Bayesian network model of crowd emotion and negative behavior

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Bayesian Network Model of Crowd Emotion and Negative Behavior

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Abstract. The effects of overcrowding have become a major concern for event organizers. One aspect of this concern has been the idea that overcrowding can enhance the occurrence of serious incidents during events. As one of the largest Muslim religious gathering attended by pilgrims from all over the world, Hajj has become extremely overcrowded with many incidents being reported. The purpose of this study is to analyze the nature of human emotion and negative behavior resulting from overcrowding during Hajj events from data gathered in Malaysian Hajj Experience Survey in 2013. The sample comprised of 147 Malaysian pilgrims (70 males and 77 females). Utilizing a probabilistic model called Bayesian network, this paper models the dependence structure between different emotions and negative behaviors of pilgrims in the crowd. The model included the following variables of emotion: negative, negative comfortable, positive, positive comfortable and positive spiritual and variables of negative behaviors; aggressive and hazardous acts. The study demonstrated that emotions of negative, negative comfortable, positive spiritual and positive emotion have a direct influence on aggressive behavior whereas emotion of negative comfortable, positive spiritual and positive have a direct influence on hazardous acts behavior. The sensitivity analysis showed that a low level of negative and negative comfortable emotions leads to a lower level of aggressive and hazardous behavior. Findings of the study can be further improved to identify the exact cause and risk factors of crowd-related incidents in preventing crowd disasters during the mass gathering events.

Keywords: Bayesian network, crowd emotion, crowd behavior, Hajj gathering.
PACS: 01

INTRODUCTION

Crowds of a large temporary gathering of people occur frequently in modern society, such as in sports events, entertainment festivals, riot, religious activity and many more spectrums of events. A crowd defined by [1] is a gathering of individuals that share a common goal and activity. Hajj, the annual Muslim's pilgrimage to Mecca, is a large group of people that engage in similar religious activities in a specified time within a confined space. Unofficial statistics revealed as many as 3.2 to 3.7 million pilgrims were gathered in Mecca to perform the rituals. In a high volume of people at the same place and time, multiple injuries and deaths have occurred consistently during this religious event. For example, in the 2006 Hajj season, a stampede during stone-throwing rituals killed at least 345 pilgrims and injured at least 289 more [2]. Another fatality was also reported previously in 2004 where at least 250 were killed in a stampede in Mina during Hajj season [3].

In the current scenario of reducing crowd disaster in Hajj season, much effort was channelled into managing and controlling crowds using sophisticated computer simulations, automated video analyses and experimental study. The most popular technique is using computer simulation software to simulate the movement of pilgrims during different rituals. For example, [4] modelled and proposed the movement of pilgrims to reduce congestion before and after stoning rituals, while [5,6,7] simulate the movement and identified the eventual problems during the Tawaf. Meanwhile [8] proposed a closed monitoring system to trigger safety measures using thermal cameras, and [9] adopted experimental work by providing some pilgrims with GPS (Global Positioning System) to track their movement during the Tawaf.

While these efforts and trends contribute to the safe and efficient management of Hajj, little definitive effort has focused on understanding what might caused the crowd disaster incidents, especially in the human behaviour context. Pilgrims involve in a series of fixed rituals that need to be performed at specific time and locations, which, in turn, influence how they respond to certain situations [4]. History has shown that crowd disaster such as crushing, stampede, asphyxiation, injuries and deaths often occurs to those that are concentrated in a narrow area with limited space. In a surging and competitive crowd, sometimes pilgrims jostle to avoid on being trampled, spread the panic and cause a stampede. This highlights the importance for parties involved in

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crowd management and control fully understand the nature of the crowd and crowd behaviour as occurring during real events in order to make timely decisions for effective action [10].

