partition of direction and N is the number of pedestrians. The authors produced an early alarm for critical crowd conditions by setting a threshold line utilizing linear regression for the entropy variations. Apart from that, Alnabulsi and Drury [2014] have proposed a method to determine the safety of estimated crowd density by utilizing multiple regression models. Other related work can be found in Mehran et al. [2009] in which the abnormal behaviour of the crowd is detected by using a social force model of pedestrian tracks.

3.2 Non-video based prediction of crowd disaster

The deployment of smartphones for crowd monitoring purposes is, mainly due to the GPS receiver being embedded into smartphones. Using the location provided by a GPS sensor, Wirz et al. [2012] introduced mathematical methods to calculate the crowd density, crowd velocity, crowd turbulence and crowd pressure. For the purpose of collecting location updates, they invented a smartphone app and tested it during the 2011 Lord Mayor Show in London. They were able to achieve 3903425 location updates from 827 different visitors and these location updates were sent simultaneously to their CoenoSense server for the purpose of processing the collected data. They calculated the crowd pressure, which was introduced by Johansson [2008] in a slightly different way by applying kernel density estimation as in Equation (5),

$$\hat{P}(X,t) = \hat{d}(X,t)\widehat{Var}_{X,t}(\vec{V}) \quad (5)$$

where $\hat{d}(X,t)$ denotes to kernel density estimation. The great limitation that needs to be addressed by using this approach is the proposed system requires user's consent in order to collect the data. This is because the system is able to collect the data only from the users who have installed the dedicated app on their smartphones. In Golas et al. [2014], continuum modelling of crowds for simulating crowd turbulence via integrating collision avoidance and frictional forces arising from pedestrian interactions is proposed. However, crowd pressure is utilized as an indicator for crowd turbulence similar to the work in Johansson [2008]. Other related work which is a preliminary work for anticipating crowd disaster is proposed by Maneesha et al. [2012] by using wireless sensor network and mobile computing techniques. They have tested the proposed system by forming a small crowd consisting of 15 students and by using three Android smartphones as participant nodes.

4. EVACUATION MODELLING VIA SOFT COMPUTING METHODS

The intelligent evacuation management system needs to model the evacuation path for the evacuees in an efficient way when any possible crowd disaster is anticipated that could lead to emergency evacuation or during any normal evacuation scenario. In this section, we offer a review of evacuation modelling via soft computing (SC) methods. Though SC had its inception pertaining to the advent of Fuzzy logic in the mid 1960's, only in the early 1990's it was considered as part of the field of formal computer science [Rao and Raju 2011]. Complex problems such as evacuation of crowd motion amidst uncertain environments can be efficiently modelled using SC approaches. As crowd motion is highly uncertain in nature due to several diverse factors such as subjective human motion, obstacles in the path, environmental influence such as variations in the weather, co-ordination between sub-groups within the crowd and so on, several SC based studies intend to propose intelligent approaches to govern and simulate crowd motion.

Evacuation models can be classified based on four typical branches of SC viz. fuzzy logic, neural computing, probabilistic graphical models and evolutionary computing as shown in Figure 3. Within the scope of the taxonomy in Figure 3, we provide a brief overview recent evacuation models that have evolved in the recent decade in the following sub-sections.

