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On School Grounds: Simulation of a School Lockdown

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Abstract

Active shooter situations are becoming increasingly more frequent every year in the United States. According to the Federal Bureau of Investigation reports, 20.6% of the incidents between 2000 and 2018 occurred at educational facilities. Thus, educational institutions should prepare personnel and students on how to react and respond during active shooter situations. This paper simulates an active shooter situation in order to investigate the effect of different student decisions and law enforcement response times on the number of casualties during a school lockdown. Different scenarios are simulated using the "run, hide, fight" protocol for various response times and student reaction strategies. The student reaction strategies are based on a survey that students from the Muscogee & Russell County school district completed for a hypothetical event. The simulation results indicate that slower police response times and having students hiding in the classrooms without locking the doors can result in an increased number of casualties.

Keywords: discrete event simulation, school lockdown, evacuation, active shooter

1. Introduction

Over the past 20 years, educational environments across the United States have experienced tremendous concern with keeping students safe due to the increased frequency of active shooter incidents. According to the Federal Bureau of Investigation (FBI) reports, 20.6% of the incidents in the United States between 2000 and 2018 occurred at educational facilities. Since 2000, there have been more than 277 active shooter events, which resulted in at least 57 casualties of faculty, staff, and students (FBI, 2018).

Specific past active shooting incidents have been analyzed to gather information from each incident and inform the training and response methods. For example, on April 20th 1999, two armed students entered Columbine High School and opened fire, killing 13 of their classmates and wounding 20 more. The analysis of this incident led to the conclusion that a faster response time would be critical to saving lives in similar situations (Manger, 2013). Thirteen years later, on December 14th 2012, an active shooter event occurred at Sandy Hook Elementary School in Newtown, Connecticut, leading to the death of 20 students and six staff members. During this incident, the actions taken by school staff reduced the number of casualties at the school. This incident indicates the necessity for school personnel to be properly trained in making independent decisions in such situations. Thus, educational organizations need to prepare and train personnel and students on how to react and respond during active shooter events by assessing the situation and choosing the most appropriate response strategy. Moreover, law enforcement officers need to be able to reduce response times since it can result in a lower number of casualties.

School districts are spending more money to

improve school safety by creating safe rooms and implementing warning systems (Sisson, 2019). Moreover, educational institutions are implementing different lockdown, evacuation, or sheltering procedures as part of emergency planning in order to keep students, faculty and staff safe in the event of an active shooter.

Simulation modeling is a useful decision support tool that can be used in the early planning stages to design and assess effective lockdown, evacuation, or sheltering procedures prior to an actual event. Creating simulation models to further explore active shooter situations can be a critical component of emergency planning and a training measure which can help familiarize students, faculty, and staff with a school's emergency procedures and provide valuable information on how to respond to these incidents.

This paper presents a preliminary discrete event simulation (DES) model that estimates the number of casualties and evacuation times using the "run, hide, fight" protocol. The model is used as a pilot testbed to execute different procedures necessary in an active shooting scenario and to investigate how the students' decisions and police response times may affect the number of casualties. The DES model represents an active shooter scenario with 50 and 90 students using the "run, hide, fight" protocol in which classroom doors can be locked. The simulation results can be used to identify the actions and measures that need to be accounted in formulating a training and safety plan.

The rest of the paper is organized as follows: Section 2 provides a literature review that focuses on the current safety procedures and policies. Section 3 describes the set-up of the simulation model of a school when an active shooter is present, while Section 4 discusses the simulation results for different response times and student strategies. Finally, Section 5 presents the conclusions and discusses future work and directions.

2. State of the art

2.1. Lockdown

Preparing for a mass shooting crisis involves various stages, with each stage carrying a significant amount of complexity. Current guidelines define preparedness efforts in five independent stages: prevention, protection, mitigation, response, and recovery (Spicer, 2018). Preparedness efforts typically focus on prevention and response. In this paper, we define the prevention stage as the events that occur before the identification of an active shooter presence, while response stage is everything that takes place after the prevention stage. The identification of the active shooter presence is considered as the emergency event.