Earlier studies in the series of the ongoing Hajj research project such as [11,12,13] have identified the important components for conceptualising and measuring crowd behaviours of pilgrims from psychological perspective, namely observable behaviour, emotions and cognition. As part of this research work, the present study aimed to identify and understand the inter-relationship between parts of these components, and how they affect one another, specifically the inter-relationship between emotion and negative behaviour among pilgrims. To this end, we propose the use of probabilistic models, Bayesian networks (BNs) models to provide information on the relationship between all variables under study and to predict its future behaviours. The objective of the study is to identify the causal relationship between emotion and negative behaviour among pilgrims in a mass gathering, and predict the likelihood of the behaviour using BN model.

The structure of the paper is as follows. This section outlines the perspective of crowd emotion and negative behaviour in the context of Hajj gathering. The following section explains the research method used in the study, called the BN approach. The next section presents the result of an empirical analysis on Hajj dataset using BN model followed by a sensitivity analysis. Finally, the paper concludes with a discussion and limitation of the study.

LITERATURE

Crowd emotion and negative behaviour during Hajj

A large number of people from all over the world in a limited time and space during Hajj season create dynamic emotional experiences and behaviours among pilgrims. Emotion is defined by sequences to complex behaviours that lead to cognitive assessment, subjective changes, autonomic and neural arousal [14]. Within that definition, [15] concludes three aspects of emotion: cognitive, feelings and actions. It starts with one's interpretation of the situations, with the urge of feelings to behave in a way. In general, there are two theories that describe the relationship between emotions and behaviour, i.e. direct and indirect influence [16]. Emotions directly influence behaviour when actions can be explained from the function of emotion, or in other words, emotion caused individuals to act in a particular way. On the other hand, the influence of emotion on behaviour is indirect when emotions tends to come after behaviour and can be seen as an inner feedback system that urge individuals to reflect on the behaviour and its consequences.

In the context of Hajj or any large gathering events, emotions experienced by individuals are completely different depending on the variability in activities, situations and interaction with other people around them [17]. An exploratory study by [11] differentiates two broad-ranges of emotions: positive and negative emotions during Umrah rituals (Umrah is relatively similar to Hajj but in a smaller gathering). Positive emotions associated with the general feelings experienced by pilgrims when the rituals were conducted during a less crowded situation were feelings such as "serene", "peace", "relax", "disbelieve", "special" and "selected". While negative emotions associated with being in crowded places were emotions such as "frustration", "anger", "worried", "tense", "frightened" and "panic".

In a similar study by [12], an identical category of behaviour is recorded in the behaviour of pilgrims during Umrah rituals, i.e. positive and negative behaviour. Rituals that are performed in confined areas have resulted in negative behaviours such as "pushing", "elbowing", "bulldozing" and "stepping others". Observed behaviours such as "hitting others" and "pushing the wheelchair carelessly" are hazardous and harmful to other pilgrims. These hazardous behaviours are as a result of negative emotions experienced such as feelings of "anger", "worry", "discomfort" and "fear". On the other hand, positive emotions and behaviours are observed when they have the correct intention in performing the rituals, without paying too much attention to the circumstances or surroundings.

Bayesian Networks

BNs or Bayesian belief networks are graphical model that use Bayesian probabilities to represent a set of variables and the dependencies that exist between them [18]. It can provide interesting information on the relationships between the variables in the network or can be interpreted as cause-effect relationships. This model enabled us to make probabilistic inference, which is determined by the probability distribution of the unknown variables, based on the known variables.

A Bayesian network is a Directed Acyclic Graph (DAG) that represents the dependency of a set of random variables that can be expressed by the distribution of the collective probability. The directional arch in the network represents causal influences, and this causal nature allows independencies to be represented by the network. Variables or nodes that are causes of a particular node are referred to as *parents* of that node. A *child*

of a node is influenced directly by that node, which is the consequence of that node. The directed graph is said acyclic since cycles are forbidden, i.e. it is not possible to start from a variable (node) and following the directions of the arches, go back to the starting node.

