Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 71 (1994)

Artikel: Assessment of human and structural safety of sports grounds
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DOI: https://doi.org/10.5169/seals-54153

Assessment of Human and Structural Safety of Sports Grounds

Évaluation de la sécurité personnelle et structurelle dans les centres sportifs

Bewertung menschlicher und baulicher Sicherheit auf Sportgeländen

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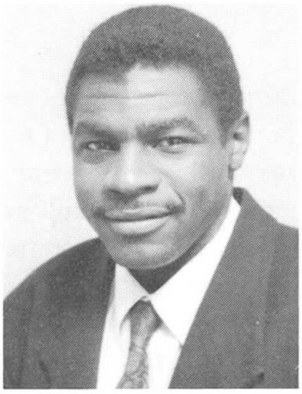

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SUMMARY

This paper describes a flexible automated decision-support system for assessing the safety of sports grounds. The system focuses primarily on three factors: the occupancy, management and structural aspects. It considers overall interdependencies between these factors, and makes managerial and design recommendations for improving the safety of a venue.

RÉSUMÉ

La communication présente un système expert flexible et automatique, en vue de contrôler la sécurité des installations sportives, et qui s'appuie sur trois facteurs principaux: spectateurs, exploitation et aspects constructifs. Ce système tient ainsi compte de la dépendance réciproque de ces facteurs, ce qui conduit à des propositions d'amélioration de la gestion, mais également à des recommandations pour le projet.

ZUSAMMENFASSUNG

Es wird ein flexibles, automatisiertes Expertensystem für die Sicherheitsuntersuchung von Sportanlagen beschrieben, das sich auf drei Hauptfaktoren stützt: Belegung, Management und bauliche Aspekte. Dabei wird die gegenseitige Abhängigkeit dieser Faktoren berücksichtigt, die zu Verbesserungsvorschlägen bezüglich Management, aber auch zu Entwurfsempfehlungen führt.

1 INTRODUCTION

There has been a continual attempt to raise safety standards of places of close assembly, for example, sports grounds. Major disasters including the incidents at Ibrox stadium (1971), Bradford (1985) and Hillsborough (1989) in which many people died and extensive damage was experienced, have led to more stringent scrutiny of safety legislation. Guidelines on measures for improving safety of spectators at sports grounds first became available when the Wheatley Inquiry was published after the Ibrox Park disaster [6]. Along with the Safety of Sports Ground Act 1975, these guidelines formulated the basis of the document commonly known as the 'Green Guide' [7]. Revision of this guide resulted from the Popplewell Inquiry [11] that followed the Bradford Football Stadium disaster. Further changes were incorporated, based on recommendations made in Lord Justice Taylor's inquiry, after the Hillsborough tragedy [14]. The Guide basically outlines measures for improving spectator safety and applies to all types of sports grounds where accommodation is provided for spectators [8]. In this paper, the authors concentrate on football stadia which have a long history of major and minor crowd disorders. In addition, football attracts a large number of spectators making their safety an item of primary concern.

The assessment of sports grounds before, during and after an event is a time-consuming and costly exercise requiring much co-ordination and planning. Because of the excessive number of factors that have to be considered in the assessment process, the assessment personnel generally suffer from a cognitive overload of information. This overload tends to result in some fairly obvious scenarios not being anticipated at all, or the implications of a change in a parameter not being completely appreciated. A significant amount of assessment is done from experience but it is rightly stated [15] that, "...those dealing with disasters and their prevention know that they have to continually re-learn old lessons stated in new ways".

In order to significantly speed up the assessment of sports ground safety, and to provide a system whereby the influence of different parameters on a safety plan can be thoroughly investigated, the authors suggest a flexible model, implemented as a knowledge-based decision-support computer program that contains relevant evacuation, crowd behaviour and structural safety knowledge.

2 BACKGROUND

Evacuation modelling has been a useful technique in simulating human behaviour and movement patterns of occupants and has been used by several researchers to investigate the effects of various parameters on evacuation time and procedure [1,5,9]. In this paper, the authors have utilised certain evacuation modelling principles in the design of a safety assessment system for sport grounds.