The prevention stage requires assessing the potential dangers in a school and community and identifying the required steps to prevent and reduce injury and property damage (Department of Education, 2004). Assessing for potential hazards and the safety surrounding the school should occur frequently and must be a part of daily operations. Access to school buildings is also important during the prevention stage, as procedures surrounding access can prevent intruders from harming school grounds. The National Center for Education Statistics showed that the secure measures incorporated in public schools buildings in 2015-2016 increased compared to the 1999-2000 school year. More specifically, the use of security cameras increased by 61% and controlled access increase by approximately 20%. Moreover, many federal policies have been established and are currently in place to prevent school violence nationally. The Gun-Free Schools Act was passed in 1994 and mandates expulsion to any student that brings a firearm to school. Most recently, the No Child Left behind Act of 2001 requires states to report statistics of school safety to the public and to use federal school funds to assist in forming a plan for keeping schools safe and drug free.

The response stage is also of vital importance. Present day active shooter events at schools average 12.5 minutes (Glover, 2016), with many incidents involving a suspect seeking for targets within 5 minutes or less before the arrival of law enforcement. Therefore, in order to decrease the number of casualties and efficiently protect students during active shooter events, procedures should occur in less than five minutes.

Schools practice five main drill procedures: evacuation, reverse evacuation, lockdown, shelter-in-place, and duck-cover-hold (Zhe and Nickerson, 2007). In this work, the lockdown procedure is modeled and simulated. Lockdowns in schools are becoming an addition of many of safety procedures, such as fire and tornado drills. The overall goal of a lockdown is to compartmentalize an attack. According to National Association of School Psychologist (NASP), lockdowns are intended to secure a school to keep out a threat (National Association of School Psychologists, 2018). Depending on the school requirements, different protocols can be incorporated in a lockdown event.

One of the most known protocols to respond to an active shooter during a lockdown event is "Run, Hide, Fight." During "Run, Hide, Fight" people will immediately recognize the warning sound as a hazard requiring them to respond; decide where it is coming from; determine where it is going next; choose from three distinctly different options of what to do about it (run, hide, or fight); and then spring into action (Adelman, 2016).

The next section describes the model set up for an active shooter event during a lockdown by applying the "Run, Hide, Fight" protocol.

2.2. Evacuations

Efficient and timely small-scale evacuations are affected by both physical factors, such as layout, density and timing, as well as human factors. On small scale evacuations, such as a classroom or a building, an improved physical layout can definitely improve evacuation time. Human decisions have also a significant effect on the evacuation time (Madireddy et al., 2011; Ahmed et al., 2019). Evacuation route selection by individuals is one of those factors that may speed up or slow down the evacuation process. For example, those evacuating a building frequently choose what appears to be a fast route. This evacuation strategy not only increases congestion and slows the evacuation process (Madireddy et al., 2011), but also is not as effective as having an overall evacuation strategy for the building in which the best evacuation exit may not necessarily be visible (Zia and Ferscha 2009). McCormack and Chen (2014) also demonstrated that providing guidance to individuals during route selection by either directing them to or leading them on paths that avoid obstacles significantly improves evacuation times. Therefore, having a simulation model that informs on the outcomes of alternative plans and assesses evacuation procedures can help reduce the evacuation time and may result in a more efficient process than an unplanned approach.

In the present model, we consider one exit that students can use to escape. We also assume that there will be congestion at the exit, which is modeled through the time distributions.

3. Simulation Model Description

Simulation modeling is a way to test different options, assess the outcomes and take informed decisions to augment protocols and enhance safety. This work uses the Arena simulation software for the development of a pilot DES model that captures the lockdown protocol during an active shooter event. The model can be used to examine different responses and update best practices during procedures.