Assume that a set of random variables $V=\{X_1,X_2,...,X_T\}$ and a DAG for V is defined by the pair $B=(V,G)$, where V is the set of variables (nodes) and G is the set of directed edges (arrows) connecting pair of nodes. Nodes represent the variables of interest in the studied problem. In this study, each node is associated with a random variable relative to the characteristics of crowd emotion and negative behaviour. Whereas G is a DAG in which each arrow represents a direct dependency relation between the variables. The direction of the arrows indicates that the variable (*child* node) 'pointed at' by the arrow depends on the variable found at its origin (*parent* node). An example of DAG is provided in Figure 1. In this example, X_1 is called *parent* of X_2 (or X_2 is called *child* of X_1) denoted by $pa(X_2)$, and the two variables are dependent. Another example is variables X_1 and X_3 are *parents* of X_4.

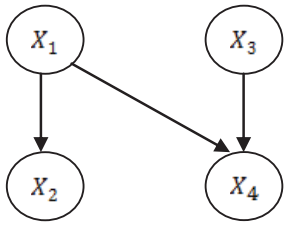

FIGURE 1. An example of DAG

Given a network of T variables in $V=\{X_1,X_2,...,X_T\}$. Each variable $X_i, i\in V$ is associated with the conditional probability distribution of the variable of interest given its *parents*, $p(X_i|pa(X_i))$. If a variable X_i has no *parents*, then it is associated with the marginal distribution of X_i, $p(X_i)$. The joint probability distribution of $X_1,X_2,...,X_T$ thus can be factorised as:

$$p(X_1,X_2,...,X_T)=\prod_{i\in V}p(X_i|pa(X_i)) \tag{1}$$

For the DAG in Figure 1, we have the joint probability distribution:

$$p(X_1,X_2,X_3,X_4)=p(X_1)p(X_2|X_1)p(X_4|X_1,X_3)p(X_3)$$

In general, in order to design and use BN, the appropriate network structure and the corresponding probabilities value in (1) must be determined. Usually, the dependence structure is learnt (estimated) directly from available data, unless the structure is known or can be built manually on the basis of expert knowledge. There are two categories of algorithm in structure learning: score-based algorithms and constraint-based algorithms. The score-based algorithms find the possible network structure that minimizes a given score functions. Meanwhile the constraint-based algorithms employ a series of conditional independence tests and identify the network structure that satisfies the conditional independence properties. The two most popular algorithms under this category are SGS (Spirtes, Glymour and Scheines) and PC (Peter Spirtes and Clark Glymour) algorithm.

The next step after the network structure has been determined is to identify the parameters of the model (conditional probabilities). Examples of parameter learning techniques are Maximum Likelihood (ML) estimation, Bayesian estimation and EM (Expectation-Maximization) algorithm. Once the model structure and parameter have been estimated, information propagation technique or sensitivity analysis can be performed in order to assess the effect of changes of specific variables.

The graphical model of BN is a good tool to represent understanding of relationship of variables in a compact manner. BN permit to merge knowledge from expert's know-how and data from feedback experience, handling data that include partial data and does not require a specific distribution type to the data like any statistical technique, for example Structural Equation Modelling (SEM) [19]. Furthermore, they offer flexible

methods of reasoning based on the propagation of probabilities throughout the network in accordance with the laws of probability theory [18].

There is a variety of software packages available for building BNs such as Netica, Hugin, Analytica, Genie and Bayes Net Toolbox. These tools enable the process of construction, analysis, and visualization of BNs to be performed efficiently and with ease. For our application we use the Genie software (http://genie.sis.pitt.edu/) and apply two step procedures of structure and parameter learning that will be described in the following section.

METHODS

Data Description

The data used in the study were taken from the Malaysian Hajj Experience Survey 2013 conducted during the 2013 Hajj season in Mecca by researchers from the Hajj Research Cluster in Universiti Sains Malaysia (USM). The objective of the survey was to identify the psychological experiences in three different aspects of behavior, emotion and cognition among Malaysian pilgrims when performing the Hajj rituals. The instrument used is a questionnaire developed in the series on research work [11,12,13] that contains three sections of psychological aspect of experiences. However, for the purpose of this study, we focus on elements of emotions and negative behavior as presented in Table 1 and Table 2, respectively. The variables involved in measuring emotions are Positive (7 items), Negative (7 items), Positive Comfortable (7 items), Negative Comfortable (3 items) and Positive Spiritual (6 items) while two variables measuring negative behavior are Aggressive (12 items) and Hazardous Acts (3 Items). The response scale was coded as 1 = strongly disagree, 2 = disagree, 3 = somewhat agree, 4 = agree and 5 = strongly agree.

