AGENT-BASED MODELING TO ASSESS THE EFFECTIVENESS OF RUN HIDE FIGHT

by

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I dedicate my thesis to the victims and the impacted families and friends of 1999 Columbine High School shooting.

ACKNOWLEDGMENTS


```
//Remembering my first hello_world.
public class acknowledgement {
    public static void main (String[] args)
    {
        String ack_family [] = {"Young Mi Sohn", "Jennifer Goran", "Chang Hyun Lee",
        "William Goran" ,"Su Yun Lee", "Dan Goran", "Noel Goran",
        "David Goran", "Shannon Goran", "Jake Goran"};
        String ack_fmaily_cont = "";
        for(int ctr = 0; ctr < ack_family.length; ctr ++)
        {
            if(ctr < ack_family.length - 1)
            {
                ack_fmaily_cont += ack_family[ctr] + ", ";
            }
            else
            {
                ack_fmaily_cont += "and " + ack_family[ctr] + ".";
            }
        }
        System.out.println("I would first like to acknowledge my family "
        + ack_fmaily_cont);
        String ack_committee = "Eric Dietz, Eric Matson, and John Springer" ;
        System.out.println("Second, I would like to acknowledge my committee
        members " + ack_committee +" for providing me with academic and professional
        feedback which lead to the completion of my thesis on time while deploying
        various quantitative research methods.");
```

```
        String ack_funding = "Ravai Guity, and Victor Barlow";
        System.out.println("Third, I would like to acknowledge my source of funding, "
        + ack_funding + " providing me with precious opportunities to TA for CNIT 155,
        and 180.");

        String ack_phsi [] = {"James Lerums", "La'Reshia Poe", "Colby Craig",
        "Katherine Reichart", "Alissa Gilbert","Braiden Frantz", "Travis Cline",
        "Joseph Cacciatore"};
        String ack_phsi_cont = "";
        for(int ctr = 0; ctr < ack_phsi.length; ctr ++)
        {
            if(ctr < ack_phsi.length - 1)
            {
                ack_phsi_cont += ack_phsi[ctr] + ", ";
            }
            else
            {
                ack_phsi_cont += "and " + ack_phsi[ctr];
            }
        }
        System.out.println("Finally, I would like to acknowledge my colleagues at
        Purdue Homeland Security Institute, " + ack_phsi_cont + " for intellectually
        rocking my world.");
    }
}
```

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LIST OF ABBREVIATIONS

ABM	Agent-Based Modeling
ADD	AvoidDenyDefend^{TM}
ALERRT	Advanced Law Enforcement Rapid Response Training
ALICE	Alert, Lockdown, Inform, Counter, Evacuate
ASI	Active Shooter Incident
DOE	Department of Education
DHS	Department of Homeland Security
FASTER	Faculty/Administrator Safety Training and Emergency Response
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Agency
IHE	Institution of Higher Education
ISP	Indiana State Police
LEC	Law Enforcement Community
REMS	Readiness and Emergency Management for Schools
RHF	RUN.HIDE.FIGHT.®
SRO	School Resource Officer

ABSTRACT

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The 1999 Columbine High School shooting was a bold reminder which emphasized the importance of active shooter preparedness for the first responder communities and the general public. Since Columbine, the preparedness for active shooter incidents (ASIs) both in the public and private sectors proactively took place. Currently, the RUN.HIDE.FIGHT.® (RHF) response for unarmed individuals is implemented as part of the emergency response throughout the United States. Despite the RHF's nationwide implementation, there is a lack of literature that supports the effectiveness of RHF to lower casualty rates during ASIs.

This thesis examined casualty differences of RHF and the shooters' discharge interval by creating the incidents that have occurred in the library during the 1999 Columbine High School shooting with AnyLogic's agent-based modeling capabilities. Recreating ASI in a virtual environment naturally removes the participants physiological and psychological implications. Additionally, the flexibility of agent-based modeling allows validating the model based on the historical events than to run various what-if scenarios. The outcome of this thesis examines the effectiveness of RHF by comparing the output data from the actual event to models with RHF implementation.

CHAPTER 1. INTRODUCTION

This chapter provides the thesis overview of this thesis research by discussing the background, problem statement, significance, assumptions, limitation, delimitation and summary.

