Towards Compliance-based inspection modeling

Ana Calderon* and Simon Parkinson**

*acalderon@cardiffmet.ac.uk
Department of Computer Science, Cardiff School of Technology, Cardiff Metropolitan University
biographical statement
Dr Ana Calderon is a senior lecturer in Computing at Cardiff Metropolitan University, with a background in mathematical computer science, and in particular expertise in game semantics for programming languages and on developing new frameworks to model programming paradigms. She is interested in creating mathematical tools for modelling computing concepts, but also in applying them to real-world problems.

**sparkinson@hud.ac.uk
Department of Computer Science, University of Huddersfield, HD1 3DH
biographical statement
Simon Parkinson is a Reader (Associate Professor) in the Department of Computer Science at the University of Huddersfield and is leading the Centre for Cyber Security. Parkinson's research interest is in the intersection between Computer Security and Artificial Intelligence. This includes undertaking research in biometric authentication systems and access control policy analysis. He has authored numerous papers on these topics as well as other cross-discipline applications of artificial intelligence, where he has a special interest in Automated Planning.

ABSTRACT

We propose to move towards a risk-profiling approach to determine inspection strategies, with the aim of targeting audit of buildings that have a higher chance of being problematic. Historical data suggests that compliance of responsible persons (those in charge of ensuring fire safety at a particular dwelling) is an important factor in likelihood of danger, but it is presently overlooked in inspection models. With the goal of incorporating compliance in decisions of what and when to inspect, we construct game theoretic models for inspections, encompassing compliance likelihood of responsible persons. The (action-based) game theoretic representations serve to enable the construction of combinatorial optimization algorithms (algorithms for finding the optimal solution to problems where exhaustive searches are an impossibility), *capable of deliberative search to identify optimal sequences of inspections. This paper presents a case study on Compliance, some statistical findings, then followed by the conceptual game-theoretical modeling.*

Keywords: South Wales Fire and Rescue Service, Game Theory, Fire Inspection, Compliance-based inspections, Compliance, Automatic Planning Techniques, Fire and Rescue, Fire Regulations, Decision-making, Reducing Fire Risk,

Please include a list of 8-15 keywords that figure prominently in your article. These words should include important vocabulary, names of people, and names of organizations, primarily.

These terms will be included to generate the index for the book. Please do not include words that are part of the book title or article title. Each word should be capitalized.

INTRODUCTION AND LITERATURE REVIEW

Scientific backround and motivation

Targeted and thorough inspections are essential for preventing fires and tragedies such as those recently witnessed by the Grenfell Tower fire, London, 2017. Only by inspections it is possible to identify potential hazards and non-compliance of regulations that could lead to fires, causing damage to, or loss of, property and life. At present, inspection strategies are constructed mainly based on engineering considerations of buildings, overlooking compliance issues. There is a significant risk that a fire could happen in structures not typically identified as at risk and therefore not inspected.

The work proposed here aims at enhancing fire inspection policy through the use computational intelligence. To this end, we will investigate how to add the compliance of responsible persons[1] to computational models tasked with determining inspection strategies for dwellings, including those currently under construction.

Fire inspections take place in both residential and commercial dwellings to ensure that they comply with legislation and general best practice, minimising the risk of a fire occurring and damage, including the loss of life, should a fire occur. Fire inspectors are in short supply and they often develop an inspection strategy detailing which buildings to inspect first based on their knowledge and expertise. Due to the volume and variety of decision criteria to consider (properties most at risk, habitants most at risk, time required, etc.), deriving a strategy is a challenging task for human cognition. This often results in strategies for fire inspection being tackled nearly uni-dimensionally, collapsing a number of important issues into a single measurable component. This is done for practical reasons; however, it can lead to significant factors being overlooked, something which is heightened by the continuous financial squeeze on Fire Service resources. This paper aims to begin work towards a comprehensive approach to generating inspection schedules, by focusing on the development of the mathematical structures

1 Information about what duties the responsible person must carry out are detailed in https://www.gov.uk/workplace-fire-safety-your-responsibilities/who-is-responsible

required for modelling inspection strategies, in a manner that could be ultimately used in the implementation of a system capable of generating optimal inspections plans, where optimality can be measured in terms of the best use of the Fire Inspectors' time against the properties deemed to be most at risk.

