Agent Based Modelling Simulations to support Security Risk Management: Active Shooter Scenario

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Abstract

Mitigating the impact of Active Shooter incidents is of the utmost importance. These tragic events not only claim innocent lives but also instil fear and can ultimately disrupt social fabric. The developed model seeks to support Security Experts decision making while performing the Risk Management cycle during the Assessment and Mitigations stages by using Problem-Solving Agents to simulate the threat environment and determine the threat scenario impact over the exposed resources. Based on simulation results, the model proposes and configures security measures based on their relevance for the specific threat scenario under scrutiny. The Agents behaviour during the generated simulations are similar to the behaviour observed in footages of Active Shooter Incidents and the generated security measure implementation are coherent with the Security industry best practices and recommendations emitted by post active shooter incident committee boards. The authors advocate the relevance of the use of Problem-Solving Agents to improve the tractability of Security Risk Management.

Keywords: Security Risk Management, Simulation, Active Shooter, Problem-Solving Agents, Agent Based Modelling

Título: Simulações de modelação baseada em agentes para suporte de segurança em gestão de risco: Cenário de atirador ativo

Resumo: Mitigar o impacto dos incidentes do Active Shooter é de extrema importância. Estes acontecimentos trágicos não só ceifam vidas inocentes, como também inspiram medo e podem, em última análise, perturbar o tecido social. O modelo desenvolvido procura apoiar a tomada de decisão dos Especialistas de Segurança durante a execução do ciclo de Gestão de Riscos durante as etapas de Avaliação e Mitigação, utilizando Agentes de Resolução de Problemas para simular o ambiente de ameaça e determinar o impacto do cenário de ameaça sobre os recursos expostos. Com base nos resultados da simulação, o modelo propõe e configura medidas de segurança com base na sua relevância para o cenário de ameaça específico em análise. O comportamento dos Agentes durante as simulações geradas é semelhante ao comportamento observado nas filmagens de Incidentes com Atiradores Ativos e a implementação das medidas de segurança geradas é coerente com as melhores práticas e recomendações do setor de Segurança emitidas pelos conselhos do comité de incidentes pós-atiradores ativos. Os autores defendem a relevância da utilização de Agentes de Resolução de Problemas para melhorar a tratabilidade da Gestão de Riscos de Segurança.

Palavras-chave: Gestão de Riscos de Segurança, Simulação, Atirador Ativo, Agentes de Resolução de Problemas, Modelação Baseada em Agentes

1. Introduction

The FBI (2023, April) defines an active shooter as an event where “one or more individuals are actively engaged in killing or attempting to kill people in a populated area” with the used of small arms fire. During these events perpetrators can carry additional weapons ammunition and may as well use white weapons, incendiary, smoke grenade, tear gas canister or explosive devices to increase the number of victims or ballistic body armour to increase their survivability.

The formal and legal definition of an “Active Shooter Incident” generates distinct incident enumeration per country and thus creates hurdles on the statistical representation of these occurrences in time. Even with the removal of occurrences due to suicides and unintentional discharges from the per country statistics on the number of persons killed by firearms, the publicly available data is not complete nor allows for the definition of statistical trends as the data is dependent on the respective state legal definition considered (homicide) and excludes casualties that have occurred due to wounds on the medical facilities.

Active shooter incidents can occur in any location at any moment. Past Incidents have been observed in open spaces, commerce, education, residential, governmental, worship, manufacturing, transportation, offices, health care and others FBI (2023).

Although there are several studies, like Blair, J. P., & Schweit, K. W. (2014), that enumerate a describe with detail a set of active shooter events, the time registered has start of the event on the public available data does not allow for the definition of a period where the occurrence of an active shooter event is more likely.

In response to active shooter incidents, public and private organizations deploy security measures and develop protocols to protect and respond to this security incident. These intend to reduce the negative impact of this event by reducing the number of victims.

Private and Governmental entities implement risk management frameworks depending on their legal and regulatory requirements. This research paper will use the international standard defined on ISO 31000(2009) as the risk management framework used to conceptualize and address the active shooter problem.

Risk Management process is a set of systematic steps that allows stakeholder to reduce risks to an acceptable level, ISO 31000(2009). A threat scenario risk level is a classification that combines the likelihood and the consequences impact over the exposed assets.

$$Risk_{Scenario\ A} = likelihood_{\ Scenario\ A} \times impact_{\ Scenario\ A}$$

The complex and dynamic nature of the variables considered during Risk Management is acknowledged on the risk management framework with the acceptance that the process is based on the best available information and that is dependent on expert judgement, ISO 31000(2009).

This limitation arises during the characterization of the internal and external contexts used to define the likelihood and impact because the considered variables may vary with:

1. the passage of time;
2. depending on the spatial location;
3. depending on their previous state;
4. depending on the state of other objects;
5. may evolve on a non-liner manner.

Additionally, the variables and classification used to analyse the objects, and their state may not be able to describe the problem because they lack the adequate granularity or classification that enables the capture from the available data a useful cause and effect patterns. As risk management is an analytical process aims to support the prediction of threat actors' behaviour on future incidents related to the defined scenario, this data and analytical related limitations cannot be easily addressed due to the non-repetitive nature of the phenomena that consider human behaviour and complex dynamic environments.