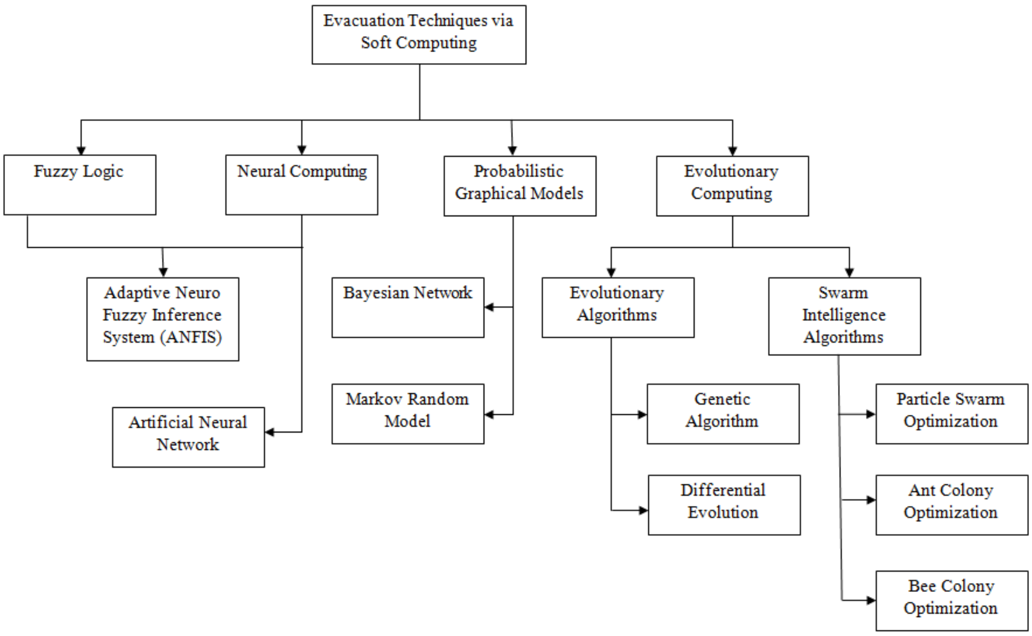

Fig. 3. Taxonomy chart of evacuation modelling via SC techniques

4.1 Fuzzy Logic based Evacuation Models

Fuzzy Logic (FL) based approaches intend to counter uncertainties inherent in subjective domains such as crowd dynamics and crowd evacuation by making use of intuitive decision rules which are otherwise hard to express using the conventional Boolean logic. We shall describe some typical FL based approaches relevant to the evacuation mechanisms of human crowd in this section. In 2008, Zhu et al. [2008] have proposed a fuzzy modelling approach to simulate and analyse potential factors such as evacuation time against varying velocities of the crowd. The authors have basically attempted to generalize the well-known social force model proposed by Helbing and Molnar [1995] which treats motion of pedestrians analogous to particles subject to forces governed by the laws of physics. Takagi-Sugeno type fuzzy rules have been deployed in the proposed fuzzy model to transform physical laws of pedestrian motion into a fuzzy inference system. By means of simulations, the authors have shown that the parameters of their proposed model are capable of interpreting certain psychological and physical quantities inherent in the pedestrian motion. The proposed FL approach has mainly used hyperbolic tangent as a membership function. Future crowd evacuation studies based on FL could explore other choices of fuzzy membership functions.

Very recently, Hsu and Peeta [2013] have proposed a FL based model to counter the vast uncertainty imposed on emergency evacuation measures due to the heterogeneous behaviour of evacuees in the aftermath of disasters such as earthquakes, explosion of chemical plants and so on. The authors have incorporated linguistic fuzzy variables to model the subjectivity involved in the perception and interpretation of such ambient scenarios. Further, experimental evaluations have been presented at an aggregate level for the case of a hypothetical terror attack to study the capability of the model to assimilate the evacuation-related behavioural aspects of evacuees such as herding attitude under time pressure. The method can be further developed to solve evacuation problems during disasters by integrating with traffic management and control strategies.

An agent-based system to emulate crowd behaviour such as team cooperation, guidance via navigations, adaptability to learn, actions amidst panic scenarios and how such complex characteristics can be modelled using FL have been demonstrated by Sharma and Lohgaonkar [2010]. The goal finding strategies of the agents have been modelled using two linguistic fuzzy variables viz., angle and distance. Basically, the agents use distance based computations to avoid collisions between other agents as well as obstacles. The authors suggest that their simulation model can be used to estimate crowd density while estimating emergency evacuations. Such investigations serve as preliminary studies to further research in crowd evacuation pertaining to intelligent modelling of more complex crowd behaviour such as actions amidst stress, anger, altruism and so on. Very recently, Popescu et al. [2013] also have proposed an agent based fuzzy model to model the emotional dynamics of crowd using geospatial quantities such as elevation, population density and locations of interest and study the feasibility of the model during emergency evacuations. Other related studies in the domain of FL based evacuation approaches include the works of Janacek [2010], Tan et al. [2009], Qiao et al. [2009], Xie et al. [2006] and Han et al. [2004].

4.2 Overview of Evacuation Models using Artificial Neural Networks

Inspired by the modelling of neurons in the brain, the emergence of Artificial Neural Networks (ANN) which forms part of SC emulate human intelligence in the form of machine learning algorithms. ANNs provide sophisticated means to model evacuation scenarios where learning from data is one of the ideal choices and applying direct analytical solutions might not be feasible due to the complexities inherent in the pedestrian domain. We provide an overview of some typical recent ANN based evacuation models here.

Simulation of evacuation mechanisms using an ANN based cellular automata model in the presence and absence of obstacles within the scope of a classroom setting has been examined by Zainuddin and Aik [2012]. The authors have attempted to exploit the decision-making ability of the pedestrians and simulate an exit-selection phenomenon. Experimental results reveal that their method is a relationship between crowd density and the choice of selection of exits. Nevertheless, the proposed technique did not include the experiments involving high crowd density which could produce a more realistic outcome.