2.1 Basis of the assessment model

Three factors are critical in affecting safety: occupancy, management and structure of football stadia. In order to identify critical parameters that operate during emergencies, and to develop relationships between these factors, the authors adopted the molecular kinetic theory of gases as the basis of a safety assessment model. The molecular kinetic theory of gases [2] relates the temperature, pressure and volume of a gas by the equation $PV = nRT$; where P denotes pressure, V volume, T temperature, n the number of moles of the gas, and R the real gas constant.

For a constant volume, the pressure of a gas varies linearly with its absolute thermodynamic temperature. Temperature is a measure of the kinetic energy of the molecules. Raising the temperature results in an increase in the velocity of the molecules and consequently, an increase in the frequency of collisions that the molecules experience with each other and with the sides of the vessel containing them. This is manifested as a pressure increase. This basic behaviour shares certain similarities with that of a large number of occupants in confined spaces, at least in the two-dimensional sense. The kinetic theory is adopted purely to generate conceptual ideas that simulate human behaviour. Differences between the two concepts have been accounted for in the assessment model.

The analogy between molecular kinetic theory and a real-life emergency on a sports ground is evident form the following scenario: Assume gaseous molecules represent occupants while the vessel containing these molecules represents the stadium. A fire, for example, on any part of a ground would stimulate some response from occupants. After they perceive the fire as endangering their lives they would attempt to leave the ground to go to a place of safety. As a result of the fire, speed of movement of occupants as they attempt to distance themselves from the danger, would most likely increase as would the number of collisions or impacts between the occupants and between occupants and the physical structures in the stand. Thus 'temperature rise' or an emergency has an effect on occupancy, management and structural aspects. Table 1 summarises some of the analogies between molecular kinetic theory and the assessment model.

Molecular kinetic theory	Assessment model
Concentration of molecules	Density of occupants in football stand
Uniform or non-uniform mixture	The distribution of occupants in accommodation areas
Type of molecules	Type of occupants present (disabled, able-bodied, young, old, in groups, etc.)
Forces of attraction between molecules	Affiliation ties between occupants
Material of the vessel	Structure of the stand
Path of motion of molecules	Movement patterns of occupants

Table 1: Analogy between molecular kinetic theory and safety assessment model

2.2 Observations from evacuation study

The kinetic theory analogy of crowd behaviour was reinforced by observations of a football stand evacuation exercise carried out at Preston North End football ground [12]. The stand evacuated was the Fulwood End terrace which has a maximum holding capacity of 3,500 occupants. The number of spectators occupying the stand on this occasion was estimated at 1,350.

Before the match, the ingress of occupants into the stand could be likened to filling a vessel with gaseous molecules. The movement of occupants to their positions appeared to be random, but in fact, they were likely to be influenced by factors such as group relationships, familiarity with the stand layout etc. From the safety point of view, an even distribution of occupants was desirable in order to avoid surging and pressure build-up near crush barriers. This was achieved primarily by effective stewarding. In the kinetic theory analogy, stirring a gaseous mixture would eventually give a uniform mixture.

At the half-way interval of the match, a cue was given to evacuate the stand. This cue can be taken to represent a 'temperature rise' which invoked a reaction manifested as movement of the occupants into the assembly area. From kinetic theory, a localised temperature rise would result in increased energy of nearby molecules, which would cause them to move at a higher velocity and experience more frequent collisions. This effect spreads throughout the mixture until equilibrium is reached. In the football ground situation, a localised hazard would cause a reaction from occupants closest to the hazard. This reaction would spread to other occupants via a 'collision effect' at a rate proportional to the degree of danger perceived to result from the hazard. During the evacuation exercise, movement was initiated by spectators nearer the front gates. These spectators set the pace of evacuation for the crowd behind them.