Security experts cope with this complex and dynamic reality by simplifying the number of considered variables or by accepting a set of baseline assumptions grounded on passed incident observations. These incomplete inductions improve the tractability of the problem by simplification or linearization of the environmental variables but will also reduce the quality of the analysis as they are not complete nor consider all available data.

The use of software simulations to support the assessment phase of a risk management process in complex and dynamic environments is not new and is used in multiple areas. Horteborn and Ringsberg (2021) sought to improve the risk analysis limitations that spurred from the lack of adequate data granularity on the determination of the relevant variables by using the data conveyed by software simulations. Further proposing that simulation-based approaches can be used to evaluate the consequence of mitigations actions on the risk assessment process.

However, as stated by Sterman (2002), the modelling of a complex dynamic problem requires more than a formal mathematical model and computer simulations, as most important problems have no pure technical solution. Terrorism[1] is identified by Sterman (2002) as a complex and dynamic subject area that should be modelled via a multidisciplinary approach.

This research paper presents the results of a developed model that, based on a user provided representation of a buildings, uses Problem-Solving Agents to simulate active shooter scenarios and proposes effective or efficient mitigation measures in support of a Risk Management Process.

In continuation of the work already developed on this field, this paper presents the implementation of an agent-based simulation for active shooter scenarios and the algorithms that will select the most effective set of security measures that within the

[1] Not all active shooter incidents can be linked to groups formally designated by a state as a terrorist organization. However, Active shooter events can be classified as tactical incidents where the perpetrator armed with small arms seeks to inflict a vast number of casualties and deconstruct the implemented societal order.

available budget are more adequate to the reduction casualty rate on the building under scrutiny.

Section 2 and 3 will present the bibliographic research and the set of concepts relevant for the framing and conceptualization of Agent Based modelling simulations of active shooter scenarios. Section 4 will present the results that were used for the validation of the mathematical model used on the simulations. Finalizing with section 5 and 6 where a brief discussion and the conclusions of the performed research.

2. Background

To tackle complex dynamic problems, computer simulations should provide assistance that facilitates the cognitive tasks necessary to understand the complexity of the problem under analysis and avoid incorrect inferences. The formulation of models for a complex dynamic problem may be done by portraying decisions rules of the agents, natural processes and physical structures relevant to the purpose of the model, Sterman (2002).

A model for a dynamic system will specify a set of variables and their respective rule-based behaviour. The use of a discrete time model will facilitate the problem understanding, development and simulation, Sayama (2015).

Hayes and Hayes (2014) shown that the simulation of active shooter incidents can be modelled by a set of Zero-Intelligence Problem-Solving Agents that interact with one other in a set environment that considers a discrete global time.

As other works related to Problem-Solving Agent simulation of active shooter incidents, Lee (2023), proposes that the active shooter simulations should consider the Physical layout of the infrastructure and Agents of type Civilian, Shooter and Police Force with distinct behaviours in terms of movement and actions.

Lee and Dietz (2019) shown that the Run, Hide, Fight behaviour effectiveness at reducing the number of casualties in Active Shooter incidents is dependent on the infrastructure design of the building an on the properties of the security measures.

Stewart (2017) has sought to simulate Active Shooter incidents with the use of Problem-Solving Agents. In this study the key parameters considered where Police Response Time, Cognitive Delay of the Civilians and Civilian Response Strategy.

Briggs and Kennedy (2016) proposed that Active Shooter Problem-Solving Agent Simulations should consider the possibility that a Civilian might decide to attempt to restrain and subdue the shooter as a relevant variable to consider.

As stated by St. John (2020) there has been and increase implementation of security measures that seek to mitigate or protect against Active Shooters in the targeted facilities. These can be procedural, physical, technical or security officer related.

The use of virtual environments to simulate Active Shooter incidents and evaluate the usefulness of a security measure has been performed by Zhu et al. (2022). This study suggests further work on the assessment of security measures should be performed.

Sandy Hook Advisory Commission (2015) stated that the use of doors that contain or block shooter movement and create safe-haven areas or implement a full perimeter lockdown are effective security measures to reduce the impact of active shooter incidents.

In continuation of the performed research, this paper seeks to explore the use of the described simulation model to improve active shooter security risk management tractability within a Risk Management Framework.

3. Methodology

3.1. Model Architectural Design Options

There is no function that models human behaviour in situations of extreme violence in a complete and objective manner. Agent decision-making in the simulation is based on a reduced selection of variables that seek to generalize previous case studies and in accordance with heuristics considered appropriate by the security industry.

The simulations seek to replicate the physical behaviour of the building's structures, the attack method used and the expected human behaviour observed in footages of past active shooter incidents. This replication allows the automated integration of expert opinions based on passed incident knowledge with a specific structural design while considering the specific configuration and deployment of the protection measures implementation for the scenario under assessment.