The process of fire inspection is truly a globally adopted process to reduce fire risk. One recent and key work in the area of applying computational intelligence was performed by a US based collaboration, including the Atlanta Fire Rescue Department [Madaio 2016]. In their work, they used historic data to develop a predictive model based on unsupervised machine learning techniques (SVM, Random Forest), achieving a 71% in predicting fire risk scores on 5,000 buildings. One key limitation of their research is that their research lists properties that require inspection, but does not consider prioritisation of which to visit when insufficient resources are available. This is particularly important to this project, due to budgetary pressures as highlighted by SWFRS.

A significant challenge exists when trying to develop or use a generalised optimisation solution as conflicts will inevitably arise and need to be resolved. One possible solution (which we will present later in the paper) is that of Game theory (GT), which is an established research discipline with decades of research having been dedicated mainly to the application areas of economics and security. GT enables the creation of mathematical models of both conflict and cooperation amongst (rational) agents, and abstracts the decision-making process in mathematical terms. The strength of GT as a mathematical framework comes from its flexibility and ability to provide an accurate way to describe real-world situations. However, malleability is also where most of the scientific challenges in providing games models lies when one needs to narrow down to the correct formalism. GT has been used in scheduling for a variety of applications, including spotting Poachers [Bondi 2018] and multi-event scheduling [Maheswaran 2004].

We highlight that effective approaches have been demonstrated in applying game theoretic studies to facilitate automated planning [Li 2008]. Multiple mechanisms of autonomous deliberation exist; however, the one likely to be exploited in this proposal is that of domain-independent Automated Planning (AP), a rapidly increasing research community area with an increasing uptake of real-world applications. Domain-independent AP algorithms perform deliberation to provide plans of how to solve a problem with the specification of an initial state, goal state, and a set domain-specific actions [Ghallab 04]. AP is well suited to the process of modelling and automating fire inspections, and previous work has demonstrated promising results in application areas with similar challenges, such as crime prevention [Monchuk 19]. However, previous applications are focused on a single agent approach with a single optimisation objective, and in our work, we move towards the ability to perform multi-objective optimisation based on developed GT modelling techniques.

Real world background and motivation

Evidence [Department for Communities and Local Government 2013] suggest that performing comprehensive risk profiling prior to deciding on a fire inspection strategy can reduce risk considerably. However, it is still the case that the majority of fire incidents attended by fire and rescue services occurred in buildings that would not ordinarily have been identified as at risk and therefore would not have attracted any attention or audit (Data gathered between 2010 and 2015). For SWFRS in particular, that was the case for 78% of responded incidents between 2010-15. From an applicability perspective, the hypothesis (based on the expertise of fire inspectors and the SWFRS headquarters) is that compliance of responsible persons is an important metric in determining likelihood of fire.

Statistical data [Fire Statistics 2013] suggests that most fires are accidental, and therefore enhanced strategies that focus on compliance (whilst not neglecting structural considerations of the buildings) can have a big impact in reducing the incidence of fires. Furthermore, it is observed that the Chief Fire Officers Association (CFOA) estimates that one of the impacts in funds reduction and budget cuts has led to a 30% reduction in audits and inspections and a 27% reduction in personnel hours spent on fire safety checks carried out by fire and rescue authorities [Department for Communities 2013]. The impact of such budget cuts can be minimised through the use of more efficient schedules, with greater predicative power.

The economic and human impact of disasters such as the recently observed Grenfell Tower fire is evident. A recent parliamentary update (November 2018) [Brokenshire 2018] highlights monetary commitments to victim support of £80 million for bereaved and survivors, including rehousing and mental health services costs. Furthermore, NHS England announced it will provide up to £50 million towards funding long term mental and physical health checks and treatments to those affected.