Sharma et al. [2012] have proposed an ANN framework in conjunction with genetic algorithms to investigate an agent-based evacuation model which can assist in the planning of emergency evacuations and model pedestrian dynamic notions. This evacuation model captures individual as well as group behaviour of evacuees with the objective of artificially aiding autonomous agents to find their target exits. The authors show that such intelligent agents have the capability to adapt their behaviour by learning from the environment as well by interacting with other agents. Information such as agent's location, direction attributes and the number of exits that the agent has reached in the search space are all utilized well in the proposed framework. Although the methodology is formulated well, the performance analysis of the approach in terms of standard metrics and a comparative study of the proposed approach with other approaches are not evident. Future studies might propose solid experimental setups to evaluate such learning models. Very recently, Yuen et al. [2014] developed an artificial neural network (ANN) model to predict the route choice behaviour in a transportation station. They adopted a multilayered perceptron (MLP) model because of its simplicity and flexible nature to predict the probability of passengers choosing the exit gate. The authors used backpropagation (BP) to train the algorithm used for the MLP model. The developed intelligent model achieved prediction accuracy of 86%.

An Adaptive Network based Fuzzy Inference System (ANFIS) has been proposed by Lo et al. [2009] to predict the pre-evacuation behaviour of evacuees based on back propagation oriented learning procedures. The authors have modelled their proposed soft computing approach by training the network with data acquired from structured human behaviour. Further, they also use fuzzy logic to transform certain human decision notions. Basically, the feasibility of the model under anticipated fire scenarios has been investigated in this contribution.

4.3 Evacuation Modelling via Probabilistic Graphical Models

Probabilistic graphical models refer to the structuring of likelihood decisions and subjective convictions about the probabilities of consequences and the frequencies of occasions. It is a statistical tool that approximates the likelihood of an event happening again based on past information. Uncertainty in the behaviour of a crowd is unavoidable during any evacuation scenario, especially during emergency evacuation. We can almost never predict with certainty what will happen during such scenario. Probability theory gives us the basic foundation to model our beliefs about the different possible states of the evacuation scenario, and to update these beliefs as well. Bayesian Network and Markov Random Models are examples of methods using probabilistic graphical models for the purpose of evacuation modelling.

4.3.1 Bayesian Network based Evacuation Approaches

A Bayesian network (BN) is a directed acyclic graph, consisting of nodes and arcs in which nodes represent random variables and arcs corresponding to interaction between those nodes. It can be used to illustrate the level of uncertainty and also to reduce it, predicting a highly complex scenario, and also to make important decisions in various situations. BN could be used to minimize the evacuation time by modelling the evacuation scenario of a particular place or building [Sarshar et al. 2013a]. Peng and Zhang [2013] proposed dynamic decision making for dam-break emergency management in both time scale and space scale in order to minimize the expected total loss of evacuees by optimizing the evacuation time. They have also utilized a BN to build Human Risk Analysis Model (HURAM) to evaluate the decision making process during emergency situations.

A pedestrian distribution forecasting model is developed by Zheng and Liu [2010] by using a dynamic Gaussian Bayesian network (GBN) in order to minimize the evacuation time. They minimize the evacuation time by enhancing the route choice coefficient, while they acquire better forecasting results by correcting and updating the regression coefficient of the GBN. However, the proposed GBN is not validated sufficiently enough due to the limitation in getting the test samples. Other related works on BN based evacuation can be achieved in Sarshar et al. [2013b], Matellini et al. [2013] and Eckel et al. [2009].

4.3.2 Markov Network based Evacuation Approaches

In contrast to BN, Markov network (MN) or Markov Random Field (MRF) is an undirected graphical model, consisting of nodes and edges, in which nodes represent the variables, while edges represent the direct probabilistic interaction between the neighbouring variables. Minimizing health effects during emergency evacuation is one of the important factors for any evacuation model [Jianfeng and Bin 2009]. Li et al. [2013] minimized the negative health effect of evacuees by using MN. They utilized MN to estimate the health effects during emergency evacuation by using a stochastic temporal variation of particular regions under evacuation. For the proposed MN model, they divide the particular regions into several discrete nodes, which indicate the variable size and shape, and then, connect the nodes via links. Although the proposed method can give a positive effect for reducing health factors during evacuation process, it might not be able to minimize the evacuation time and increase the flow rate of evacuees.

4.4 Typical Evolutionary Computing based Evacuation models

Bio-inspired Evolutionary Computing (EC) inspired by Darwinian principles of natural selection has proved to be a robust SC tool to solve many complex problems including crowd evacuation. Under the umbrella of artificial intelligence, EC techniques have been providing solutions to a diverse range of problems that involves optimization. Evolutionary Algorithms (EA) and Swarm Intelligence Algorithms (SIA) are a subset of EC. In this section we give a brief overview of typical evacuation models based on EA and SIA which have been proposed under the principles of evolutionary computing within the scope of this contribution.