The generated simulations are computations that resulted from the execution of the interactions rules of each participating agent placed in the simulation environment that considered the following limitations:

- Only the Active Shooter scenario was developed. Other actions and behaviours that frequently occur in real situations similar to the scenario under study, such as explosions and knife attacks, were not implemented;
- The simulation environment is reduced to only two dimensions and limited to the simulation zone as such all considered scenario building plants can only have one floor;
- The simulation space and Agent movements are discrete and not continuous. Therefore, one space unit cannot be further divided and can only contain one Agent or one structural component;
- Time is discrete and will advance one unit at the end of each iteration;
- The behaviour of the agents aims to replicate only the expected behaviour resulting passed observed examples of the scenario under study;
- All protective elements are only endowed with the properties defined in the simulation. These do not change between distinct equipment sets nor will be altered with the passage of time.

All agents are goal-based and seek to consider the consequences of their actions on the goal before executing the action. The following table presents the PEAS of the agents implemented in the simulation.

The next section will detail on the agents states transitions and actions executions in order to achieve the respective performance goals.

Table 1. PEAS of Agents

Agent	Performance Measurement	Environment	Actuator	Sensor
Occupant	Minimize time to exit scenario	Building structure positions, state of agents in the observed field of view	Run, Hide, or Fight	Internal state, location, Field of view over building structures and location of other agents
Shooter	Maximize number of victims		Move, Shoot, Turn	
Intervention Force (IF)	Minimize the number of victims		Move, Shoot, Turn or Stabilize Occupant	

3.2. Model Description

The business domain is implemented based on the following classes:

- Risk Assessment: Considers user input to generate simulations. Implements a optimization algorithm to generate and evaluate security measures to implement.
- Simulation: Represents the start and end, as well as the variables defined by the user. The simulation ends when the Shooter is neutralized or when the maximum simulation time is reached.
- Scenario: Involves the two-dimensional definition of the building structure and agent locations. The building consists of simple walls or concrete walls, windows, simple doors, doors with mechanical resistance, or ballistic resistance.
- Agents: The state transition model of agents considers a global clock that synchronizes the execution of actions among agents. The cost of all actions is one time unit. All agents have a field of view and can move in any direction if not blocked by another agent or building structural component.

In the simulation, agents seek to optimally satisfy the set of rules defined according to their type:

Table 2. Agent states and actions

Type	Initial	Objective	State	Actions
Occupant	Static or Moving	$\neg Dead$	Static	BeAlerted, GetWounded, Die,
			Moving	Move, GetWounded, Die, Enrage
			Safe	$\emptyset$ (removed from simulation)
			Enraged	Move, GetWounded, Die, Attack
			Wounded	Die, BeSaved (removed from simulation)
			Dead	$\emptyset$ (removed from simulation)
Shooter	Moving	$Max(Dead(Occupant))$	Moving	Move, Turn, Shoot, Die
			Dead	$\emptyset$ (end of simulation)
IF	Moving	$Min(Dead(Occupant))$	Moving	Move, Turn, Shoot, Die, Save
			Dead	$\emptyset$ (removed from simulation)

Table 2 presents the states and actions implemented by the agents in the simulation.

- Occupant: Will start with the complete knowledge of the floor plan but do not have knowledge of the presence or location of the other agents. Occupants start the simulation in the *Static* or *Moving* state according to the parameters defined by the user. They can open all doors. If *Static*, they may switch to the *Moving* state if the alarm is triggered, if they hear gunshots or see the shooter on their file of view. When *Moving*, occupants run towards the exit. If the Shooter enters their field of vision during the escape, the Occupant considers the shooter position to select the closest exit while moving away from the shooter. If the Shooter is within 4 spatial units of the Occupant, there is a probability that the Occupant will become *Enraged*. If occupant state is *Enraged* will move towards shooter and attempt to fight and attack the Shooter if adjacent to it. If the Occupant is hit by the Shooter, they may either pass to the state *Dead* or be *Wounded*. If *Wounded*, they cannot move and there is a probability of dying with the passage of time. *Wounded* occupants can be saved by IF adjacent to their position.
- Shooter: Will start in the state *Moving* and will pass to *Dead* if attacked by another agent. The Shooter does not have any initial knowledge of the floor plant not the other agent locations. Will seek to move around the building and explore areas that have not yet been observed by his internal representation built by the field of vision. A shooter can open doors that do not have mechanical resistance. Shooters move more slowly than Occupants as before advancing one spatial unit, they rotate in search of targets, these being Occupants or IF. If they spot a target in their field of vision, they shoot at it until all targets are dead instead of moving. The shot effects over the target depend on the distance between the Shooter and the target. A shot can impact more than one target and penetrate building elements without ballistic resistance. The simulation ends if the Shooter is neutralized or if the maximum time is reached.
- Intervention Force (IF): The IF behaves similarly to the Shooter but only shoots at the Shooter and can open all doors. If they see a *Wounded* Occupant in their field of vision, they move to an adjacent position and try to stabilize the victim.