1.1 Background

The 1999 Columbine High School Shooting changed the perception of active shooter mitigation strategies for the first responders and the civilian communities. During the Columbine incident, the first responders were unable to enter the school premise until the Special Weapons and Tactics (SWAT) team was on-site. Additionally, an immediate evacuation was not initiated for staff and students to escape from danger. The lack of active shooter centered mitigation policies in 1999 increased the casualty rates among high school staff members and students. The traditional mitigation tactics such as "Shelter-in-Place" were not effective during Columbine due to the shooters' high mobility unlike traditional emergencies. Therefore, implementing an active shooter mitigation policies make a great impact in our everyday lives, and policies without the proof of effectiveness could yield negative consequences.

To better mitigate the increasing rate of ASI, the City of Houston, Texas developed the RUN.HIDE.FIGHT.® (2012) mitigation strategy to lower casualty rates during ASI . The RHF was developed under the Ready Houston program which was funded by the Federal Emergency Management Agency. The RHF advises unarmed individuals to “run” away from the shooter, ideally seeking the nearest exits, “hide”, if unable to run from the shooter and lastly, ”fight” the shooter when your life is at imminent danger. This concept could be used interchangeably where the course of action is determined by unarmed individual to either “run”, “hide” or “fight”.

The RHF or responses similar to RHF were implemented among private and public sectors. All four branches of the United States military trains and applies RHF tactics to mitigate on-base ASIs (Ready Marine Corps, n.d.), (Ready Navy, n.d.), (U.S. Army, n.d.), (U.S. Air

Force, n.d.). The Department of Education recommends the RHF under the Readiness and Emergency Management of School program (DOE, 2013). The Department of Homeland Security (2008) recommends “Evacuate”, “Hide Out”, and “Take Actions” under the active shooter handbook . The Indiana State Police (Hogue & Indiana State Police, 2015) recommends Escape/Run, Lockdown/Hide, or Fight. Finally, the Santa Ana Unified School District (Santa Ana Unified School District, n.d.) in California recommends RHF while emphasizing the importance of following instructions by the students from the teaching staff. The RHF or the RHF alike are implemented throughout the nation at various levels of public organizations.

The RHF and its subsidiaries lack in proof of effectiveness to lower casualty rate during ASI, despite its popularity. The Ready Houston web page explains the RHF application as well as advising what to do once law enforcement arrives and how to communicate to the 911 operator (2012). However, neither the Ready Houston nor the City of Houston’s web-pages has proof of the RHF’s effectiveness. The implementation of policies that are not proven to be effective could cause another Columbine like incidents as the occurrence of ASI arises. This thesis assessed the effectiveness of the RUN.HIDE.FIGHT.® response in lowering the casualty rate of the students and staff memebers in the Columbine High School’s library during the day of the incident.

1.2 Problem Statement

The current active shooter incident (ASI) response for unarmed individuals lacks in supporting research literature. The law enforcement communities’ (LECs’) active shooter response has changed drastically since the Columbine. Prior to Columbine, evacuation or “Shelter-In-Place” (Occupational Safety and Health Administration, n.d.) were predominantly used during the majority of emergency situations. As seen in Columbine’s library, the students were instructed to “Shelter-In-Place”. However, traditional emergency response policies were not sufficient to mitigate ASI due to shooters’ characteristic and randomness since the threat’s origin no longer stationary.

The ASIs complexity have changed the LEC, public and private sectors' mitigation policies for the ASIs. The policy improvements for LEC included collaboration with the local community, operating incident command system, and applying first aid to gunshot wounds (Scott & Schwartz, 2014). In addition to the LEC progress, the private and public sectors have either implemented the RUN.HIDE.FIGHT.® (RHF) by the City of Houston, or developed a RHF alike mitigation plan to lower the casualties. The complexity of ASI not only prepared the LEC and the first responder agencies but also the civilian communities to better mitigate future active shooter incidents.

1.3 Research Question

Does the RUN.HIDE.FIGHT.® implementation during the 1999 Columbine High School shooting in the library lowers the casualty rate from the historical incident?