4.4.1 EA based Evacuation Models

Generally, EA is a genetic operator to maintain a population of structures based on metaheuristic optimization algorithm and it utilizes mechanisms instigated by biological or natural evolution according to rules of selection, recombination, mutation and survival. Here, we present a review of evacuation modelling based on Genetic Algorithms (GA) and Differential Evolution (DE), which are typical examples of algorithms that use principles of EA. Park et al. [2012] have proposed a GA based optimization approach to reduce the evacuation time by locating optimal tsunami shelters. Basically, the authors have performed a fragility analysis to assess the probability of survival with respect to the time of evacuation. The authors have shown that fragilities are capable of offering information pertaining to the position of evacuation shelters which in turn helps to make useful decisions which are vital to evacuation time. Location vectors have been used as design variables of the problem domain, while, distance metrics based objective functions have been formulated to achieve the optimization task. Also, additional factors such as reaction time of evacuees that arise when people evacuate to a destined shelter have also been taken into account pertaining to the evacuation problem. While such studies attempt to demonstrate basic optimization algorithms by limiting the scope to a small coastal study, future studies could explore the possibility of extending such optimization models to a broader scenario with the aid of several modern optimization techniques such as Harmony search algorithms.

Also Sato and Osana [2012] have proposed a GA based approach to evaluate office layout plans. Basically evacuees are considered as artificial agents who decide on the escape routes based on the inputs gained from information available from the given office layouts which are polygonal shaped entities. Verma and Thakur [2010], Bandini et al. [2008] and Li et al. [2010] are the other papers that implemented evacuation modelling via GA.

At present, we are able to find only one piece of work that utilized a DE based evacuation model. Very recently, Wan [2014] presented DE for emergency evacuation route assignment in public places. The author tested the proposed system at the Wuhan Sports Center in China. The author proposed a novel method of local search scheme for DE and combined this with prediction strategy and population core-based multi-population strategy to solve the route assignment problem during a complex emergency evacuation scenario. The work of Wan [2014] could be a stepping stone in order to promote more research of DE based evacuation approaches in the near future.

4.4.2 SIA based Evacuation Models

A swarm intelligence algorithm is the study of collective intelligence of a self-organized system due to the teamwork of huge numbers of similar agents in the environment. Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Artificial Immune System (AIS), Bat Algorithm and so on are typical examples of SIA. A brief review of evacuation modelling via PSO, ACO and ABC is given here. A very recent evacuation study performed by Zheng et al. [2014] has used an approach based on multi-objective particle swarm optimization and shows that classification of the evacuee population into several useful categories mitigates the complexities involved in the evacuation process. Based on the situation of evacuees such as 'being trapped', 'capable of escaping with or without some help', 'evacuees who can or cannot communicate information with the responders, the authors attempt to classify the evacuees into seven useful groups. The classification rule mining problem has been formulated as a particle swarm optimization problem and experiments were performed using part of a real-world fire evacuation dataset which comprises of evacuation events that occurred in China. The authors report that their approach yields better results than other state-of-the-art approaches. However, utilizing the proposed method is complicated and time consuming if the evacuation management authorities need to classify the population of evacuees in large-scale gatherings of crowds especially during a typical emergency evacuation scenario. Kou et al. [2011] and Yusoff et al. [2011] are other examples of PSO based evacuation models.

Fang et al. [2011] have proposed a bio-inspired ACO based algorithm as a remedy to counter the intricacies involved with evacuation planning. The authors have chosen the stadium in the Wuhan Sports Center in China for their case study. In order to model the evacuation routing problem, the proposed multi-objective optimization approach takes three objectives into consideration viz., minimization of total evacuation time, evacuation route length and cumulative congestion degrees which are considered as vital parameters in an evacuation process. The basic assumption is that the potential of each subzone out of the 157 subzones of the stadium has been represented by the potential at the center point of the subzone and the evacuees are seen as positive test charges that would always move from a high potential subzone to a low potential sub-zone. The authors have mentioned that the proposed approach generates some uneven routes and this is considered as one of the limitations that could be improved in future studies. Other related evolutionary oriented evacuation studies based on ACO are Wei et al. [2012], Wang et al. [2011] and Zong et al. [2010].

Samadzadegan and Yadegari [2010] proposed a novel method using ABC for the emergency evacuation problem. The authors characterized the hives as safe regions, unsafe regions represented by food sources, while bees correspond to the partial capability of secure regions. The motivation behind the proposed strategy is an ideal allotment of limit of secure regions to dangerous zones by bees as devoting agents of safe ranges to occupants of risky regions. The ideal allotment is aimed for evacuating crowds to safer regions at the minimal time. The authors have claimed that the method proposed by them yields a robust evacuation plan for a disaster preparedness system and achieved minimal evacuation time. However, comparative study of the proposed method with other approaches are not evident. Recently, Lee and Tseng [2014] and Peng et al. [2013] have utilized the ABC technique for modelling the evacuation problem. Also there are other related works using ABC for crowd related studies such as Mohammadi et al. [2012] and Hong et al. [2012].

5. EVACUATION PATH GUIDELINES

Finally, successful IEMS should be able to suggest proper evacuation instruction paths in order to achieve safe evacuation. Any improper evacuation path taken by evacuees may lead to increase in evacuation time, congestion, crowd panic and also stampedes. The fundamental goals of evacuation path guidelines are to reduce the evacuation time, to avoid the crowd congestion and also to shun any emergency cases or loss of lives due to crowd disaster. Here, we provide a brief review of works that proposed evacuation guidelines via IEMS embedded with mobile phones, visual aids and wireless sensor networks.