Table 3. Physical properties of building structural components

		Allows			
Structural Component	**Char**	**Vision**	**Projectile**	**Shooter Movement**	**Occupant and IF Movement**
Space	‘ ’	T	T	T	T
Exit	‘E’	T	T	T	T
Simple Wall	‘.’	F	T	F	F
Reinforced Wall	‘:’	F	F	F	F
Glass	‘-’	T	T	F	F
Ballistic Glass	‘=’	T	F	F	F
Simple Door	‘/’	F	T	T	T
RC3 Mechanical Resistant Door	‘{’	F	T	F	T
FB6 Ballistic Resistant Glass Door	‘[’	T	F	F	T

The building's structure and the nature of its elements in terms of mechanical or ballistic properties are defined by the character type used, according to the following values presented in Table 3.

Formal definition of the developed model:

1. Let a representation of the scenario building structure S with l lines and c columns be an array of characters, char[l*c], with the physical properties indicated in table 3.
2. All scenarios S can position a set of Agents A on the scenario valid positions.
3. All scenarios S have the properties $(survivability\ rate, KillZone)_S$ that are initialized at zero and are updated after the simulation execution.
4. Let a simulation be the function that takes a scenario, a maximum time and a set of agents to execute the programmed behaviour until all occupants are dead, all shooters are dead or the maximum time as been reached. The simulation returns the survivability rare and the kill zone.

   $$Simulation: S_i \times Time \times A \rightarrow (survivability\ rate, KillZone)_{S_i}$$

   A simulation is computed asynchronously for a set number of executions. On each simulation all agents are randomly positioned on the building structure. To cope with the uncertainty of the exact number of occupants, simulations with the half and the double of the occupancy rate will also be executed. Each simulation will return the number of survivors divided by the initial population (survivability rate) and the bidimensional array with the casualty accumulate count (Kill Zone).

Algorithm 1 – Simulation.Run()

```
Input: Scenario Building Structure, number of Occupants, number of Shooters and number of Intervention Forces, _maxTime
Output: Count of non-dead occupants and array with count of hit on target on each Position
Initialization of variables: CurrentTime = 0, RunningScenario = _initialScenario with Agents randomly placed
While Shooters.Count > 0 and CurrentTime < _maxTime and Occupants.Count > 0
    if (CurrentTime == _interventionTime)
        Insert Intervention Forces in Running Scenario
    Foreach Agent in RunningScenario //perception of environment
        Update Agent Field Of View
    Foreach Agent in RunningScenario
        Update Agent Knowledge
    Foreach Agent of Type (Shooter or Intervention Force)
        If (Target in Sight)
            Shoot at Closest target
            Foreach Agent hit by shot
                If Agent not wounded => Agent is wounded
                If Agent wounded => Agent is killed
            Foreach Occupant not Alerted
                Alert with 33% change
        Else if (unknown position adjacent)
            Turn towards closest unknow position
```

```
    Else
        If(CurrentTime is even)
            Move towards target or closest unknow position
        Else
            Turn towards random direction
Foreach Agent of type Occupant
    If(Close to shooter)
        Enrage with 25% change
    If(Not close to shooter and is Enraged)
        Calm down (!Enrage)
    If(is Enraged and adjacent to Shooter)
        Punch Shooter(25% change of shooter becoming controlled)
    Else
        Move //only Alerted Occupants will move and if enraged will move
        towards shooter
Foreach Agent //internal state changes
    If(Agent is wounded)
        Die due to wounds with 25% change
    Remove all Agents from RunningScenario
        Agent state is Dead
        Agent type is Occupant and Agent position is an Exit
CurrentTime++ // passage of time
```

The result of all executed Simulations is considered to calculate the survivability rate (heighted average of the number of survivors) and the Kill Zone (array with count of total hits per position).

5. Let add security measure be the function that receives a scenario, a budget and a kill zone and returns a scenario with an improvements made on the structural component where the kill zone value is higher and within the available budget;

$$AddSecMeasure: S_i \times budget \times KillZ \rightarrow S_i^+$$

6. Let remove security measure be a function that receives a scenario and a kill zone and diminish a security measure where the kill zone value is lower;

$$RemoveSecMeasure: S_i \times KillZ \rightarrow S_i^-$$

The cost for each added security measure is considered in comparison with the original scenario provided by the user.

7. Let the function assess receive a scenario and a kill zone and return a scenario. Asses will take the initial scenario, execute a set number of simulations to obtain a kill zone and call remove security measure and add security measure to generate the new scenario that considers the results generated by the simulations.

$$Assess: S_a \times KillZone \rightarrow S_b$$
$$S_b' = RemoveSecMeasure\left(Simulate_{(S_a, kz)}\right)$$
$$S_b = AddSecMeasure(S_b', budget, KillZone)$$

Algorithm 2 – RiskAssessment.Assess()

```
Input: InitialScenario, _maxBudget and Zill Zone generated by Simulations
Output: Scenario Building Structure with modified security measures
Initialization of variables: simNumber = 0, NumberOf Simulations = 100,
survivabilityRate = 0, KillZone is null array, RunningScenario = InitialScenario
While survivabilityRate < 0.95 and budget <= _maxBudget
    While simNumber < NumberOfSimulations
        (survivability, KillZone) += Simulation.RunAsync(RunningScenario)
    RunningScenario = RemoveSecurityMeasure(RunningScenario, KillZone)
    RunningScenario = AddSecurityMeasure(RunningScenario, _maxBudget,
    KillZone)
```

3.3. Model Implementation

Receiving from the user a representation of the physical structures of a building, the number of occupants, and the available budget, the model will generate versions of the building with safety measures within the available budget. The building with additional security measures are generated based on their performance in the executed simulations for the assessed active shooter scenario.