The occupants left the stand passing through the gaps between the barriers, moving randomly within the available space. A significant amount of queuing was experienced as occupants moved through the exits. The choice of exit appeared to be governed by proximity to the exit. This is in agreement with the behaviour of gaseous molecules which tend to flow through an available nearby opening. If an opening is surrounded by group of molecules, the remaining ones will move along the path of least resistance to find a less-crowded alternative. In the same way, during an evacuation of occupants, if queuing occurs at an exit, an alternative nearby exit is sought. In case of equally crowded conditions, where there is queuing at all exits, occupants cannot avoid becoming part of a queue.

3 A COMPUTER SYSTEM FOR ASSESSING THE SAFETY OF SPORTS GROUNDS

The molecular kinetic theory analogy outlined above served as a vehicle for identifying and developing simple condition-action rules describing the interactions between occupant behaviour, managerial decisions and structure in sports grounds. These rules incorporate evacuation, crowd behaviour and structural safety knowledge, as well as normative knowledge from the Green Guide. The rules have been implemented in computer-usable form as the knowledge-base of an intelligent decision-support system.

The computer program comprises principally of a knowledge-based component, implemented using the CLIPS 5.1 production-rule system [4], and a custom-built hypertext system, HTEX 1.0 [10]. The two subsystems are fully compatible with one another, allowing two-way information exchange. Based on a user's input specifications, the knowledge-based component makes decisions about whether or not safety requirements are satisfied at a ground. In the latter case, it recommends corrective actions, whereas in the former, it may suggest methods to improve on the safety of the ground. The recommendations arrived at may, for justification, reference relevant sections of the Guide or the research literature, which are also represented in the system (in textual form) in the hypertext module.

Hypertext systems allow the representation of normative knowledge, such as is contained in the Guide, as a network of related but independent information units [3,13]. Two units of information are linked in the network if one is referenced in the other. The network representation allows a user to transverse the Guide as he desires, following links that he deems important. This is in contrast to a flat representation which constrains the user to follow the author's chain of reasoning.

Once within the hypertext module, the system allows the user to query the status of the Guide's clauses, that is, whether they are violated or satisfied. This is achieved through a call back to the knowledge-based component. The queried clauses do not necessarily have to be the same as those in the initial recommendation that caused the jump into the hypertext module. Fig. 1 illustrates English versions of some of the rules in the system, and Fig. 2 depicts hypertext windows invoked by querying the recommendation arrived at by Rule 1. The top window shows the information displayed when the recommendation is queried, while the bottom window shows additional information displayed when the underlined phrase Stewards in the first window is queried.

1. **If** (distribution of occupants) is (locally clustered around exits) **then**
   recommend(managerial, "stewards disperse the crowd in order to attain uniform distribution")
2. **If** (pre-event planning) **then**
   data((ground assessment), needs-to-be, (routine))
3. **If** (some occupants) have (disabilities) **then**
   recommend(managerial, "proper provision should be made to accommodate the disabled occupants")
4. **If** (surveillance/communication system) needs-to-be (checked) **then**
   recommend(managerial, "perform surveillance/communication system check")

