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Improving the reliability of visual inspections conducted by fire and rescue services during pre-incident planning visits

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Fire and rescues services the world over commonly conduct pre-incident planning familiarisation visits. During such visits, fire crews typically look for observable fire safety hazards. Accordingly, two research questions were investigated in this study being; how many fire hazards are typically observed during such familiarisation visits and can the reliability of visual inspection conduct be improved by using a novel systematic visual inspection method. A fire and rescue service with 22 fire fighters was recruited, and they conducted 21 pre-incident planning visits to occupied apartments blocks. The experimental design involved one of the fire crew being tasked with observing fire hazards using systematic visual inspection. The researcher collated the forms used by all fire crews to record fire hazards observed during their visual inspections. The mean number of fire hazards observed by fire crews using their normal custom and practice for visual inspection was 9.03 per visit (SD=4.39). In sharp contrast, the fire fighter who used systematic visual search, observed a mean 28.87 fire hazards per visit (SD=10.72). These results were highly significant and with a large effect size as measured by Cohen's "*d"*. In conclusion, the evidence from this study supports the use of systematic visual search as a method of increasing the reliability of pre-incident planning visits conducted by fire a rescue services worldwide.

Keywords: Observable, Fire, Hazards, Systematic, Visual, Inspection, Reliability, Pre-incident, Planning

1. Introduction

Fire and rescue services the world over conduct familiarisation visits to buildings. This is a procedure commonly referred to as pre-incident planning (Kapalo & Viola 2019; NFPA 1620). During these visits, fire and rescue personnel typically walk around the premises in an informal manner. This is so that fire fighters can gain understanding as to the facilities, layout and risks that they may one day encounter in reality.

Clearly these visits are important in terms of preparing for future outbreaks of fire and allowing strategy and resilience to be considered in advance. These visits are in effect valuable opportunities to conduct informal fire risk assessments whereby fire hazards can be identified, risks evaluated and control measures for any potential firefighting operations considered.

By framing these visits as informal fire risk assessments, one research question that emerges is how reliable are these familiarisation visits in terms of fire hazard identification. Given that fire and rescue personnel typically look around the premises being visited, the number of fire hazards observed during these visual inspections, becomes an important dependant variable for subsequent statistical analysis.

The second research question that becomes applicable is whether the number of observable fire hazards during these visual inspections can be maximised. By ensuring all relevant observable fire hazards are seen as far as is possible, fire and rescue services would elicit all easily available and relevant available information from the building under analysis. This will clearly be of benefit to fire and rescue services and be used as part of their overall planning and firefighting strategies.

This study set out to investigate these two research questions. Firstly, to evidence how many fire hazards are typically observed during pre-incident planning visits. Secondly, whether the number of observable fire hazards seen during these visits could be improved by using a novel visual search behavioural algorithm known as

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systematic visual inspection. This method has already been successfully trialled and validated for use by environmental health and safety professionals in the food services sector (Hrymak & DeVries, 2020) and in aircraft maintenance pre-flight visual inspections (Hrymak & Codd, 2021).

In both of these studies, the overall number of observable hazards seen were increased as a result of using systematic visual inspection. This study therefore reports on the results of applying this visual search behavioural algorithm to pre-planning visits conducted by an Irish fire and rescues service.

1.1. Pre-incident planning

Pre-incident planning was first formalised in 1987 after a large warehouse fire in the US. The National Fire Protection Association (NFPA) and the insurance industry combined to issue recommendations on producing pre-incident plans (NFPA, 1620). The NFPA define a pre-incident plan as a “document developed by gathering general and detailed data that is used by responding personnel in effectively managing emergencies for the protection of occupants participants, personnel, property and the environment” Further detail on conducting pre-incident planning is given by Baker, (2011); Baker Bouchlaghem & Emmitt, (2013); Kapalo & LaViola (2019); and NFPA, (1620).

Pre-incident planning calls for the gathering of data on relevant building features including structural integrity, constructional detail, and any building management systems in the building under analysis. Such plans typically include occupancy characteristics, means of escape, the presence of any hazardous materials such as flammable or combustible materials, obstructed escape routes, smoke management systems, risers for extinguishing media, lift access, condition of internal linings and any unprotected openings allowing fire and smoke to spread.