The optimization function of the simulation is the number of victims. The model will output the location where the victims were hit by the shooter to allow considerations about the building's structure and protective elements.

Although default values can be considered, at the beginning of each assessment the user can define parameters that are considered by the multiple simulations:

- The position and type of physical building structure and protective elements;
- Total available budget;
- Number of occupants;
- Time for the Intervention Force to enter the scenario;
- Definition of other options to change agent behaviour:
    - Occupant – Static, Run/Hide, Run/Hide/Fight.
    - Shooter – Shooting proficiency.
    - IF – time for the start of intervention, initial position and number of IF members.

The result of each simulation will allow the calculation of the survival ratio and the positions where the occupants were shot by the shooter. The conduction of the risk assessment and proposal of the building security measures rely on the Algorithm 2 that uses the survival ratio and the kill zone of each building as the optimization function to allocate security measures and determine if an adequate solution has been reached.

After the assessment is executed, the following values will be presented to the user:

- Survival rate: number of survivors / initial number of occupants;
- Cost of implemented security measures;
- Floor plan of the new building;
- Building floor plan with the sum of casualties by position.

The improvement of building structure considers the relevance of the security measure taking into account the number of casualties that occurred in adjacent cells. This promotes the removal of less relevant security measures and the introduction of security measures in the most casualty impactful positions.

3.4. Validation of model

The available information regarding the optimal behaviour that the agents should exhibit in the case of active shooter scenario is incomplete. The case studies available are based only on partial reports or the partial observations of videos of past incidents.

It is not possible to discern all the variables that describe the state and decision-making of the participants in the case under study. Therefore, it is not possible to enumerate the complete set of variables and their respective values to create a function that models decision-making in the scenario under study.

The implemented model aims to provide a result in non-deterministic polynomial time that considers only a limited set of variables in accordance with the heuristic solutions implemented by security experts.

The research was based on the premises that:

- If the generated agent-based simulations are coherent with past observed active shooter incidents;
- And that if the implemented security measures perform in accordance with the mechanical and ballistic properties defined by their respective certification grade.

Then, the output of the model should be coherent with the security best practices in terms of placement and selection of the security measures.

As an adequate model allows for the improvement in the tractability of a dynamic complex problem without simplifying or linearizing the analytical process, as stated by Sterman (2002). Is hypothesised that the use of the develop model improves the tractability of security risk management when assessing the implementation of security measures to mitigate the risk of an active shooter scenario.

4. Results

The used prototype was run on multiple scenarios with distinct sizes and configurations and with up to 100 distinct Agents. The execution times are compatible with the use of the developed algorithms in support of the assessments performed by Security Experts with non-specialized hardware.

The model substantially increases its execution time according to the size of the scenario (n). The used algorithm has an asymptotic complexity of n^2 imposed by the cycles that implement the behaviour of the agents, that need to update their knowledge of the environment before taking action.

4.1. Validation of the simulation

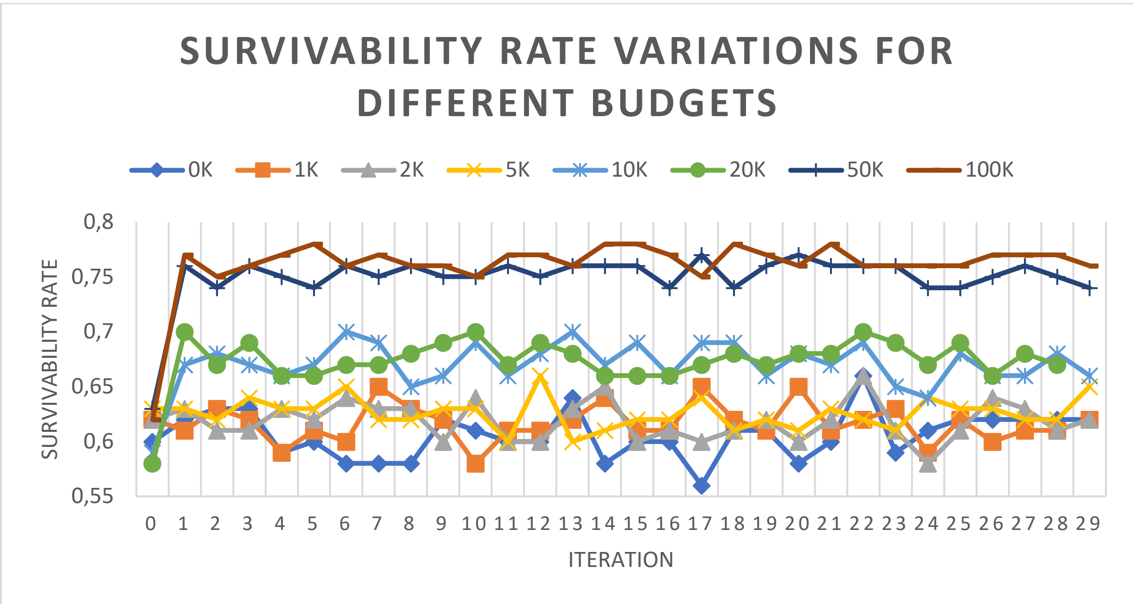
The case study used for the validation of the developed model was the active shooter incident that occurred on 14th February 2018 in Parkland at Marjory Stoneman Douglas High School. The comparison considered the publicly available footages presented by the police authorities on the after-action report.