Our aim is to systematically evaluate and develop models of inspector-inspectee games that incorporates compliance shaped to suit the needs of SWFRS. This will result in focused inspections, decreasing personnel and resource pressures through targeting buildings that are most at risk

COMPLIANCE INSPECTION: A CASE STUDY

Between 2018 and 2019 (data downloaded 25th of September 2019) out of 29,570 fires attended in dwellings, 26,610 were accidental [Gov 2019]. In this section, a case study is presented where the lack of compliance resulted in a serious fire incident within the region under the remit of South Wales Fire & Rescue Service (henceforth SWFRS). The case study demonstrates the impact of non-compliance. The presented case study is named “Lack of Compliance with The Regulatory Reform (Fire Safety) Order 2005” by SWFRS. Key people, locations and fire crews were anonymised by SWFRS since, at the time of analysis the case studies, it was still going through judiciary procedures. Before the case study is presented, a background on regulation and process is provided.

BACKGROUND AND EXPLANATION OF THE REGULATORY REFORM ORDER 2005:

The Regulatory Reform (Fire Safety) Order 2005 requires a responsible person to carry out "suitable and sufficient" assessment of the risk from fire, as part of Fire Risk Assessments (FRAs). Determining what must be assessed to meet that requirement depends on the risks in each building. In some cases, an assessment of the common parts is sufficient, in others a destructive assessment of parts of the building is needed, but rarely executed. FRAs are applicable in offices and shops, care providers (including care homes and hospitals), community halls, places of worship and other community premises, the shared areas of properties several households live in (housing laws may also apply), pubs, clubs and restaurants, schools and sports centres, tents and marquees, hotels and hostels, and factories and warehouses; but not dwellings. Assessing the quality of the FRAs is the responsibility of the Fire and Rescue Service (FRS) of which there are 45 in the UK. Fire Safety Inspectors from the relevant FRS undertake Fire Risk Audits (FRAuds). The audit is an examination of the premises and relevant documents to ascertain how the premises are being managed regarding fire safety. Due to the complexity of buildings and the variety of things to consider when undertaking FRAuds, such as building users most at risk, the time required for undertaking the work, and the reduced resources of the FRS, deriving a strategy is a challenging task for human cognition. This often results in strategies for FRAuds being tackled as a one-dimension problem, collapsing a number of important issues into a single measurable component. This is done for practical reasons; however, it can lead to significant factors being overlooked, something which is heightened by the continuous squeeze on FRS resources, across the UK. This paper proposes an approach to generating FRAuds inspection schedules, by focusing on the development of the mathematical structures required for modelling FRAuds inspection strategies. Our aim is to help ensure that significant catastrophes such as that of the recent Grenfell Tower are not repeated.

Case Study

Location: The Company (A premises)

Cause: The fire was caused by a clothing rail being placed close to an electrical heater.

Operational fire crews: from A, C, B, D, and attended the scene and extinguished the fire.

Road Closures and evacuations: A large section of R Road, A was closed for the majority of the day, and a number of adjacent premises had to be evacuated. T

Previous inspections: An inspection of the A premises was carried out by Watch Manager, with a number of contraventions of the Regulatory Reform (Fire Safety) Order 2005 ("the Order") being discovered.

The concerns from this inspection led to another inspection of other The Company stores at ("the M premises") and ("the B premises"). Further contraventions of the Order were discovered at both the M premises and the B premises.

Compliance: The Regulatory Reform (Fire Safety) Order 2005 came into force on the 1 October 2006, and applies to a range of non-domestic premises, including premises of the type operated by in A, M and B. The Order is designed to provide a minimum fire safety standard in most non-domestic premises. The Responsible Person (or a person acting on their behalf) is required to carry out certain fire safety duties, which include ensuring that general fire precautions are satisfactory, and conducting a fire risk assessment, in order to protect relevant Persons[2] in case of fire. The Order requires that fire precautions are put in place "where necessary", and to the extent that it is reasonable and practicable in the circumstances. The Order provides that responsibility for complying with its requirements rests with the "Responsible Person". In the case of a workplace (as is the case here), the Responsible Person is the employer, and any other person who may have control of any part of the premises. In this instance, the employer was The Company Limited. The Company Limited therefore had to ensure that any duties imposed by Articles 8 to 22 of the Order (the "Fire Safety Duties") were complied with. Being the employer, this was an absolute duty, with strict liability imposed under the Order.