Nowadays, smartphone technology is being adopted in our daily usage due to its various advantages. Among its several applications, it can be used for crowd monitoring purpose and also for guiding evacuation paths. Evacuation path guidelines can be presented in a 3D view on the evacuees' smartphones as described by Chittaro and Nadalutti [2008]. In fact, the authors provide the evacuation navigation on the mobile phones based on the evacuees' position and also the condition of the evacuation area. They evaluated their system by using 11 users and claimed that their system can effectively be utilized for indoor evacuation path guidelines. Later, they also performed several other evaluation tests (Chittaro and Nadalutti [2009]). Other related works in adopting mobile phones for evacuation navigation can be found in Chu [2010], Mulloni et al. [2011], Rahman et al. [2012] and Soni et al. [2014].

For visual based navigation, a minimal infrastructure method using augmented photos with arrows can be used as presented in Merico and Bisiani [2007]. Besides this, fixed display such as the Hermes2 digital display is employed by Taher et al. [2009] for visual based navigation. Very recently, Zhang et al. [2014] proposed the implementation of intelligent emergency lighting and an evacuation indicatory lifesaving system. In this system, the evacuation path will be mainly shown by using sign lamps. Besides using visual based evacuation guiding, they proposed the integration of hearing based evacuation navigation as well by utilizing stroboflash, voice, two-way adjustment, and signal lamps. Although using visual aids for the evacuation navigation path is low cost, it would not contain much information on condition of the evacuation area and congestion information. In addition, using visual aids are also not easy in achieving minimal evacuation time due to the possibility of congestion.

Wireless sensor networks (WSNs) are also being utilized for the purpose of evacuation path guidelines. One of the WSNs' applications is to provide a shorter evacuation route for the evacuees in order to escape from dangerous region to the safe region. Lin et al. [2013] proposed a distributed and adaptive guiding protocol for evacuation path navigation based on WSNs. They claimed that their method can balance the evacuation paths and exits, considering the congestion information in deciding the shortest path for evacuation and also guiding people from a dangerous area to the safe area. Other similar evacuation path guidelines based on WSNs are proposed by Chen et al. [2012] and Li et al. [2011].

Currently, a variety of emergency notification methods are available, in order to provide the evacuees with proper evacuation orders and directions to the safe evacuation area. However, the research works in terms of evacuation path guidelines for normal and emergency evacuation scenarios outdoors and especially during a large-scale gathering of a crowd is very limited. For application of the evacuation path in emergency and normal evacuation scenarios of large crowds, further research and thorough study are needed, which can serve as a decision support during any evacuation scenario and lead to a safe evacuation. Hence, research opportunities in the area of the evacuation navigation path, especially for mass gatherings of the crowd appears to be widely open.

6. DISCUSSION AND CONCLUSION

This article intend on providing insights on an IEMS by reviewing and analyzing the different aspects of IEMS, such as crowd monitoring, anticipation of crowd disaster, evacuation modelling approaches and evacuation navigation path.

First, we have reviewed the aspects of video and non-video based crowd monitoring. Table II summarizes our findings on latest available techniques of crowd monitoring and its advantages and disadvantages. Based on the findings, we conclude that the present day researchers are more interested in performing crowd monitoring via non-video based techniques such as GPS, Bluetooth and RFID. There are many challenges in tracking the crowds using computer vision techniques due to the volume of people in the scene and completely occluded scenes, especially in large-scale gathering scenarios. Thus, we believe that crowd monitoring via non-video based techniques such as GPS, Bluetooth and RFID could yield better outcomes. However, the general drawback of utilizing GPS and RFID sensors for crowd monitoring is that the user's consent is required to permit the system to access the location of the user. On the other hand, using Bluetooth for crowd monitoring is limited only to the relatively small coverage area.