Based on a building structure similar to the case study incident, Algorithm 1 allows the agents to behave in an identical manner as to the publicly available footages if the case study. The shooter searches the building and proceeds to shoot at the nearest occupant as soon as they are detected.

The Agents present movement and attack patterns consistent with available videos of active shooter incidents.

4.2. Validation of the risk assessment

The execution of Algorithm 2 generates building designs that have less casualties in the simulations. The reduction in the total casualty rate is dependent on the available budget but also on the type and position of the implemented security measures. Graphic 1 shows the results obtained for the same scenario but altering the available budget.



Graphic 1. Survivability rate variation for different budget values

Diagram 2 shows the bidimensional mapping of casualties and the proposed security measures after executing Algorithm 2 with 0 and with 100K of budget.

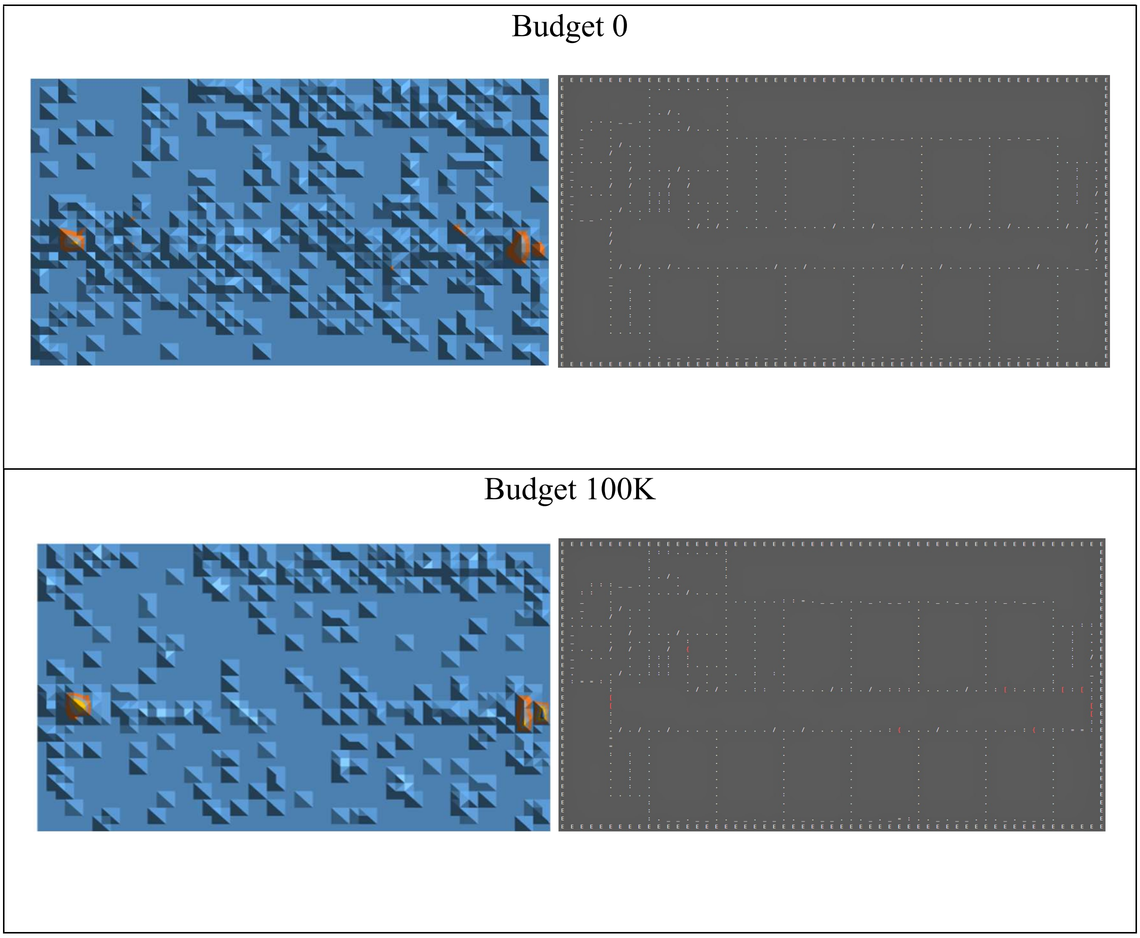


Diagram 2. Example of Algorithm 2 results for budget 0 and 100K

In the lower budget bracket, the attacker was still able to enter the building. With the progressive implementation of security measures, the total casualty rate decreased and was concentrated mostly on the exterior envelop of the protected building.

