Improving the evacuation of high-risk buildings with adaptive exit guidance

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Summary

Effective evacuation is reliant upon a combination of factors including procedural planning, route mapping, training and technology. These considerations are essential to all commercial buildings, which must not only be prepared for the possibility of a fire but a range of newer potential threats including terrorism, civil unrest or extreme weather. The need for rigorous evacuation planning is heightened in buildings that carry particular risk factors. Firstly, there are buildings where the process of evacuation can be more challenging because they are large, complicated in their layout or occupied by large volumes of people who are unfamiliar with escape routes and procedures. Secondly, there are some buildings more likely to be affected by an emergency than others, particularly if they have an above-average risk of being targeted by terrorists.

Characteristics like these may require evacuation procedures or technologies that are more sophisticated. Studies into prominent incidents including the Dusseldorf Airport fire of 1996 and the World Trade Center attack in 2001, as well as academic research into crowd behaviour during emergencies, have identified scope for improvement in the way evacuations are managed in some circumstances. A common finding is that panic, congestion and difficulty in locating safe exits can inhibit the process of evacuation.

One of the most important findings is that static exit signs may not be noticed or indeed acted upon. Research has indicated that only 38% of people 'see' conventional exit signs in presumed emergency situations when they are in an unfamiliar built environment.[1] Conventional exit signs, being generally static, are unable to adjust their guidance or direction according to changing circumstances or dangers. This is a potentially significant weakness given the diversification of threats facing complex buildings and the ways in which these threats can escalate in real time.

New forms of escape guidance systems are now being introduced to improve visual recognition of exit routes and provide greater flexibility in the routing of building occupants.

The technologies include dynamic exit signage, which can direct occupants to an alternative exit point, and adaptive systems, which enable continuous adjustment of exit route guidance in line with the location or nature of the hazard.

In a paper published by ZVEI, the German Electrical and Electronic Manufacturers Association, Dr Sebastian Festag, chairman of the ZVEI working group on adaptive escape routing, said: "Particularly vulnerable individuals like the growing number of elderly often suffering from reduced mobility, pregnant women, children and disabled persons, as well as larger and more complex building structures generate new requirements for solutions that are up-to-date and secure in case of demand. There is an obvious trend to use adaptive escape routing with intelligent readjustment of the safety system technology to the development of a hazardous situation."[2]

There are three stages to consider in emergency planning:

- Detect – detection of the hazard and analysis of the appropriate response
- Alert – notification of building occupants via visual or audio communication
- Evacuate – provision of safe exits and guidance to help locate them

This whitepaper shall focus primarily on the third stage of emergency planning: evacuation, although it is important to bear in mind that all three stages are intrinsically linked.

Diversification of risk

From fire to violence, the range of triggers for evacuation of a commercial building is growing as the risk landscape diversifies. Of the 34 countries that comprise the OECD area, 21 experienced terrorist attacks in 2015, and the number of deaths rose by 65%, according to the 2016 Global Terrorism Index from the Institute of Economics and Peace (IEP).[3] And while fatalities resulting from fires are generally decreasing, the death toll across Europe is still measured in terms of many thousands[4]. In addition, civil unrest, severe weather and crime involving the use of weapons are being reported around the world and can all be triggers for evacuation or, alternatively, lockdown procedures, whereby it is considered safer to keep occupants at a set location indoors.

The number of deaths from terrorists attacks rose by 65% in 2015 [1]

The primary goal of evacuation is the protection of people, which ought to be a more than sufficient motivation to prioritise planning, but there are also legal, financial, reputational and operational reasons why this obligation cannot be overlooked. The IEP calculated the global economic impact of terrorism at $89.6 billion in 2015, while The Geneva Association estimates that fires carry a cost of around 1% of global GDP each year.[3]

Today it is more important than ever to develop, maintain and continuously review an evacuation plan. Commercial buildings face an increasing diversity of external risks that might trigger an evacuation. At the same time, the trends of urbanisation, coupled with an ageing population, can make the process of evacuation more challenging.

The precise nature of the evacuation procedure and the emergency lighting and notification systems that are required to support it, are dependent on a number of variable factors. To determine these factors, a comprehensive and regularly reviewed risk assessment must be the foundation of evacuation planning. It should establish the risk profile of the building, including consideration of its layout, an assessment of the characteristics and activities of its occupants, its location and its existing life safety infrastructure.