In order for an offence to be committed under the Order, there must be a contravention of a fire safety duty to sufficient extent so as to cause a risk of death or serious injury to one or more relevant persons. A failure to adhere to a fire safety duty but which does not putrelevant persons at risk of death or serious injury does not, therefore, constitute an offence under the Order. The Crown's case is that The Company Limited committed a significant number of offences under the Order, since each of the contraventions which form the subject matter of these proceedings put one or more relevant persons at risk of death or serious injury.

Fire incident:

Location: The premises form part of a terrace on R Road, A, and are two stories in [redacted] height. The upstairs at the premises was not occupied

On the morning of the [redacted] , [redacted] , then (but no longer) an employee of The Company Limited, arrived at the A premises at 8:50am. When she arrived, she found the door shutters up, and the store illuminated. She described this as unusual, since the premises were usually locked with the shutters down and all lights turned off. She telephoned Defendant B, who explained that he had

2 "Relevant Persons" is defined in the Order as "*any person … who is, or may be lawfully on the premises; and any person in the immediate vicinity of the premises who is at risk from a fire on the premises*".

been at the store at around 6am before departing for [redacted]. X entered the premises, and observed the inside of the shop to be warm, observing that a portable electric heater had been turned on.

There were, in fact, four heaters in the shop, one by the till, one in the middle of the shop, and two in the vicinity of the changing rooms at the rear of the store. No other facilities for heating were installed. X's evidence is that the heaters were always located near to clothing. She had been concerned about this, but had been told that the heaters needed to be on. She describes always being conscious of their positioning. In her evidence, she also refers to her view that these heaters were a risk to customers as they walked around the store, and she recalled an occasion around [redacted] when a child knocked over one of the heaters, but was uninjured and no damage occurred.

Before commencing her duties on the morning of [redacted], X turned on the remaining heaters. At around 10:00am, X moved a full rail of clothing from the rear of the store out to the pavement at the front of the store, as she had been instructed to do by Defendant B. In doing so, she had to drag the rail past two of the electric heaters. Owing the amount to stock in the shop, X described the route through the store as very narrow, and the clothes on the rail brushed the stock hanging out in the store.

Having placed the rail outside on the pavement, X returned into the store and stood behind the sales counter. She estimates that around five to ten minutes later, she looked towards the rear of the shop and saw thick, black smoke in the vicinity of one of the heaters at the rear of the store, concentrated against the wall and up to the ceiling. She described not having smelt or otherwise being alerted to the fire before she saw it.

On closer inspection, X observed that a rail of dresses (in the vicinity of one of the heaters) had ignited. She began to look for a fire extinguisher in order to tackle the fire, but could not locate one, recalling that she had not previously seen any at the store. She returned to the front of the store in order to call the Fire Service from the shop telephone. By this time, the fire had begun to quickly develop. Whilst X was on the telephone to the 999 operator, the store's power cut out. She therefore grabbed her handbag and mobile telephone and left through the front entrance, resuming her call to the emergency services. As she left the premises, she could see that the fire had developed into the middle of the store, and had also spread further back towards the rear.

After telephoning the emergency services, X telephoned Defendant B. Having been told that there had been a fire at the store, M evidence is that he said to her "don't tell the fire brigade about the heaters". Defendant B arrived around one and a half hours to two hours later, and upon arrival, X describes him as being unconcerned as to her welfare. X did not seek medical assistance, and was uninjured.

The operational fire crew that tackled and extinguished the fire at the premises was concerned about the fire safety arrangements. Consequently, SWFR's Business Fire Safety team was contacted and, later that afternoon, a fire safety investigation was undertaken at the premises by Watch Manager [redacted] and Station Manager [redacted] . During the course of the investigation, a total of 28 images were taken at the premises, a selection of which appear as Exhibits.

During the inspection, a number of contraventions of the fire safety duties set out in the Order were discovered, which were also considered to be offence under the Order as the failures in question would have put relevant persons at risk of death or serious injury. The following contraventions were discovered:

a. the escape route which served the rear of the premises could not be used as quickly and safely as possible, as a gate was secured with a padlock, and the final rear exit door was screwed shut.

b. the premises were not equipped with the appropriate fire detectors and alarms

c. the premises were not equipped with appropriate fire-fighting equipment.