The implemented Algorithm 2 promoted the implementation of security measures until the casualties are occurring mostly outside of the protected facility, stabilising on this solution and returning a final security measure implementation within the available budget.

The application proposed security measure location and type follows some best practices and principles recommended by security experts. Specifically, it aims to:

- Block the shooter's access to the interior of the perimeter.
- Create multiple layers of consecutive security.
- Reduce the application of security measures where they are not relevant.
- Apply security measures without creating gaps.

5. Discussion

The use of additional security measures other than security doors and ballistic glass should allow the model to further reduce the casualty rate on the building envelope surroundings. Given the limitation of the current implementation, it is considered that the prototype achieves its functional objectives by supporting decision-making through:

- Considering multiple scenario configurations that assess diverse occupant locations, shooter entries and security measures;
- Presenting a set of security measures to reduce the scenario casualty rate;
- Associating budget constraints with each scenario simulation;
- Allowing for the quantification of the effectiveness of security measures based on simulation data.

The use the bidimensional location of the fatalities in the optimization function to assess the security measure relevance returns more coherent results than a simple sum of the total casualty rate on the scenario. Although the total casualty rate is a parameter useful to determine if an acceptable solution has been found.

As the generated agent-based simulations are coherent with past observed active shooter incidents and the resulting security assessments are coherent with the security best practices in terms of placement and selection of the security measures, therefore, the developed model improves the tractability of the security risk management problem for an active shooter scenario.

The developed model allowed the demonstration that Agent Based Model simulations can be used to support Security Risk Management. Adding more security measures, more complex scenarios and expanding the simulation scenario beyond the bidimensional plane are improvements that should be pursued in future works.

6. Conclusion

The incomplete inductions performed by security experts during the Risk Assessment and Risk Treatment phases of the Risk Management Process cannot be completely removed due to the nature of the problem evaluated but the use of Problem-Solving Agents simulations can contribute to:

- reduce the level of simplifications and thus reducing the error margin and improving the quality of the security assessment;
- clearly exposes the set of rules that the assessment was based upon and therefore promotes the objectivity and clarity of the after action reviews of the security assessment;
- allows for the assessment of multiple scenarios and their respective variants, contributing for the increased completeness of the security assessment;
- allows for the consideration of security measures relevance on all assessed scenarios.

Thus, promoting an overall increase in the granularity and quantity of the scenarios addressed on the Risk Assessment Process and therefore contribute to the improved tractability of the risk management decision process.

7. Appendices

Initial building structure with setting considered for the real case validation with budget of 0 with initial occupant and shooter layout used for the validation of the past incident.

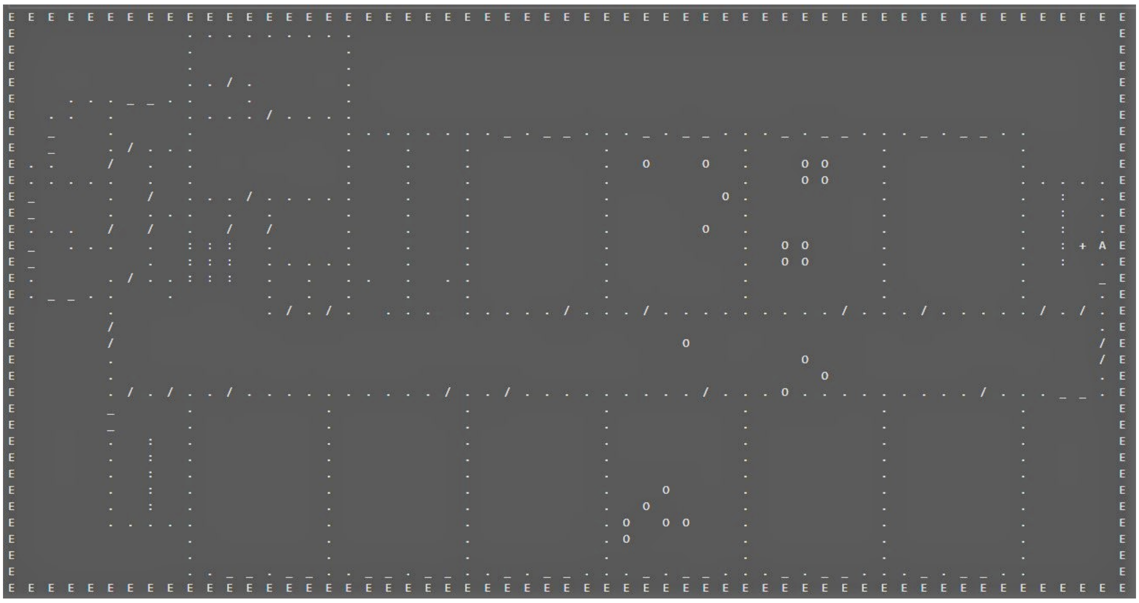


Image 3. Initial building structure

The execution of Algorithm 2 with budget limitation of 10K resulted on the output of image 4.