Table II. Summary of crowd monitoring techniques

Sensor / Technology	**Ref.**	**Year**	**Case Study**	**Tracked Crowd Number**	**Appliances**	**Advantages**	**Limitations**
GPS	Blanke et al. [2014]	14	Züri Fäscht 2013	29k	Mobile App	Low cost, accurate	Needs user's consent
	Rahman et al. [2012]	12	Bangladesh	10	Mobile App, Open Street Map,		
	Soni et al. [2014]	14	India	n/a	Mobile App, Google Map		
	Koshak and Fouda [2008]	08	Hajj	>1000k	GPS device, Geographic Information System	Large data are collected	Less accuracy
	Zheng et al. [2010]	10	Diverse Locations	162	GPS device	Large GPS dataset and trajectories	Needs user's consent
	Maneesha et al. [2012]	12	n/a	15	Mobile App, Wireless multimedia sensor networks (WMS)	Low cost, accurate	
Bluetooth	Versichele et al. [2012]	12	Ghent Festivities	80,828	Bluetooth sensor, Geographic Information System	Low cost, tracking large crowd, indoor and outdoor	Small range, Battery usage
	Versichele et al. [2012]	12	Tour of Flanders	16182	Bluetooth sensor, Bluetooth enabled mobile phones		
	Weppner and Lukowicz [2013]	13	European Soccer Championship	<5200	Bluetooth sensor, Android App		
Computer Vision	Helbing et al. [2007]	07	Hajj	<3000k	Extract position and speed via new computer vision algorithm	Relatively low cost, without complementary companion equipment	Clothing, occlusion and illumination conditions
	Johansson et al. [2008]	08	Hajj	<3000k	Video tracking, automated people counting		
	Ali and Shah [2008]	08	Marathon sequences	20 - 143	Scene structure based force model		
RFID	Mitchell et al. [2013]	13	Hajj	n/a	RFID reader and tag, mobile app	Low cost, track large crowds	Small range, needs user's consent

	Nair and Daniel [2014]	14	Hajj	n/a	RFID reader and tag, microcontroller and zigbee transceiver		
	Mowafi et al. [2013]	13	North Carolina State Fair	n/a	WISP readers and writers, tickets containing WISP	Includes sensing and computing power	
	Mohandes [2010]	10	Hajj	1000	Wristband RFID tad and RFID reader, software	Low cost	
IR Transmitter & Receiver	Shelke et al. [2014]	14	Four way junction	n/a	Infrared transmitters and receiver	Low cost, no need power supply for object detection	The system fully dependent on internet connection

Also, we have reviewed the aspect of prediction of crowd disaster via video and non-video based approaches. Table III discusses the advantages and disadvantages of those works in predicting crowd disaster. In our view, the research in the area of anticipating crowd disaster is still in the beginning phase and requires more sophisticated and reliable work which may prevent serious misfortunes of human lives. This is because successful prediction of crowd disaster at an early stage can prevent occurrence of crowd panic which can lead to stampedes. Besides that, in the near future, in order to find out dependencies between crowds and events, it is important to have an algorithm which is able to detect crowd abnormalities by performing spatio-temporal data mining using association rules. For instance, it is usual for subway stations to be crowded to a certain degree after a football match, hence there is no immediate need for triggering an alert.

Table III. Advantages and disadvantages of crowd disaster prediction models

Reference	**Techniques**	**Case Study**	**Advantages**	**Disadvantages**
Johansson [2008]	Video based, crowd pressure	2006 Hajj at Mina	Able to detect crowd turbulence of congested density and also dangerous irregular movement of the crowd	- Detection of critical crowd condition should be earlier, if possible, when stop-and-go waves emerge. - Difficult to track each individual due to clutter and occlusion
Golas et al. [2014]	Non-video based, continuum model	Simulation of Love Parade 2010, Duisburg, Germany and Hajj in Mecca	- Simulations of different densities, from 3.5 people per m2 (4400 agents) to 6 people per m2 (6800 agents) - Able to detect crowd turbulence	- Proposed algorithm not yet tested in real time. - Detection of critical crowd condition should be earlier, if possible, when stop-and-go waves appear
Krausz and Bauckhage [2012]	Video based, mirror symmetry of an optical flow histogram	Love Parade 2010, Duisburg, Germany	Able to detect overcrowding area without tracking each individual	Detection of overcrowding area only would not lead to crowd disaster, need to include detection of crowd risky irregular movement
Wirz et al. [2012]	Non-video based, crowd pressure	2011 Lord Mayors Show in London	Able to extract the real position of the crowd and also detect crowd turbulence	Requires users' consent to install the dedicated mobile app.
Wu et al. [2009]	Video based, Multi resolution	Several video clips taken in	Able to detect overcrowding area	- Algorithm shows detection of about less

	density cells and texture analysis	Tian'anmen Square of Beijing and also in Hong Kong	in outdoor and indoor with occlusion occurs.	than 30 people per frame; very few in number compare to crowd in mass gatherings. - Detection of overcrowding area only would not lead to crowd disaster, need to include detection of crowd dangerous irregular movement.
Zhao et al. [2015]	Video based, Crowd behaviour Entropy Model	Outdoor video clips	- Able to detect and differentiate crowd ordered, disordered and mutation.	- Needed more validation to prove that sudden entropy change can be utilized to predict crowd disaster in large-scale crowd gathering.