Inspections

Inspections of the M and B premises:

Consequent to his inspection of the A premises, Watch Manager [redacted] determined that The Company Limited operated other premises at M and B. Given the contraventions and offences discovered at the A premises, it was determined both necessary and appropriate to carry out inspections of the M and B premises.

On [redacted] (the day immediately following the fire in A), Watch Manager attended the M Premises, which is three storeys in height. The Company Limited occupied the ground floor only – the remaining floors were unoccupied offices.

Watch Manager asked to see a copy of the fire risk assessment for the premises, but [redacted] was unable to produce one, stating that they did not know if one had been completed. [redacted] also confirmed that they had not received any fire safety training, or any instructions on the procedures to be followed in the event of a fire.

The failure to provide any staff training clearly placed employees and other relevant persons on the premises at risk of death or serious injury in the event of a fire.

Watch Manager [redacted] (accompanied by Station Manager [redacted]) then commenced a physical inspection of the premises. During the course of the inspection, the following contraventions are discovered:

a. the rear corridor and escape route to the emergency exit which served the rear of the premises was obstructed by a large amount of combustible materials in the form of crates, bags and shelving.

b. the escape route which served the rear of the premises had a door which was jammed shut

c. firefighting equipment provided for the premises was not subject to a suitable system of maintenance and note maintained in an efficient state, in efficient working order and in good repair

d. a number of portable type heaters were being stored in close proximity to combustible items, creating the risk of fire

On the 14 March 2014, Watch Manager [redacted] attended again at the M premises, where the purpose of the visit was to establish whether remedial work had been carried out to make the rear fire exit available. The rear corridor had been cleared, and the rear door could be opened, but was in need of further maintenance. Defendant B confirmed that a fire risk assessment had not been carried out in relation to the premises.

Later on the 14 March 2014, Watch Manager [redacted] and Station Manager conducted an inspection of the B premises. The premises are four storeys height, all of which were occupied by The Company Limited.

Watch Manager [redacted] (accompanied by Station Manager) then commenced a physical inspection of the premises. During the course of the inspection, the following contraventions are discovered:

a. the final exit doors leading from the ground and first floor of the premises, which gave egress to the rear fire escape were only available with the use of a key which was not immediately available, thus preventing persons from easily and immediately opening the doors in an emergency

b. the rear fire escape was not maintained in good repair as there were holes in the tread plate and it was rusty.

c. the fire warning and detection system provided for the premises was not subject to a suitable system of maintenance and not maintained in an efficient state, in efficient working order and in good repair.

d. the fire-fighting equipment provided for the premises was not subject to a suitable system of maintenance and not maintained in an efficient state, in efficient working order and in good repair.

In respect of the fire safety deficiencies identified at the M and B premises, Enforcement Notices were served.

Post-inspection investigation

SWFR's Compliance Team is charged with investigating alleged offences under the Order. The case was therefore passed to Station Manager [redacted] to investigate. On the [redacted] Station Manager wrote to The Company Limited at its registered address, requesting certain information in respect of the A premises. This was followed by two letters on the 19 August 2014 in respect of the M and B premises

Under cover of three letters, Defendant A responded to [redacted] Station Manager letters, the content of which confirmed that:

a. no fire risk assessments existed in respect of the A, M and B premises as at the [redacted] ;

b. no documentation was available relating to the maintenance or testing of fire precautions for the period in question for any of the premises;

c. no paperwork was available pertaining to the fire safety training of employees for the period in question.

Conclusion of Case Study

This case study demonstrates significant risk to life and property due to fire safety neglect; and highlights the importance of inspection in preventing fires such as the one outlined. In particular, it serves to demonstrate how a lack of compliance with fire safety regulations exacerbated the fire incident and why it is important to include compliance in considerations of inspection strategies.