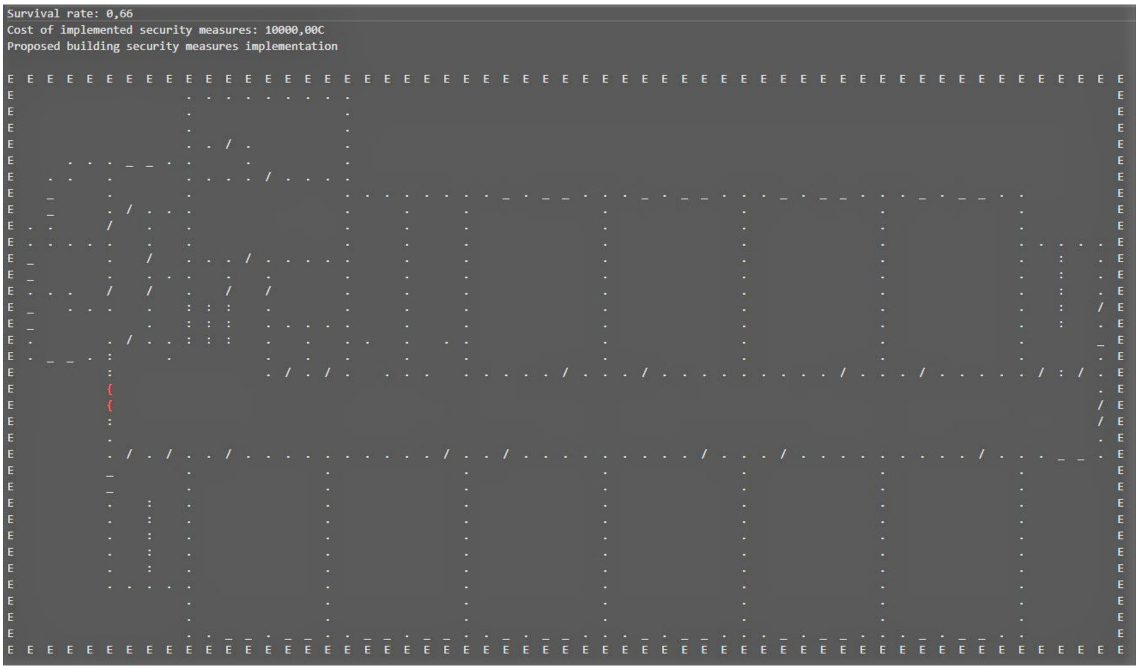


Image 4. Execution output for 10K

The execution of Algorithm 2 with budget limitation of 100K resulted on the output of image 5.

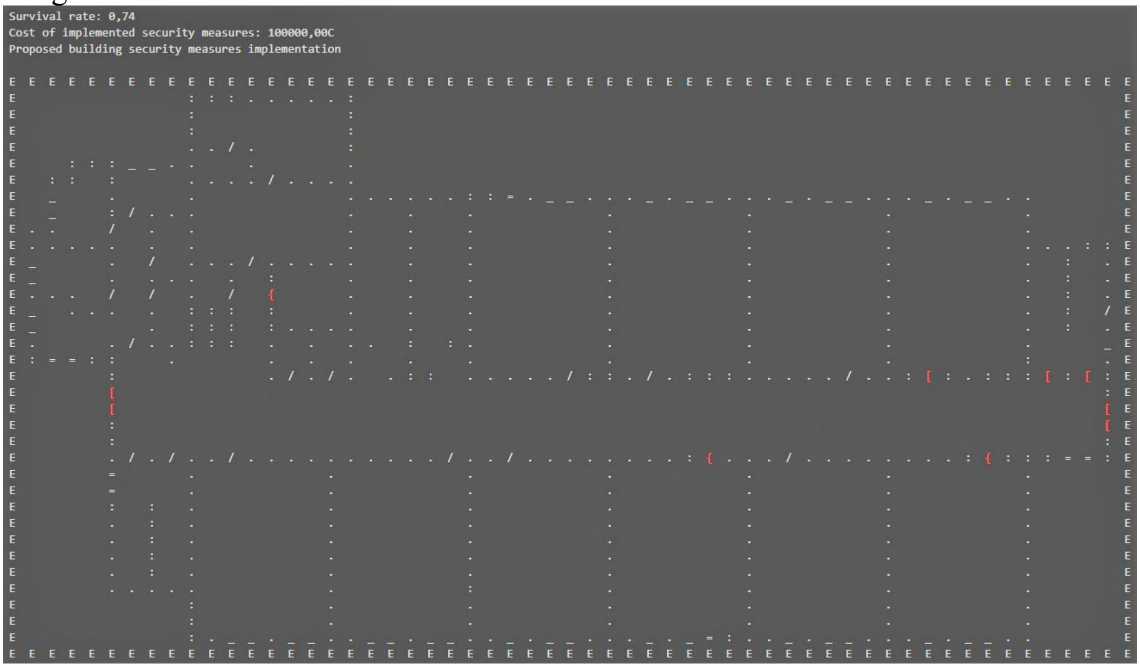


Image 5. Execution output for 100K

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