The survey process involved four different locations with different Hajj rituals: Mecca, Mina, Muzdalifah and Mount Arafat. The sampling procedure used was non-probability sampling, i.e. convenience sampling due to respondents' availability at each location and by considering the limitation of other sampling procedures for a highly crowded condition at the event with limited time. A total of 147 respondents were involved, 70 of them are men (47.6%) and 77 are women (52.4%) with most between the ages of 41-60 years old (69.4%). Majority of the respondents (91.2%) are new pilgrims, only a few among them reported to have previous experience in Hajj. Details of the respondents' characteristics are presented in Table 3.

TABLE (1). Content of the psychological aspects of emotion in Hajj survey.

Emotion variable	Items	Emotion variable	Items
Positive	Happy	Negative	Angry
	Delighted		Frightened
	Excited		Selfish
	Inspired		Self-preferred
	Amazed		Anxious
	Determined		Intimidating
	Sympathy		Intimidated
Positive comfortable	Relax	Negative comfortable	Scared
	Easy		Confused
	Comfortable		Bumbled
	Fresh		
	Bearable		
	Energetic		
	Calm		
Positive spiritual	Patient		
	Blessed		
	Grateful		
	Tawakkal		
	Trying to be patient		
	Control anger		

TABLE (2). Content of the psychological aspects of negative behavior in Hajj survey.

Negative behavior variable	Items
Aggressive	Bulldozing others
	Ramming others

	Pushing others
	Shoving others
	Being rude
	Stepping over others
	Making noise
	Frightening others
	Being selfish
	Retaliate when pushed
	Cutting the queue
	Rushing to complete the rituals
Hazardous acts	Stopping at inappropriate points
	Disturbing others with objects such as wheelchair
	Walking against the flow

TABLE (3). Demographic characteristics of the respondents.

	n	Percentage
Gender		
Male	70	47.6%
Female	77	52.4%
Age		
Below 20 years old	1	0.7%
21-40 years old	24	16.3%
41-60 years old	102	69.4%
61 years old and above	20	13.6%
Hajj experience		
Yes	134	91.2%
No	13	8.8%

Learning the Network For Hajj Experience

The network modelling of the dependence structure among Hajj experience variables has been learnt directly from data using PC algorithms. The PC algorithm conducts independence tests between all the variable pairs conditioned on the subsets of other node variables that are sorted from small to large sizes. For example, it starts by forming the complete undirected graph, which it then thins by removing edges with zero order conditional independence relationships, and then retains with first order conditional independence relationships, and so on. The set of variables conditioned only needs to be a subset of the set of variables adjacent to one or other of the variables conditioned; this is constantly changing as the algorithm progresses. In this study, an independence Chi-Square test is used based on the measure of conditional mutual information, with a fixed confidence level equal to 0.95.

In order to complete the construction of the model, the conditional distributions from the data is estimated using Bayesian parameter estimation technique. Thus technique starts with a prior distribution, and use experience (dataset) to update the distribution using Bayes' rule.

FINDINGS

Bayesian Network for Hajj Experience

Graphical inter-relationship between emotions (negative, negative comfortable, positive, positive comfortable and positive spiritual) and negative behaviours (aggressive and hazardous acts) of Hajj experience dataset is shown in Figure 2. Moving through the network from one node to another node (sequence of nodes connected by arrows), we can identify which variables influence directly or indirectly to other variables. For example, pilgrim's emotion of negative comfortable, positive spiritual and positive emotion have a direct influence on hazardous acts behaviour, whereas negative emotion has an indirect influence on hazardous acts behaviour. Also, negative, negative comfortable, positive spiritual and positive emotions have a direct influence on aggressive behaviour, which then may turn to hazardous acts behaviour. Knowing which emotion variables have a direct or an indirect influence on the negative variables and identifying the path is importance to plan and develop an appropriate motivation module for the pilgrims.