The success of pre-incident planning in preventing injuries, fatalities and economic loss has also been reported. For example, a case study is presented in NFPA, (1620) which refers to a 2008 fire that occurred in a four storey residential care home for the elderly in Florida. A fire in this facility was reported to the fire and rescue service as being in the laundry room area. The first fire and rescue service to attend this fire had conducted a pre-incident planning visit to this residential care home. As a result, the attending fire and rescue service implemented their pre-incident plan and were quickly and successfully able to bring the fire under control. This was possible because part of the pre-incident plan involved firefighters accessing upper floors to see if smoke spread had reached residents. As this had not occurred, a defend in place strategy was adopted allowing residents to remain in the building whilst the fire was successfully tackled.

Evacuating a group of very vulnerable mobility impaired residents from a multi storey health care facility due to fire, is one of the most challenging fire and rescue operations to undertake (Manion, 2004). The pre-incident plan in this case was implemented and as a result, did not lead to the evacuation of the elderly residents. This was clearly a successful fire and rescue operation based on the pre-incident planning visual inspection conducted.

1.2. Not seeing observable fire hazards

A fundamental process that occurs every time any safety professional visits a premises to conduct any safety related inspection is a visual search. But there is little procedural guidance as to how this visual inspection should be conducted. As Woodcock, (2014) reports, the wider environmental health and safety community tend to regard inspections as either done or not done, with little regard to their accuracy.

However, the issue of not seeing observable hazards during inspections has long been known about and first reported in the literature in the 1930’s (Juran, 1935). Furthermore, there are numerous instances of when safety professionals, have visited premises to conduct risk assessments but have failed to observe hazards within the premises under analysis. For example, two judicially investigated fire related examples that evidence this issue are now presented.

The first example is detailed in a report by the United States Government Accountability Office (GAO, 2004). This statutory body investigated the role of fire surveyors who had inspected a number of nursing homes prior to fires that resulted in fatalities. They found that surveyors had missed observable hazards that had contributed to fire spread and subsequent fatalities. An example given in this report is that of inspections having missed ceiling openings from pipe work. These breaches in building compartmentation, allowed fire and smoke to spread from a kitchen to bedrooms above, thereby contributing to fatalities.

The second example is detailed by the Coroner's report into the Rosepark Nursing Home fire in Scotland that also resulted in fatalities (Lockhart, 2013). In this case, the Environmental Health and Safety professional who visited the premises prior to the fire, did not observe numerous fire hazards. For example, he failed to observe the inappropriate storage of flammable aerosol cans in an electrical cabinet that caused the fire. These two examples, clearly demonstrate the potential consequences of not observing fire hazards during visual inspections.

1.3. Systematic visual inspection

In order to improve the observation of fire hazards that can be seen by safety professionals during visual inspections, a recently trialled and validated method called systematic visual inspection (Hrymak & DeVries, 2020; Codd & Hrymak, 2021) was used in this study. Systematic visual inspection method consists of three key steps.

The first step is to break down the room or area under analysis into its constituent constructional elements being each individual wall, the ceiling and floor. The second step is to iteratively select a particular element for individual observation. The third step is to observe the entirety of the selected element by applying a visual eye scan pattern, that begins at the top left corner of the element and tracks to the right until the next element is reached. Visual search is then redirected to the left hand side of the element underneath the area already observed, and the process continued until the element has been fully searched.

A useful analogy to describe systematic visual search would be reading the element in the same way you would read a page of writing in a book. That is; starting at the top of the page and moving left to right until the whole page has been read. In effect, a visual overlay is imagined which guides an eye scan pattern across the element. In this manner systematic visual search will ensure the meticulous and exhaustive observation of the element under analysis, without missing any observable hazards present. A more detailed description of the systematic visual inspection method is given by Hrymak & deVries, (2020).

2. Methodology

A fire and rescue service in Ireland was recruited to participate in this study with a total of 22 fire fighters involved. The total number of pre-incident planning visits conducted for this study by this fire and rescue service was 21. All participants in this study were full time fire fighters with the requisite fire and rescue training. All participants had previous experience of conducting pre-incident planning visits. The mean years of fire and rescue service employment was 12.89 years (SD=8.25). Five of the fire fighters had five years or less in terms of employment. The remaining 19 fire fighters had between six and 33 years of employment. In short, this was an experienced group of fire fighters who participated.