Conceptual Model

The formation and acquisition of models will enable a robust mechanism to strategise if a premises should be inspected. However, in the practical application of optimising visit schedules, many other factors need to be considered. More specifically, there are many exogenous and endogenous events that occur in the environment that need to be considered. `The world' can be modelled in terms of abstract symbolic knowledge, represented as first-order logic statements. To justify the use and research of autonomous deliberation techniques in this application, the following high-level preliminary system is described:

The inspector needs to decide whether to inspect or not based on previous behaviour, and the strategies must contain considerations of proximities between inspection sites. In making the decision to inspect or not, the *inspector* will know the previous behaviour of the *inspectee*, which contains also violation strategies. Our framework was built using Games Theory techniques, and the main definitions are given below:

S is the set of states, consisting of a pair *(l,t)* where *l* is the building and *t* is the time. Location *l* can be subdivide into sub-locations, such as apartments.

A is the set of actions and *a(s)* is the set of actions present in state *s*.

E is the set of entities, i.e., the responsible persons.

N is the set of rules that need to be abided by each entity.

We define a partial function $c: E \rightarrow [0,1]$, where $c_{j(e)} \in [0,1]$ is the probability of compliance for each rule $j \in N$, by entity *e*, since likeliness to engage in risky behaviour varies amongst entities.

We also need compliance observations $o_{\{t,j\}} \in \{-1,0,1\}$ where -1 indicates non-compliance of rule *j* in time interval *t*, 0 no observation, and 1 compliance.

We take discrete time intervals in a set *T*, and at each interval each entity either complies or not to each of the rules in *N* (so there are potentially several violations) and penalties will be modeled as a vector. We need to incorporate the incremental penalties for failure to comply, as well as how differing levels; for instance, for failures to comply with the requirements imposed by an enforcement notice or prohibition notice, the maximum penalty on summary conviction (in the Magistrates' Courts) is unlimited based on turnover. On conviction on indictment (in the Crown Court), the maximum penalty is an unlimited fine and/or two years' imprisonment.

Inspection history is known, and the result of the inspections in the last *t* time intervals is given by $insp_i = (\alpha(t-1),....,\alpha(t-l))$, where $\alpha(i)$ is a positive integer, indicates compliance, so it is a function $\alpha(i) = 0,n,m$ for non-inspection, lack of compliance, and compliance respectively. $1 \leq l \leq t$. A utility function would intuitively provide, where *u(i,t)* is read as the utility of RP *i* and time interval *t* :

$$u(i, t) = \Sigma_j \left(\max_i \left(c_{i,j}(t)\, \pi_{i,j}(t) \cdot k_j \right)\right)$$

$\pi_{i,j}(t)$ is the expected punishment that entity i suffers for violating rule *j* at time *t*. $c_{i,j}(t)$ is a measure of how likely entity *i* is to violate rule *j* at time *t*, and k_j is a fine.

i is an RP,

Application Example

Note: This example is theoretical in that it does not correspond exactly to a previous inspection; however, the partial list was obtained from [Minnesota 2019], so it was generated by a real world example fire inspection.

Suppose fire inspectors are inspecting a building of 16 apartments called 16 Towers. They are looking for, amongst other things:

- *Fire lanes are marked and unobstructed;*
- *The address is visible;*
- *The fire hydrants/water supply accessible;*
- *Combustible accumulations/storage acceptable;*
- *Fire Department key box present/maintained;*
- *Fire Department connections visible/maintained;*
- *Gas meter/piping protected against impact; and*
- *Dumpsters are outside and 5 ft. or more from combustible walls, openings or combustible roof eave lines.*

In this example each set specified in the model would be defined as follows:

The S is the set of all states consisting of pairs (16Towers, t) where t is the time, and 16Towers is the building. When we need to specify apartments, say A-P, the model, through the usage of the sub-locations, allows for this. For instance, if an inspector is inspecting apartment A after 2 minutes into the inspection, this would be modelled as $(16Towers_A, 2min)$.

The set, A, of actions would then consist of all the inspection checks required in the rule list above, labelled $a_1, \ldots, a_8$. *For instance, an element of the set might be* $a_3(16Towers_A, 2min)$ *to signify that an inspector is checking that the fire hydrants and water supply are accessible in apartment number A of the tower block, and has been conducting the inspection for 2 minutes.*

The set of entities E in this case would be the landlord of the building, or building management company in charge with ensuring fire safety regulations are obeyed.