Figure 3 displays the marginal probabilities values estimated from the data. The values indicate the estimated probabilities of negative behaviours according to their different states. The sum of state 3 (somewhat agree), state 4 (agree) and state 5 (strongly agree) in each node can be represented as an acceptable value of agreement for that corresponding variables. On the other hand, the sum of state 1 (strongly disagree) and 2 (disagree) can be represented as a disagreement of the particular variable. For example, since there is a direct influence of negative comfortable emotions to hazardous acts behaviour, we might want to know the extent of the effect on this relationship. Notice that the percentage value for state 3 until 4 in negative comfortable emotions is quite low. That is, about 31% of the negative comfortable emotions are found to have contributed to the hazardous act behaviour. Meanwhile, negative emotions contribute about 6% to aggressive behaviour.

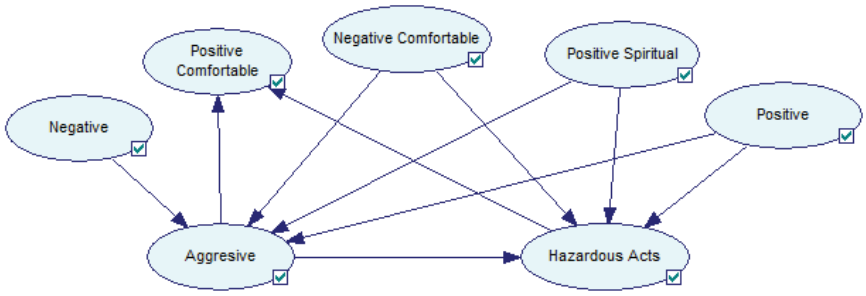

FIGURE 2. Graphical network of emotions and negative behaviour in Hajj experience.

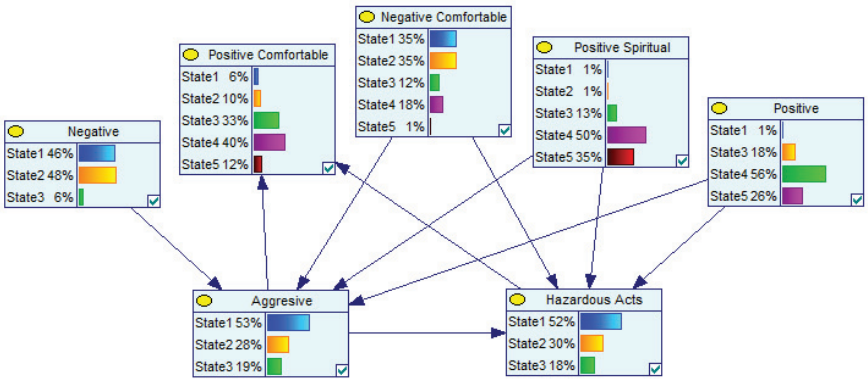

FIGURE 3. Estimated marginal probabilities (percentage values) for the Hajj experience network in FIGURE 2.

Sensitivity analysis for the network

Once the BN has been estimated, we can address a number of queries about the effect of emotions to negative behaviours. This can be done by inserting and propagating the appropriate evidence throughout the network.

For example, if we wish to examine the effects of no or less negative emotions experienced by the pilgrims, we can assign a probability of 100% to state 1 (strongly disagree) of negative emotion variable and the effect of this change on all the remaining variables of the network can be immediately obtained, i.e. we can obtained the updated marginal probability values of all variables. Figure 4 and Table 4 show the sensitivity analysis to determine the effects of no or low level in negative and negative comfortable emotions by assigning a probability of 100% to state 1 (strongly disagree) to each variable. In this case, the disagreement of aggressive behaviour increased to 93% and hazardous acts behaviour increased to 90% from its initial status. In other words, when there is less feeling of negative and negative comfortable emotions among the pilgrims, their level of being aggressive and hazardous is also low.