The experimental design involved one of the fire crew being tasked with observing fire hazards using the novel systematic visual inspection method during his pre-incident planning visits, as detailed in section 1.3 above. In this manner, a direct comparison for the same premises was enabled between the fire fighter who used the systematic visual inspection, and those who used their normal visual inspection custom and practice. All these visits to apartment blocks were conducted during 2020. These buildings varied from three to six floors as shown in Table 1 below.

Table 1. Number of floors per apartment block

Number of Floors	Number of Buildings Visited
6	2
5	12
4	6
3	1

The fire fighter who used the systematic visual search method visited all 21 apartment blocks. During each of these visits he was accompanied by either two or three different fire fighters. All pre-incident visits to apartment blocks were unannounced. During these pre-incident planning visits, fire crews used their normal custom and practice in terms of how they conducted their visual inspections which included writing down the fire hazards they observed during their visits on standard issue forms. The author collated all these forms and data was inputted into Excel, office 2019 and SPSS v24 for subsequent analysis.

The fire crew member recruited to use systematic visual search was trained in its use by the author as part of this study and prior to the pre-incident planning visits used in this study. This training was conducted in one three hour session and included a demonstration. This participant was also very experienced and had 29 years of experience as a fire fighter. This particular fire fighter also conducted a pilot inspection on a building prior to the visits to the 21 apartment blocks. The experimental design was therefore correlational and set within a naturalistic framework with a high degree of ecological validity. In short, the data generated was from the normal day to day duties of experienced fire fighters. This data was then statistically compared with results from the fire fighter who used the systematic visual inspection method during his pre-incident planning visits to the same premises as his colleagues.

2.1. Limitations

This study does possess a high degree of ecological validity. This is due to the field data collected from fire crews observing and writing down fire hazards being a normative procedure during their pre-incident planning visits. However, there are a number of limitations when comparing these written accounts, to the data generated by the one fire fighter who used systematic visual inspection on the same premises. These limitations will now be detailed.

By using a visual search behavioural algorithm, the fire fighter who used this method may have been motivated to improve his performance relative to his colleagues. In contrast, the level of motivational effort from the remaining fire fighters was not known and they could have either under or overperformed in this study. These fire fighters may also have plagiarised their results. In addition, there was no opportunity to incorporate any inter-rater analysis for the study. Finally, the results assume that any observed fire hazards were consistently written down by all participants which may or may not have been the case. However, given the relatively high number of participants involved with a good degree of ecological validity, the data suggests reliability and validity were achieved to a large extent.

2.2. Categorisation of fire hazards

Table 2 below details observable fire hazards written by fire crews during their pre-incident visits grouped into two categories, high risk and the remaining hazards. The construct of high fire risk was created for analysis purposes for the fire and rescue service involved, rather than as a definitive statement and is subjectively defined as follows. This category consists of those hazards that fire and rescue services consider require an immediate intervention with building occupants and management. Such fire hazards are characterised by their potential ability for residents to be unaware of any fire starting, subsequently spreading, and or preventing escape.

The remaining observed fire hazards consisted of condition of escape routes, condition of active and passive fire protection equipment and other fire prevention measures. In short, these two categories ensured that the expected range of fire hazards within apartment blocks were considered using established pre-incident planning guidance as per NFPA, (1620). A full listing and explanation on all types of fire hazards typically found within residential accommodation can be found in for example; DCLG, 2006 and Todd, 2011.

Table 2. Brief description of fire hazards

Category	Description
High Risk Hazards	Faults with; Fire alarm panels Manual call points Emergency lighting Fire doors fire doors left open
All Other Hazards	Including; Combustibles in escape routes Damaged fire rated glazing Breached compartmentation Faulty risers, smoke venting units or shut off valves Electrical issues or smoking in common areas

3. Results

The number of fire hazards observed by fire crews per visit and using their normal custom and practice for visual inspection was 8.99 (SD = 4.44). In sharp contrast, the fire fighter who used systematic visual inspection search, observed a mean 28.62 fire hazards per visit (SD = 10.50).

In effect, just over three times the number of observable fire hazards were elicited by using systematic visual search during pre-incident planning visits, when compared to custom and practice visual inspection. A comparison between the number of high fire risk hazards found that the systematic visual inspection user observed a mean 2.44 times the number from the remaining 21 fire fighters (SD; 2.50). Both these results were highly significant when compared by an independent *t* test and also represented large effect sizes as measured by Cohen's "*d"* (Field, 2013).