Evacuation planning is more challenging in large, tall and multi-functional buildings that may include residential and commercial premises, as well as restaurants and shops. Hosting large populations of people, these buildings are vulnerable to hazards that could lead to a mass evacuation, and yet, if no set of practices are applied to the whole building, systems and procedures may vary between different groups situated within it.

The owner or manager of the building has a moral responsibility to ensure a thorough risk assessment is conducted, acted upon and continually updated. In most countries, the obligation to implement such a process is enshrined in law.

Identifying high-risk factors

A thorough risk assessment will identify usage patterns that present particular evacuation challenges in a building. Consider, for example, shopping centres, university sites, stadia, airports, train stations, tunnels or subway stations, civic buildings, arenas, high-rise offices and hotel or leisure complexes.

What they have in common is that they are often large and complex, generally easily accessible to the public and frequently contain a high density of people. Furthermore, they may be considered as primary targets for terrorism, crime or unrest.

In buildings like these, there is heightened risk and an acute need to consider evacuation procedures that are adaptable to changing circumstances.

Tall buildings are an important example. In the event of an emergency, safely evacuating a skyscraper with 49 floors and over 5,000 occupants is an incredibly complex and difficult process. When a building is multiple storeys high, the stairs act as major constriction points, causing congestion on the escape routes. Furthermore, the risk of people stumbling on stairs is considerably higher than on a level escape route.

A 2011 study by two US universities of the 9/11 terror attack on the World Trade Center concluded that while the evacuation was largely successful, with 87% of occupants exiting the building in less than two hours, the timings were highly variable and lessons could be learned.[5]

"Analysis of survey data collected from a sample of 1,444 evacuees identified several facilitators and barriers to length of time to initiate and fully evacuate from WTC Towers 1 and 2. At the individual level, these included sociodemographic and occupational variables, health status, sensory cues, risk perception, delaying behaviours, and following a group or an emergent leader. At the organizational level, factors included emergency preparedness safety climate variables. Structural (environmental) factors included egress route barriers, poor signage, congestion, and communication system failures. Many factors identified in the study are modifiable. Therefore, these data have the potential to inform high-rise preparedness and response policies and procedures," said the report.

Transport hubs also present particular challenges. In 1987, a fire at Kings Cross station in Central London saw 31 people lose their lives. The escalator's wooden decking and balustrades were preheated by the fire and, once ignited, the flames spread up the escalator trench and caused a flashover in the ticket hall. Evacuation of the lower levels of the station was underway at the time of the flashover, though unfortunately the escape route taken was up a separate set of escalators and through the ticket hall where the flashover occurred.

The investigation called 150 witnesses, took 12 months to publish its findings, ran to more than 250 pages and made 157 recommendations. In addition to specific technical recommendations for London Underground, the tragedy led to broader changes in the understanding of fire safety that have informed and improved safety policies over subsequent years, according to a report by David A Charters of the third-party approval organisation BRE Global, published in Fire Protection Engineering.[6]

"The importance of human behaviour in fire was also recognised. For example, some passengers did not act on instructions from station staff because they did not perceive them to be authoritative. This perception had developed during normal operation and has important implications for the training of staff. Other passengers responded to police officers who happened to be on the scene and used their initiative, but had little or no knowledge of the station or its emergency procedures. Fire safety management, and in particular the importance of a safety culture, gained greater recognition. After the fire, there was a radically different approach to near-misses and internal inquiries into accidents were undertaken."

Almost 10 years later, in April 1996, one of the largest fire disasters in Germany began in a departure hall at Dusseldorf Airport, in which 17 people lost their lives and 62 people were seriously injured.[7]

The inquiry identified a number of reasons for the extent of the disaster, including the use of flammable insulation materials in suspended ceilings and cable ducts and a lack of automatic fire extinguishing systems. However, there were also shortcomings in the evacuation process, including defective lift control systems which opened the lifts onto the fire, inadequate escape routes from the VIP lounge and insufficient partitioning of escalator openings and stairwells.

The UK's Fire Industry Association summaries the key factors that should be considered to ensure an adequate means of escape is provided (see fig 1) [1].

The FIA's best practise
GUIDE TO FIRE SAFETY

Distance to an exit
Maximum distance occupants must travel to reach a place of relative or ultimate safety such as an exit to a protected stairway of a final exit.