3.1. Study Design

The model was implemented using DES. At the beginning of the simulation, the students (entities) are notified about an active shooter presence. An active shooter is defined as "an individual actively engaged in killing or attempting to kill people in a confined and populated area" (Glover, 2016). Then, the students can make different decisions and follow a different path: run, hide, fight (if confronted by the intruder), evacuate, or become a fatality. Active shooters usually choose their victims randomly, so the model assumes that the students make a decision based on probabilities and not on influential factors.

Students can use different school areas for hiding. In the system, the classrooms are considered as resources that hold students secure during a school lockdown until it is safe for them to escape. Other actions include run, fight intruder, escape or become a fatality by the shooter. Once the selected action is completed, the statistics are recorded and the entity exits the system.

3.2. Discrete Event Simulation Model Setup

Before simulating the model, the model parameters need to be setup. Figure 1 shows the DES process flow logic of the lockdown assuming the "run, hide, fight" protocol.

Entities are generated into the system until the maximum number of students is reached (in this case, 50 or 90 students). Once in the system, 20% of the entities will run and 80% will hide in one of the locked rooms. Each of the locked rooms has a maximum capacity of 25. Once a student entity is safe to leave the classroom, it will leave the system safely by escaping and exiting the system. Students that run will perform this action within two minutes. A runner entity can follow one of the four potential actions based on probabilities: escape safely (17%), hide in locked room (23%), fight the intruder (35%), or encounter the intruder and leave the system as fatality (25%). Entities that decide to fight may escape (25% chance) or become a fatality (75%). The probabilities were estimated from a school safety survey that was completed by students from Muscogee & Russell County school district ranging from sixth grade to senior students.

As a rule of thumb, Law and McComas (1990) recommended running at least 3 to 5 replications. However, this cannot guarantee stochasticity for any given model. Thus, the number of replications is calculated using the confidence interval method (with specified precision). The resulting number of replications at a 95% confidence interval is 10.

The model was set-up to run for ten replications for different student numbers (50, 90, and 100 students) in the system and different response times (12 minutes and 5 minutes).

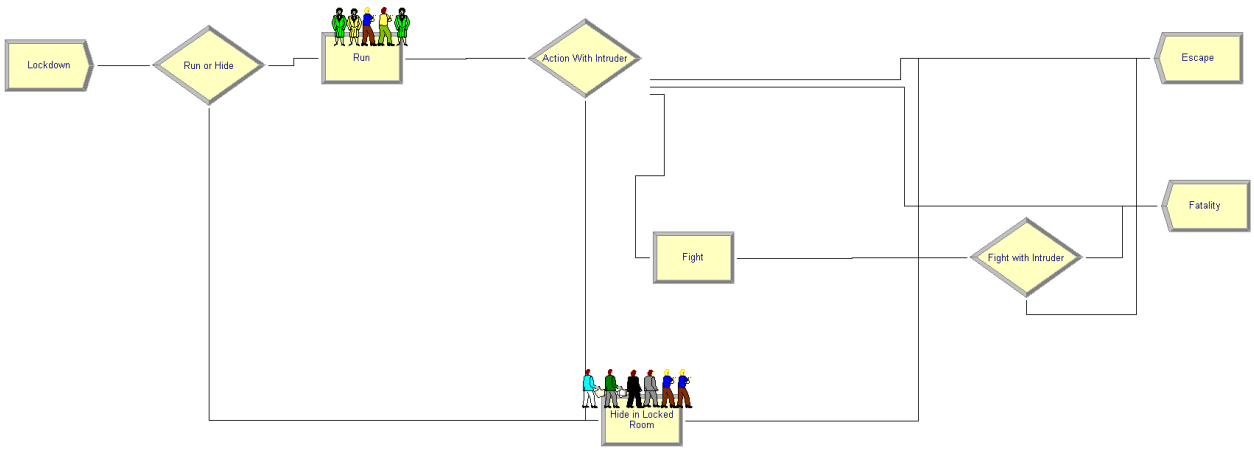

Figure 1. Simulation model for the "Run, Hide, Fight" protocol during a lockdown.