   ⋮

Fig. 1: Near-English representation of some of the rules in the system

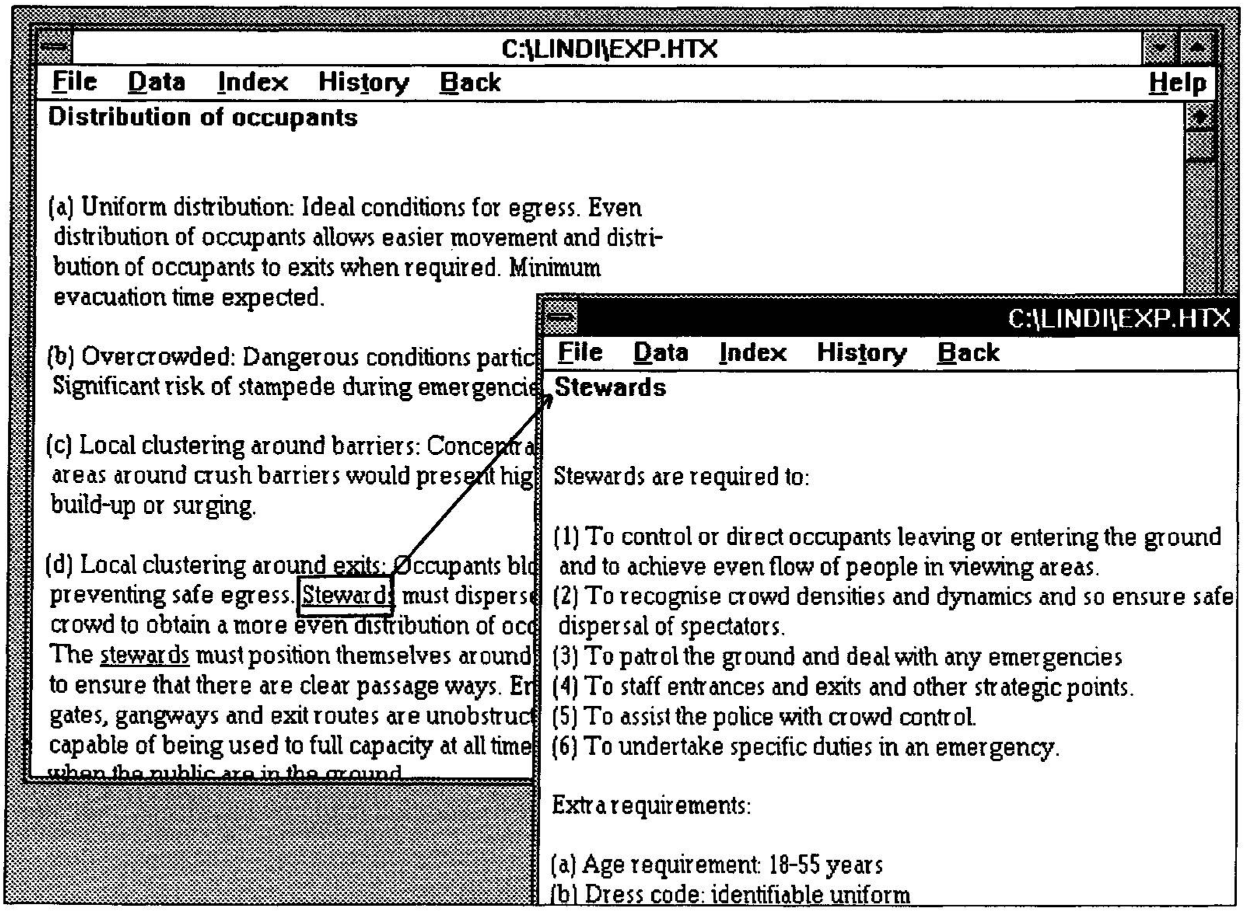

Fig. 2: HTEX windows providing further information

CONCLUSIONS

This paper has described a simple but flexible knowledge-based computer system for quickly assessing the safety of football grounds. The system considers the inter-relationships between occupancy, management and structural aspects in accommodation areas, assembly points and evacuation routes, and makes recommendations for improving the safety of a ground. This system will be particularly useful to building control and fire safety officers and management personnel. In addition, it could be used as a preliminary design assessment tool by designers of new sports grounds. The time and cost-saving benefits of the system derives primarily from automating the significant amount of paperwork involving cross-referencing of several documents inherent in conventional methods of assessment. The system attempts to unify all essential safety information, while providing a facility for incremental modification. On extension of the knowledge base, the system should be capable of being applied to a wider range of places of close assembly.

ACKNOWLEDGEMENTS

The first author would like to acknowledge the support of Mr. John Willis, Fire Safety Officer of Preston North End Football Ground. She would also like to acknowledge the assistance given by Sergeant Billsbury of Preston Police and all staff involved in organising the evacuation of Fulwood End terrace in November 1993. The support given by observers from University of Central Lancashire: Mick Ward, Pam Curwen, Gilbert Owusu, Francis Kalibala and Joseph Madida, is also greatly appreciated.

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