The partial function $c: E \rightarrow [0,1]$, then just gives probability of compliance $c_{j(e)} \in [0,1]$ is the probability of compliance for each rule $j \in N$ *and each entity.*

For an example on how the compliance observations would be modelled suppose that the rule that *F.D. key box present/maintained is noted to be broken in the inspection at 6minutes and 30seconds; this would be written as* $o_{\{6:30,5\}} = -1$. *If the rule that F.D. connections* *visible/maintained was not observed during the whole inspection, supposing it took 30minutes, then this would be recorded as* $o_{\{30,6\}} = 0$.

Relating the Conceptual Model and the Case Study

We will now demonstrate how the definitions given in the Conceptual Model section relate to the case study investigated. This section aims to place the model in context and provide an explanation for the rationale behind choosing the different components of the model (so these are justified in context). To facilitate this aim, we first break down the inspection strategy by focusing on the elements we wish to capture, namely:

- The premises are four storeys height, all of which were occupied by The Company Limited.
- a physical inspection of the premises was conducted
- all inspection checks (all possible actions to be taken by inspectors)
- During the course of the inspection, the four contraventions detailed in the Case Study section were discovered (a-d).

The model is thus applied as follows:

The S is the set of all states consisting of pairs (PremiseB, t) where t is the time, and PremiseB is the building as specified in the Case Study. Clearly, unlike the previous example, there is no need to specify sub-locations such as in this case, though as already highlighted in the application example the model does allow for this.

The set, A, of actions would then consist of all the inspection checks required in the rule list used by inspectors (which consists of several pages, and is known to inspectors), we would label the actions labelled a_1, , a_n, *for a large but finite n. For illustrative purposes we can focus on the four actions taken in the case study and label them as* a_1,… , a_4. *To save the reader from scrolling back, we'll re-state them now, adding the labels:*

a_1 check the exit doors leading from the ground and first floor of the premises;

a_2 check the rear fire escape;

a_3 check the fire warning and detection system provided for the premises; and

a_4 check the fire-fighting equipment provided for the premises.

Now, for example, an element of the set might be a_2(PremiseB,5min) to signify that an inspector is checking the rear fire escape and has been conducting the inspection for 5 minutes.

The set of entities E in this case would be the landlord of the building or building management company in charge with ensuring fire safety regulations are obeyed.

The partial function $c: E \rightarrow [0,1]$, then just gives probability of compliance $c_{j(e)} \in [0,1]$ *i*s the probability of compliance for each rule $j \in N$ *and each entity. The compliance observations are then modelled in a manner similar to the application example.*

CONCLUSION AND FUTURE WORK

Performing risk inspections to establish fire compliance is an important aspect of minimizing fire risk, protecting assets and human life. By enhancing inspections, we can ensure that people responsible for fire safety remain or become compliant, as well as reducing the likelihood of fires. As recently witnessed, fires such as that which occurred in the Grenfell Tower (London) have far reaching consequences. In this particular case, 72 human lives were lost, and 223 people escaped but lost their homes. Further, the economic cost is also evident; for example, the government committed over £80 million for victim support following the Grenfell fire. The work carried out in this project aims to minimise the likelihood of such events, saving lives and preventing the psychological trauma inflicted on those who survive it. The South Wales Fire and Rescue Services (SWFRS) inspect around 1000 buildings each year, including venues such as shopping malls or concert venues temporarily gathering thousands of people, so the potential for saving lives is tremendous.

Future work will involve the application of simulation data sets, to autonomous deliberation techniques to find optimal inspection strategies. Using simulation and mathematical foundations to further investigate forms of knowledge acquisition, learning, and methods for domain model representation. This will involve the creation of a software tool to provide a user interface to the developed models. The tool will allow editing and updating of domain models, which will be possible through direct modification of the domain model as new decision criteria is developed and also through learning from historic plans. The latter mechanism will allow the user to input previous inspection strategies and the tool will adapt and use domain learning technology to identify decision patterns [Gregory et al. 15].