Then, we have systematically overviewed recent state-of-the-art evacuation models with emphasis to the soft computing paradigm with the hope of the study serving as a handy reference for new researchers who would like to have a bird's eye view on the latest trends in evacuation models with respect to the application of prominent AI techniques such as fuzzy logic, artificial neural networks, probabilistic reasoning and evolutionary computing. Table IV shows an overview of evacuation modelling via SC approaches. Our study indicates that during these five years (2009 – 2014), the researchers are inclined to solve evacuation problems by using SC approaches as those shown in Table IV. This is due to the existence of similarities between evacuation scenario and guiding principles of soft computing techniques. Ramik [2001] has stated that the guiding principle of SC in order to achieve robust and low cost solutions is by solving the imprecision, uncertainty, partial truth, and approximation problems. Meanwhile, typical evacuation scenarios inherit these types of limitations. For example, the uncertainty behaviour of crowd is unavoidable during any evacuation scenario, especially during emergency evacuation. We can almost never predict with certainty what will happen during such a scenario. Similarly, during the emergency evacuation scenario, finding the safest exit route is inexact and imprecise. The other problems of crowd motion during an evacuation situation are obstacles in the path, environmental influence such as variations in the weather, co-ordination between sub-groups within the crowd and so on. Hence, we suggest that utilizing SC approaches could lead to a better solution for emergency evacuation problems.

In summary, we observe that, as far as fuzzy logic based approaches are concerned; there is scope to further extend research on fuzzy evacuation models with the aid of membership functions readily available in the domain. Further, the evaluation of ANN based evacuation models with the aid of standard performance evaluation metrics could complement future studies. Also, intuitively it could be inferred that modern optimization techniques such as the music inspired Harmony Search based evacuation models could also be attempted by the evolutionary computing research community. Finally, we have also presented a brief review on evacuation path guidelines. We found out that research opportunities in the area of evacuation navigation path, especially for mass gatherings of the crowd seems to be widely open.

Table IV. Overview of evacuation modelling via SC approaches (A: Avalanche-like, C: Clogging, CA: Collision avoidance, CF: Contraflow, Co: Congested, E: Emergency, ES: Exit selection, F: Freeway, FIS: Faster is slower effect, G: Group, H: Herding, HR: Human reaction, N: Normal, U: Uncertainty)

Ref.	**SC Method (s)**	**Aim(s)**	**Situation**	**Observed Behaviour**	**Case Study / Simulation**	**Total Tested Number of Evacuees: People (P) / Vehicles (V)**
Zhu et al. [2008]	FL	Modelling dynamic of crowd behaviour	N	C, A and FIS	Single Room Simulation	200 P
Hsu and Peeta [2013]	FL	No-notice mass evacuation	E	H and F	Simulation of Indianapolis downtown area network	30k V
Sharma and Lohgaonkar [2010]	FL	Simulation of agent based behaviour	E	ES and CA	Agent Based Modelling and Simulation (ABMS)	n/a
Popescu et al. [2013]	FL	Modelling the emotional dynamic behaviour	E	FIS	Simulation of hurricane evacuation scenario	1000 P and 10000 P
Tan et al. [2009]	FL	Evacuation management under uncertainty	U	n/a	City of Wuhan	3150–4000 P & 3-63 V
Qiao et al. [2009]	FL	Evacuation plan	E	CF	Simulation of Texas Medical Center via VISSIM	>1000 V
Zainuddin and Aik [2012]	ANN	Intelligent CA evacuation model	N	ES and CA	Classroom	50 P
Sharma et al. [2012]	GA and ANN	Intelligent agents' evacuation	E	ES and G	Agent Based Modelling and Simulation (ABMS)	n/a
Yuen et al. [2014]	ANN	Mimicking human decision of route choice	N	ES	Transportation station in Hong Kong	n/a
Lo et al. [2009]	ANFIS	Prediction of pre-evacuation behaviour	E	HR	High-rise domestic buildings	n/a
Sarshar et al. [2013a]	BN	Minimizing evacuation time	E	F and Co	Simulation fire on ship via GeNie software	n/a
Peng and Zhang [2013]	BN	Minimizing total loss of evacuees	E	n/a	Dam breaks emergency management	n/a
Zheng and Liu [2010]	BN	Minimizing evacuation time	E	F	Road network	n/a
Jianfeng and Bin [2009]	MN	Minimizing health effect during evacuation	E	F and Co	Road network	n/a
Li et al. [2013]	MN	Minimizing total loss of evacuees	E	F and Co	Road network	n/a