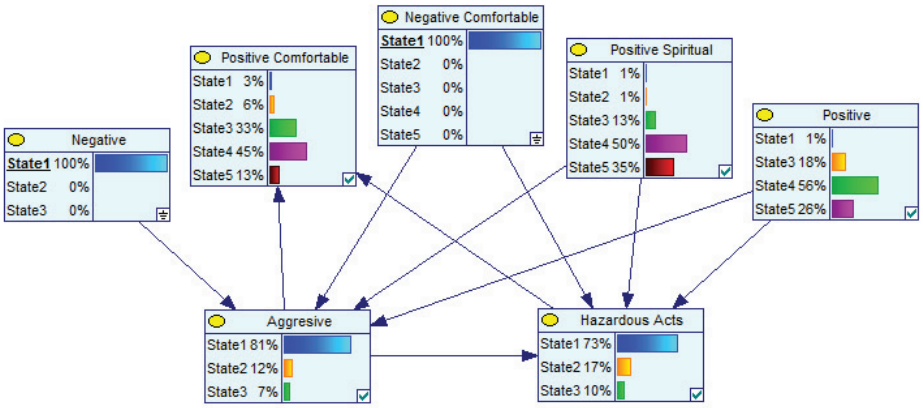

FIGURE 4. Effects of negative and negative comfortable emotion to Hajj experience network.

TABLE 4. Sensitivity analysis of negative and negative comfortable emotion to Hajj experience network.

Actual situation		**Aggressive**		**Hazardous acts**	
		State	Percentage	State	Percentage
		≤2	81%	≤2	82%
		3	19%	3	18%
Negative					
State	Percentage	State	Percentage	State	Percentage
1	100%	≤2	93%	≤2	90%
		3	7%	3	10%
Negative comfortable					
State	Percentage				
1	100%				

CONCLUSION

Individual's complexity of emotions has a large impact on their behaviors. This is particularly true in the context of crowd where the combinations and interaction of people's emotion and behavior have consequences on the nature of the crowd. As one big group of people who shared common identity and goals, and engaged in relatively similar activities, crowd disaster can be caused by individual or collective behaviours of pilgrims. In a large gathering such as Hajj, the behaviours of pilgrims are associated with the emotions people experiencing and these may be varied based on different rituals, activities, locations and situations.

In this paper we have proposed BN as an alternative methodology in determining dependencies of pilgrim's emotion and negative behavior during Hajj rituals. BN provide a structure that can be used for measuring and explaining the impact of different emotion variables to the target variables of aggressive and hazardous acts behavior. We found emotions of negative comfortable, positive spiritual and positive emotion have a direct impact to hazardous acts behaviour. On the other hand, emotion of negative, negative comfortable, positive spiritual and positive emotion have a direct influence on aggressive behaviour, and may lead to hazardous acts behaviour. Evidence propagation in BN allows the sensitivity analysis of certain variables being conducted. In order to reduce negative behaviour in the form of aggressive and hazardous action, it is important to control or limit possibilities of negative emotions to occur during specific rituals.

Using the information enclosed in Hajj experience network and the know-how concerning the Hajj management, the relevant organization can improve the strategy on crowd control. In addition to the use of technology and sophisticated control system, effort to manage crowd should take more psychological and social approach. For example, a preparatory programme designed to train people to behave more positively, prior to the congregation to the holy land of Mecca may be useful. People planning to go for Hajj can also benefit from programmes aimed at increasing people's understanding of crowd emotion and crowd behaviour thus helping them to make informed decisions of how to behave during such situations. The model could be improved by using other learning algorithms and appropriate validation technique to provide better structure model. For further investigation, other psychological variables relating to crowd emotion and behaviour and other non-psychological variable (physical factor, location, etc.) associated with the crowd-disaster during large gathering events should be included.

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