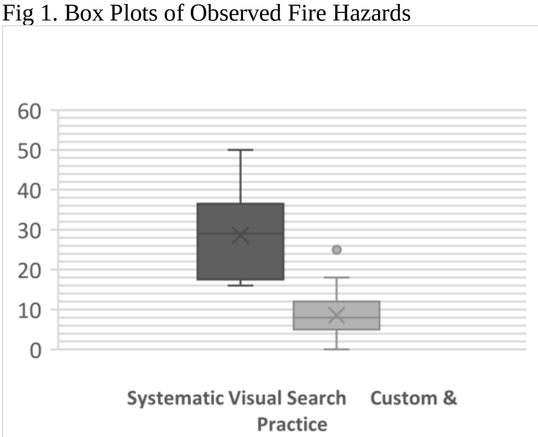
Table 3. Mean N observed hazards per visit.

	Systematic Visual Inspection	Other Fire Fighters	*p*	Cohen's *d*
All fire Hazards	28.62	8.99	<.001*	4.42
High risk	9.38	3.83	<.001*	2.22

*Using a Bonferroni correction (Field, 2013)

A graphical comparative representation of the effect of using systematic visual search is presented in the following box plots.

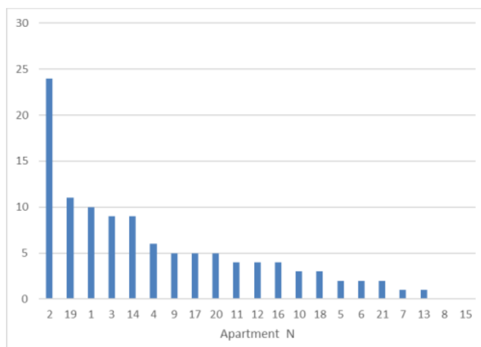
Fig 1. Box Plots of Observed Fire Hazards



A further noteworthy finding is the variability in observed hazards for the same building written down by fire fighters as seen in Fig, 2 below. In short, when examining the same apartment blocks, differing fire fighters observed differing numbers of fire hazards in 19 out of 21 buildings. The differences in the number of observed fire hazards for the same building ranged from no difference in two buildings, to one apartment block where one fire fighter observed 24 more fire hazards that his colleague visually inspecting the same building. The mean difference in the number of observable hazards between fire fighters for the same building was 5.24 (SD; 5.36). This distribution was not normal using a Shapiro Wilks test in SPSS (Field, 2013)

This result demonstrated fire fighter variability in terms of individually observed fire hazards. In short, other than for apartment blocks 8 and 15, any two fire fighters in the same building, observed a different number of fire hazards. This variability in visual inspection performance has been reported in the literature, (see for example Aust, 2022; Hrymak & DeVries, 2020; See, 2012.)

Fig 2. Difference in observed fire hazards per building



4. Discussion

There are three main findings from this study. The first is that there is now robust field based evidence that systematic visual inspection, can increase the observation of fire hazards during pre-incident planning visits. The rate of observation was found to be just over three times more, when using a visual search behavioural algorithm, compared to individual fire fighters using their normal visual inspection custom and practice.

Regarding the observation of a subjective sub-category; high risk fire hazards, the number observed using systematic visual inspection was again higher with just under two and half times more than normal custom and practice visual inspection (see Table 3 above). Although important, the number of fire hazards observed by fire fighter using their custom and practice visual inspection methods is not the primary consideration in terms of analysis. More importance is attached to this study demonstrating that the observation of fire hazards was significantly increased by using systematic visual inspection (p = <.001).

In addition, no clear pattern emerged of the systematic visual search user increasing observation of any particular fire hazard or category. Therefore, there were no specific fire hazard that emerged as more likely to be seen by the systematic visual search user when compared to his colleagues in this study. This supports the theory that systematic visual search promotes the exhaustive and meticulous observation for any selected area under analysis, rather than enabling attention to be better deployed to a particular hazard or category. In effect, the systematic visual search user in this study simply observed more fire hazards in overall terms than his colleagues, for the same building.