Avoid dead ends
Avoidance of long dead-ends which escape is only possible in one direction

Exits
Number, distribution and width of storey exits and final exits

Protecting escape routes
Means of protecting escape routes from ingress or build-up of smoke that might prevent occupants from escaping

Ability to use escape routes
Ability of occupants to use escape routes, and especially arrangements for people with disabilities.

Fig 1: The FIA's best practise guide to fire safety [1]

The guidance concludes by stating that: "In large or complex buildings, the advice of specialists on the adequacy of means of escape will often be necessary."

In buildings that are used by members of the public or guests who are unfamiliar with their layout, particular thought should be given to emergency procedures and exit routes and how occupants will find safe exit points. Regular occupants, such as employees, should be provided with relevant training, but it is more difficult to ensure visitors or temporary workers are provided with the same briefings. Additionally, the needs of these visitors should be considered, particularly if they include people with mobility impairments, children or other vulnerable individuals.

Exit sign requirements

A thorough risk assessment will identify usage patterns that present particular evacuation challenges in a building. Consider, for example, shopping centres, university sites, stadia, airports, train stations, tunnels or subway stations, civic buildings, arenas, high-rise offices and hotel or leisure complexes.

The initial notification of the hazard – a visual or audible alarm – alerts the occupants of a building to the danger but does not usually provide information on where they should go. For that, they must rely upon emergency lighting and exit signs.

Exit sign luminaires and other emergency lighting play a crucial role in guiding occupants to an exit point. There is a tendency among people to leave premises by the same way they entered, or by routes that are familiar to them but nearest exits should be clearly indicated.[9]

There have been a number of efforts to establish consistent standards for safety signs across Europe, beginning in 1996 with the Safety Signs Directive (92/58/EEC). In 2011, there was another attempt to achieve consistency with the launch of the international standard ISO7010, which encompasses a specific standard, ISO3864, on the design of fire exit signs.[10]

The build-up of regulation has been mixed and, as a result, clarity is not always easy to find. In a UK blog, the Fire Industry Association's technical director Robert Thilthorpe noted that a degree of confusion had arisen. As a result, the Fire Industry Association produced a short guide.[11]

Among the recommendations is that:

- All escape route signs should be adequately illuminated to ensure they are conspicuous and legible within the environment.
- All escape route signs should be visible under power loss conditions
- All escape route signs are required to be observed from a distance
- From any point within a building it is important that people have immediate sight of an escape route. If they do not, or doubt may exist, an escape route sign or series of escape route signs is likely to be necessary.
- An escape route sign should be positioned at every change of direction, every change of level and at any decision point within the escape route.
- Escape route signs should be sited at 2m from the floor when positioned above doors or where suspended from the ceiling, and at 1.7m from the floor when positioned on walls.

Lack of international consistency in the design and implementation of emergency exit signs is a potential problem. Shortcomings in the design or placement of exit signs have been cited as an aggravating factor in several of the examples mentioned above, including the attack on the World Trade Centre.[5]

Firstly, static signs do not always attract the required level of attention from evacuees, particularly in a highly-stressful situation; and secondly, they have no ability to adapt to changes in the nature or location of the threat, which is particularly concerning not only because of the ways in which fire can spread but also the highly unpredictable nature of modern-day terrorist attacks.

On 21st September 2013, a Somali militant group carried out a terrorist attack on the Westgate Shopping Mall in Nairobi, murdering more than 60 people. The mall had only five exits: the basement car park, the rooftop car park, the main pedestrian entrance, an emergency exit in the back corner and a delivery area for the Nakumatt supermarket. Of the mall's six emergency stairwells, only one led directly to the outside. The four gunmen controlled two of these exits, and no one inside or outside knew how many more terrorists there were. Hundreds of people had found their way to Nakumatt service entrance, either through the store or via the nearby emergency exit, and were rushing onto the street outside in search of safety.[12]

The positioning of the gunmen and the movement of occupants were largely visible to security staff via CCTV cameras but in this case they had no means by which to communicate with people in the shopping centre. Furthermore, there was subsequent criticism of the time taken for security and military forces to move in. This horrifying incident provides a stark example of the limitations of static signage in an emergency.