3.3. Model Limitations and Assumptions

Assumptions are essential when creating a simulation model. It is not feasible to include all the possible events that will occur in reality. Therefore, during this system analysis, various assumptions were taken into consideration for each model. Also, each model presents certain limitations.

In the DES model, classrooms are assumed to lock and hold students secure during a school lockdown until it is safe for them to escape. It is also assumed that there will be congestion at the exit, which is modeled through the time distributions in the module.

The limitation of the simulation is that it does not include travel and behavioral patterns of the students and the intruder. In addition, the DES treats the students as passive objects that follow a specific logic. Moreover, the percentages for student actions are based on a survey that students from Muscogee & Russell County school district completed for a hypothetical event. However, students may react differently during an actually event, so the percentages may vary. In general, it is especially challenging to accurately simulate human responses in stressful situations (Stewart, 2017). A hybrid model using a combination of DES and ABM methods would be more appropriate to capture the student and intruder behavior as well as evacuation patterns in a more realistic manner (Mykoniatis, 2015; Mykoniatis and Angelopoulou 2020).

4. Simulation results and discussion

Once the model's input parameters are set up, we ran the simulation to observe the changes in the evacuation metrics and observe the evacuation animation. The evacuation metrics include: the percentage of students that escaped, the evacuation time, and the percentage of fatalities for each scenario. The four scenarios are the following:

- Scenario 1: Simulation with 50 students and 12 minutes response time
- Scenario 2: Simulation with 50 students and 5 minutes response time
- Scenario 3: Simulation with 90 students and 12 minutes response time
- Scenario 4: Simulation with 90 students and 5 minutes response time

The simulation results are summarized in Table 1. The results indicate that the percentage of student population that manages to safely escape or is still safely hidden under current lockdown procedures with 12 minutes response time increases by 4% (from 90% to 94%) as the student population approximately doubles, while the percentage of fatalities decreases from 10% to 6%.

Table 1. Simulation results for DES model

Metrics	Results			
Scenarios	1	2	3	4
Number of students in the system	50	50	90	90
Response time in minutes	12	5	12	5
Percentage of students that escaped	74%	26%	49%	14.5%
Percentage of fatalities	10%	6%	6%	3%
Percentage of students still hiding	16%	68%	45%	82.5%
Average evacuation time in minutes	4.48	2.21	4.47	2.18

In addition, if the response time is reduced to 5 minutes, the fatality rate reduces in half. This may explained by looking at the percentage of students still hiding in each scenario. When the response time is reduced to 5 minutes, the majority of students remains hidden and do not take a further action (try to fight or escape). However, when the response time is longer, students may attempt to escape or fight the intruder, which increase the possibility of students being fatally injured. This also leads to an increased

percentage of safe students by 4% and 2.5% for the scenarios with 50 and 90 students, respectively, when the response time decreases to 5 minutes.

Simulation results indicate that reducing the response time to 5 minutes can result in minimizing the number of casualties. Since a lockdown can occur anytime during the school hour, additional measures should be taken. For example, offering additional locks and maps for more common areas in a school (bathrooms, gym, cafeteria, etc.) can assist more students to hide and find safety until law enforcement arrives. Devices to barricade doors, such as bolo sticks can be also effective.

5. Conclusions and future work

In this work, an active shooter event was modeled and simulated using a discrete event simulation approach. A pilot model was developed using discrete event simulation. The model provided insight of how different options and response times can affect a lockdown situation when classrooms are locked.

The main limitation of the discrete event simulation is that it does not consider any behavioral patterns the students may have. To overcome this limitation, the behavioral patterns of the students and the intruder in such events will be modeled using a hybrid modeling approach of discrete event and agent based simulation methods in the future. Moreover, we need to further develop the model with input from experts and the police department and validate it with real case studies.

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