The results from this study are also consistent with previous research using the systematic visual search method (Hrymak & DeVries, 2020; Codd & Hrymak, 2021). These earlier studies also demonstrated a statistically significant improvement in the number of observed safety related hazards when adopting a behavioural visual search algorithm as exemplified by the systematic visual inspection method described in this study.

The second main finding is the number of observable fire hazards that were not seen by fire fighters using their custom and practice visual inspection methods during their pre-incident planning visits. This non-observation of hazards has long been known and visual inspection has been described an error prone task that is difficult to do well. (for examples see Biggs, Kramer & Mitroff, 2018; Biggs & Mitroff, 2014). This is because of the many and varied causes of observational error which are well detailed in the visual search literature (for examples see Eckstein, 2013; Hrymak & deVries, 2020; See, 2012).

Due to the visual psycho-physics related limitations we all possess and detailed by (for example, Biggs et al, 2014 & 2018), it is important to bear in mind that there is no implied critique whatsoever of the fire fighters in this study or by inference, the wider environmental health and safety community. Instead, this study demonstrates a method that can increase visual inspection performance and should not be considered as anything other than an attempt to improve current visual inspection conduct as well as closely related risk assessment and safety auditing practices.

Furthermore, the reliability of visual inspection conduct is of crucial importance during any inspection of buildings conducted for fire safety reasons. This is because of the detrimental effect of visual search failures by fire safety professionals, that has unfortunately and tragically been reported on under judicial conditions (GAO, 2004; Lockhart, 2013)

The third and perhaps most important result from this study relates to extrapolating these results. The potential variability in observable fire hazards being recorded by fire crews will be a matter of concern from pre-incident planning perspective. Furthermore, if these finding generalise to the wider fire and rescue community then it raises an important issue that needs addressing which is; how exactly should visual inspections be conducted, when one of the primary role of pre-incident planning visits is to identify fire hazards in any given premises under analysis (Baker, 2011; Baker et al. 2013; NFPA, 1620; Kapalo & LaViola 2019).

There is a degree proceduralisation for the visual inspection of buildings published by the UK based Royal Institute of Chartered Surveyors (Hollis, 2000; RICS, 2002; RICS, 2010; Reddin, 2016). It should be noted that this guidance is incorporated and has been further refined by the systematic visual search method, with the addition of a suggested specific eye scan pattern as described in this study.

A final point is to briefly discuss the role of checklists and whether they could be used to assist in the observation of fire hazards during pre-incident planning visits. As reported in Hrymak & DeVries, 2020 checklists are ubiquitous in the wider environmental health and safety community. However, the evidence from this study does not support the use of any additional checklists by fire fighters for pre-incident planning visits. This is because the forms used by the fire fighters to record their observed hazards during visits, are already similar in design to many checklists currently available. The forms used in this study consisted of specific fire hazards and categories that were presented as headings to be detailed during visits such as; locked final exits, fire doors in dis-repair or combustible materials in escape routes. In effect, the fire fighters in this study were already using paperwork similar to checklists for the recording of observed fire hazards.

In summary, the evidence from this study strongly supports the adoption of a visual search behavioural algorithm as demonstrated by the systematic visual inspection paradigm detailed in this study.

5. Conclusion

This study has once again, reiterated the idea that visual inspection, due to cognitive limitations we all possess as humans, is an error prone task that is difficult to do well. Therefore, it should be no surprise to consider that differing fire crews observe differing fire hazards within the same building. It is also reassuring to note that the multiplicity of fire fighters visually inspecting buildings will compensate for certain individuals not observing all fire hazards during their pre-incident planning visits.

Nevertheless, the number of observable hazards seen by fire crews during familiarisation visits can be increased by using systematic visual search as described in this study. In doing so, fire and rescue services can improve their operational effectiveness due to increased reliability and visual search performance, for observable fire hazards within buildings visited.

Further research is also required not only to maximise the observation of fire hazards, but to suggest the proceduralisation of the visual inspection process. If this can be achieved, then not only will fire fighters observe more fire hazards during their pre-incident planning visits, but they can do so in a consistent manner so that individual fire fighters can increase their comparability whenever and wherever they conduct their visual inspections.

In addition, systematic visual inspection is an easily learned transferable skill. There does not appear to be any reason why this method cannot be used whenever visual inspections are conducted for risk assessment, risk management or safety auditing purpose by environmental health and safety professionals.

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