Some commentators have suggested that building owners and managers should not assume the highest possible level of protection has been achieved by complying with legal standards and regulations. In some circumstances, additional measures may need to be considered. In an article published by SFPE Europe, members of the Fire Safety Engineering Group at the University of Greenwich argue: "The passive nature of these emergency systems has contributed to the toll of avoidable deaths in fire and other emergencies. Tragedies involving the failure of legally compliant emergency signage systems to fulfil their basic purpose include the King's Cross Underground fire (UK, 1987), the Düsseldorf Airport fire (Germany, 1996), the Rhode Island Night Club fire (US, 2003) and the Nairobi Westgate Shopping Mall terrorist attack (Africa, 2013)."[13]

The authors state that in the Rhode Island and Düsseldorf incidents, there was inadequate recognition of the legally compliant emergency exit signs and, as a result, occupants did not use appropriate emergency exits quickly enough. In the King's Cross, Düsseldorf and Nairobi incidents, the emergency exit signs were incapable of adapting to the developing situation and so did not redirect people away from compromised emergency exit routes.

In response to these and other incidents, a growing body of research and development has been devoted to the development of a more technologically advanced exit sign.

A new generation of exit signs

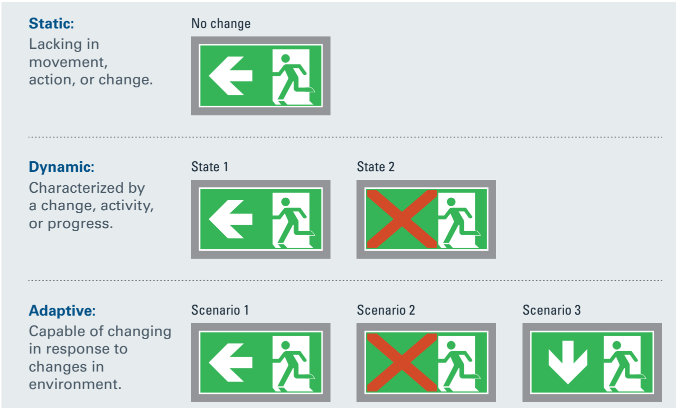

Fig 2: The difference between Static, Dynamic and Adaptive exit signs

The most widespread type of exit sign currently in use is the static exit sign (see fig 2). A static exit sign provides basic escape route guidance and may either be constantly illuminated or not illuminated. In recent years, however, new types of exit sign have been developed, beginning with active exit signs, which, unlike their static ancestors, can be illuminated (or activated) in specific circumstances when they are needed. The next stage of evolution saw the development of dynamic exit signs, which are able to indicate a single change of route. Moving forward, the new generation of exit signs incorporate adaptive technology, enabling them to continually adapt to changing circumstances. In an explanatory leaflet on Adaptive Escape Routing published by ZVEI, the German electrical and electronic manufacturers association', the characteristics of different emergency signage technologies are defined as follows:

- Active – Systems that are activated when required, but can only indicate a single evacuation route.
- Dynamic – An advancement upon active systems in which a system is not only activated but can direct evacuees to an alternative escape route
- Adaptive – Systems that are activated upon demand, can indicate an alternative route but can then continuously adapt to the development of a hazard.