The formation and acquisition of inspection models we highlighted enables the application of automated deliberation techniques to provide optimal inspection strategies. For example, Games Theory and Automated Planning are both branches of Artificial Intelligence dealing with automated deliberation. The aim of an AP system is to progress from an initial state to a goal state where the required premises have been inspected. In pursuing the goal, a state-transition system is used, which consists of a set of actions. A solution from the AP system is a valid inspection strategy, which is an ordered sequence of planned actions. There are many search algorithms capable of identifying optimal solutions for action-based problems that are planning based [Ghallab et al. 2004]. However, each algorithm and implementation performs better on problems with different characteristics (numeric, temporal, etc.) [Coles et al. 2012]. The models established in paper will be used by a wide array of techniques that are capable of solving decision-based problems (e.g., machine learning, planning and scheduling algorithms, games theory, etc.).

We also plan the development of a simulation environment to incorporate autonomous behaviour in order to demonstrate decision making capabilities for the end-user. This will be systematically and impartially tested and verified, by stakeholders within the core project team, as well as new Fire services.

Acknowledgements

Our deepest gratitude to the South Wales Fire and Rescue Service for their input in this work, we are also very grateful to the anonymous referees who have greatly improved the quality of the paper.

REFERENCES

Bondi, E., Fang, F., Hamilton, M., Kar, D., Dmello, D., Choi, J., ... & Nevatia, R. (2018, April). Spot poachers in action: Augmenting conservation drones with automatic detection in near real time. In *Thirty-Second AAAI Conference on Artificial Intelligence*.

Coles, A., Coles, A., Olaya, A. G., Jiménez, S., López, C. L., Sanner, S., & Yoon, S. (2012). A survey of the seventh international planning competition. *AI Magazine*, *33*(1), 83-88.

Brokenshire, J. (Secretary of State for Housing and Local Government). Communities. A parliamentary update on update on the government's on-going work in response Grenfell, 2018. 29-November-2018.

Department for Communities and Local Government. Bfs risk analysis and trend emergence position paper. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/456652/Fire_
Statistics_Great_Britain_2013-14___PDF_Version_.pdf , November 2015.

Fire statistics. Great britain. Department for Communities and Local Government. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/456652/Fire_
Statistics_Great_Britain_2013-14___PDF_Version_.pdf , 2014. Online; accessed 5-May-2017.
Local government report by the Comptroller and Auditor General. Impact of funding reductions on fire and rescue services. https://www.nao.org.uk/wp-content/uploads/2015/11/
Impact-of-funding-reductions-on-fire-and-rescue-services-summary-A.pdf , 2015.

Ghallab, M., Nau, D., & Traverso, P. (2004). *Automated Planning: theory and practice*. Elsevier.

Gov 2019 (retrieved 25th of September 2019) https://www.gov.uk/government/statistical-data-sets/fire-statistics-data-tables#dwelling-fires-attended.

Li, W. D., Gao, L., Li, X. Y., & Guo, Y. (2008, April). Game theory-based cooperation of process planning and scheduling. In *2008 12th International Conference on Computer Supported Cooperative Work in Design* (pp. 841-845). IEEE.

Madaio, M., Chen, S. T., Haimson, O. L., Zhang, W., Cheng, X., Hinds-Aldrich, M., ... & Dilkina, B. (2016, August). Firebird: Predicting fire risk and prioritizing fire inspections in atlanta. In *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* (pp. 185-194). ACM.

Maheswaran, R. T., Tambe, M., Bowring, E., Pearce, J. P., & Varakantham, P. (2004, July). Taking DCOP to the real world: Efficient complete solutions for distributed multi-event scheduling. In *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems-Volume 1* (pp. 310-317). IEEE Computer Society.

Minnesota Department of Public Safety 2019. Retrieved 28th October, 2019. https://dps.mn.gov/divisions/sfm/fire-code/Pages/sample-inspection-checklists.aspx

Monchuk, L., Parkinson, S., & Kitchen, J. (2019, July). Towards Automating Crime Prevention through Environmental Design (CPTED) Analysis to Predict Burglary. In *Proceedings of the International Conference on Automated Planning and Scheduling* (Vol. 29, No. 1, pp. 539-547).