Park et al. [2012]	GA	Minimizing tsunami evacuation time	E	n/a	Tsunami-The City of Cannon Beach via TOGA software	5688 P
Sato and Osana [2012]	GA	Evaluating office layout plans	N	ES	Office layout	n/a
Qiu Ping Li et al. [2010]	GA	Reducing evacuation time, total travel distance and congestion	E	Co	Stadium in Wuhan Sport Center	24727 P
Zheng et al. [2014]	PSO	Population classification fire evacuation	E	n/a	Six-story hotel building in Taizhou City, Zhejiang Province, China	51 P
Kou et al. [2011]	PSO	Optimizing evacuation plans	E	n/a	Stadium	200 P
Wei et al. [2012]	ACO	Optimizing evacuation plans	E	H	Emergency situation simulation	20000 P
Fang et al. [2011]	ACO	Reducing evacuation time, total travel distance and congestion	E	Co	Stadium in Wuhan Sport Center	25000 P
Wang et al. [2011]	ACO	Modelling dynamic of crowd behaviour	E	ES and CA	3D evacuation simulation	6000 P
Zong et al. [2010]	ACO	Reducing evacuation time and traffic load	E	ES	Area around the stadium in Wuhan Sport Center	500 P and 100 V
Samadzadegan and Yadegari [2010]	ABC	Optimizing urban evacuation problem	E	n/a	Urban area	n/a
Lee and Tseng [2014]	ABC	Optimizing evacuation route networks	E	ES and Co	Cinema Theatre Simulation via VISWALK simulator	1258 P

This review work on analysis of an IEMS as a combination of proper crowd monitoring technique, early anticipation of the crowd disaster, proper soft computing technologies in evacuation modelling and evacuation path guidelines is vital to provide insights which may develop better automated evacuation system that able to assist the evacuees to find the safer exits and also with minimal evacuation time. The four aspects reviewed above of an IEMS can be separated into two stages: i) pre-evacuation stage and ii) during-evacuation stage, which are exhibited in Table V, along with the associated general task and its specific aims. We perceive that in the future if all these aims (third column in Table V) are properly incorporated in a particular IEMS, it will lead to a better and safer evacuation. At last, as a guide for future work, all the reviewed methods in this article can be combined together as a general framework of an IEMS as shown in Figure 6. While integrating a method of every aspect, researchers could overcome the limitation embedded in the chosen method in order to gain maximum benefit of an IEMS.

Table V. IEMS Functions

Stage	General Task	Specific Aim
Pre-evacuation	Crowd monitoring	To locate and track the crowd
	Prediction of crowd disaster	To estimate the crowd density
		To analyse the flow and speed of the crowd
		To predict any possible crowd disaster
During evacuation	Evacuation Modelling	To model the evacuation scenario by utilizing computing technologies
		Evacuation path planning
		To find out shortest and safest evacuation path
	Evacuation Guidelines	To provide evacuation route

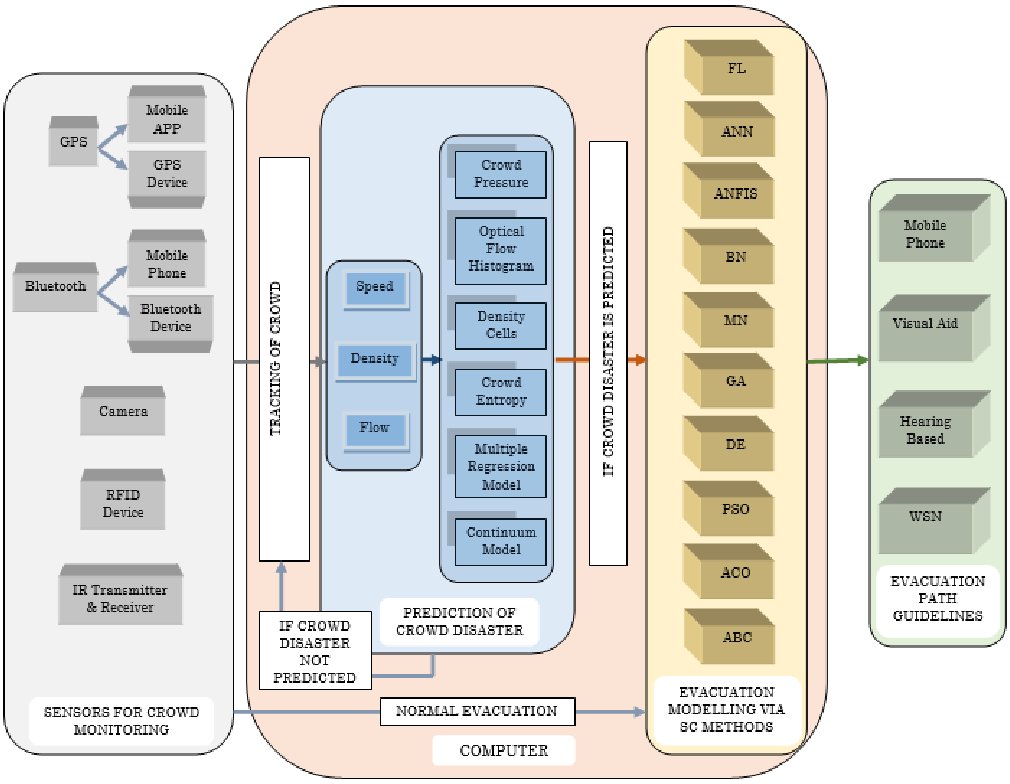

Fig. 6. General framework of an IEMS for future work based on reviewed articles in this paper.

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