The advantages of adaptive exit guidance

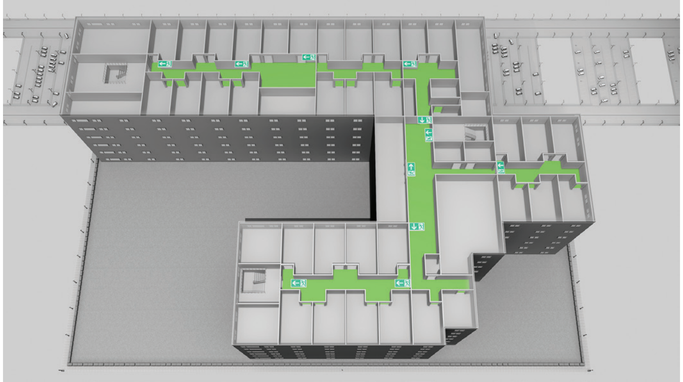

Fig 3: Illustration of a system under normal conditions

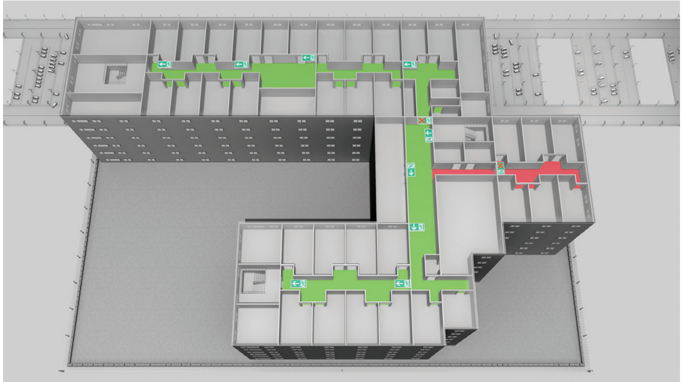

Fig 4: Illustration of an adaptive system with danger in one location

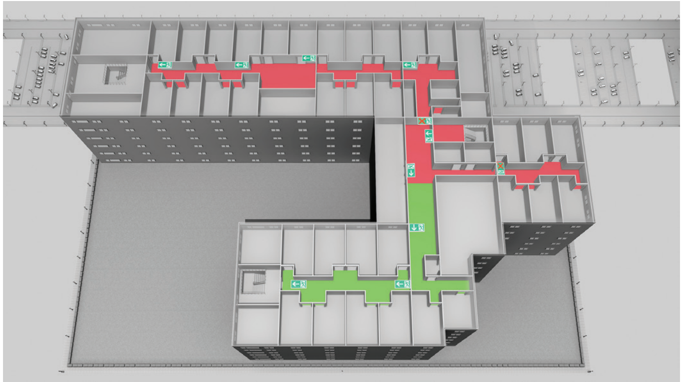

Fig 5: Illustration of a system under normal conditions Illustration of an adaptive system with danger in two locations: one blocking a main stairwell

The adaptive evacuation technology developed to date requires cause-and-effect programming at the point of installation so that differing scenarios are mapped together with appropriate responses. This process must be based upon a risk assessment performed by competent professionals. For example, if Exit A is blocked, Exit C is the preferred alternative. An instruction is issued to a central control point, usually within the building, and a trained person would then manually accept or disregard the recommendation. In this way, a degree of control is afforded to the human operative. If circumstances change, such as in the case of a roaming attacker or fast-moving fire, the system can adapt once again to guide occupants away from the hazard.

The challenges of emergency wayfinding in airports were highlighted in August 2016, when false reports of a gunman at John F Kennedy International Airport led to panicking crowds running onto the tarmac where aircraft are typically parked.[14]

A report in IEEE Spectrum pointed out that airports are typically designed as long, narrow buildings with aircraft parked at gates on both sides. This layout helps passengers board planes but it is less conducive to evacuation. Matthew Manley, clinical assistant professor of information and operations management at the Mays Business School of Texas A&M University, said: "Airports are built that way to get passengers through security and bag check and everything as quickly as possible, so that they have the best customer service experience. But from an evacuation standpoint, it's problematic because passengers might be at the end of a pier and would be required to evacuate across a very long distance and through hazards."

Adaptive exit signage is reliant upon surveillance of a building so that hazardous areas can be identified. Similarly, emergency call points or panic buttons could serve as triggers.

Germany's ZVEI organisation points out that: "Contrary to static, active and dynamic escape routing, in the event of a hazardous situation, adaptive escape routing offers the advantage of changing the routing of affected persons according to the development of the hazardous situation. With fire development, escape routes and staircases that may have been safe, can become inaccessible in no time. In this case, escaping persons have to be rerouted to alternative escape routes or staircases and diverted around newly developed hazardous areas." [15]

Furthermore, ZVEI states that: "Adaptive escape routing can reduce the duration of evacuation if groups of persons can be routed via safe escape routes and if congestion, as well as aberrations, can be avoided." [15]

While no formal international standards or regulations have yet been established to set out the requirements of adaptive exit systems, existing regulatory requirements pertaining to exit signs and emergency lighting must still be met. By adhering to these standards, adaptive exit systems can still be compliant, which provides purchasers with important reassurances.

In conclusion, the potential of adaptive exit guidance is apparent and a number of incidents can be quoted where such technology could have facilitated a safer evacuation. However, there are challenges to overcome. Firstly there is a need to raise awareness of adaptive technology among architects, planners, designers, fire authorities and safety consultants. Secondly, where life safety is at stake, a set of standards will be needed to ensure the quality and efficacy of systems coming onto the market. Thirdly, there is still scope for refinement and advancement in the capabilities of the technology, not only in isolation but through greater integration with other safety systems. For example, integration of an adaptive system with addressable detection devices could increase the inherent intelligence of the system, providing further information based on which the system can make decisions.

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