1.4 Significance

The FBI (2016) reported the rate of active shooter incidents, as well as the rate of casualties were on the rise. Among active shooter incidents (ASIs) between 2000 to 2016, the annual average rate rose from 7.4 incidents (00-08) to 19.1 incidents (09-16). Additionally, over 70 percent of ASIs have occurred in either in the areas of commerce or in educational facilities, which were densely populated (Blair & Schweit, 2013). Furthermore, over 69 percent of ASIs were terminated within 5 minutes, and 36 percent within 2 minutes (Blair & Schweit, 2013). Finally, 60 percent of ASIs have terminated prior to the first responders' arrival (Blair & Schweit, 2013). The increasing frequency of ASIs in populated areas within a short duration challenges both the first responders and the general public to implement and execute the mitigation strategies.

The significance of this research derives from the lack of supporting literature of the RUN.HIDE.FIGHT.® (RHF) response. As witnessed in Columbine, implementing policies that are not proven to be effective such as "Shelter-In-Place" could potentially increase the casualty rate of unarmed individuals. For example, California Senator Feinstein introduced a bill to limit the sales of high capacity magazines and assault rifles. The purpose of Sen. Feinstein's bill was to reduce the number of casualties during ASIs. A study was conducted by Hayes and Hayes (2015) to prove the effectiveness of Sen. Feinsteins bill by using agent-based modeling (ABM). The study suggested that the bill would have a very little impact to lower the casualty rate in an instance of ASIs. In contrast, the study found that the rate of fire was one of the major contributing factors that increase the casualty rate. The Hayes and Hayes (2015) study not only assessed the effectiveness of Sen. Feinsteins bill but also found the major factor in increasing casualty rate which was the rate of fire.

1.5 Assumptions

The following assumptions are made in the study:

- Diagram 29, Diagram 47 to Diagram 89 accurately illustrates the historical incidents that have occurred in the school library during the 1999 Columbine High School shooting.
- Diagram 47 which is based for the model layout accurately represents the physical boundaries such as desks, chairs, book shelves, computer labs, and etc.
- As the RUN.HIDE.FIGHT.® response was initiated, all staff and student agents in the model will run, hide if unable to run, and fight if unable to hide from the shooter.
- The agents that are in the "run" phase will only evacuate toward the library's north door.
- The shooter agent will always seek for its nearest target during the RUN.HIDE.FIGHT.® implementation.
- The shooter agent will always hit the target once discharged.

1.6 Limitations

The limitations for this study include:

- The incident progression of the 1999 Columbine High School shooting is based on the event diagrams released by the Jefferson County Sheriff's Office, Colorado, United States of America.
- The model only recreates the incidents that have occurred in the library, not the entirety of event during the 1999 Columbine High School shooting.
- The earliest RUN.HIDE.FIGHT.® implementation could only occur after Diagram 29 which was 300 seconds after Diagram 1.

1.7 Delimitation

The delimitation for this study include:

- The individuals who were marked as the "WITNESS" in the diagrams were excluded as agent population during the validaiton phase.
- The effectiveness of RUN.HIDE.FIGHT.® was only measured among the incidents that have occurred in the library.
- The modern first responders tactics were not implemented to the model with no police intervention present.

1.8 Summary

The purpose of this research was to assess the effectiveness of RUN.HIDE.FIGHT.® (RHF) to lower casualties among events that have occurred in the library during the 1999

Columbine High School shooting. The creator of RHF, the City of Houston, Texas shares the instructional information on how to take actions during active shooter incidents to increase serviceability. Despite the RHF's nationwide implementation, there was a lack of literature to support the effectiveness of RHF. This study would examine the effectiveness of RHF by recreating the incidents that have occurred in the library during the 1999 Columbine High School shooting. The outcome of this research would better recommend policies to reduce casualty rates during future active shooter incidents.

CHAPTER 2. REVIEW OF LITERATURE

This chapter provides a review of the literature relevant to the problem of the active shooter incident backgrounds, active shooter mitigation research, first responder communities, and the general public's current mitigation policies.

2.1 Background of Active Shooter Incidents

The 1999 Columbine High School shooting was an active shooter incident (ASI) where two high school students intentionally discharged firearms at their fellow staff and students. Columbine was an inciting incident for the law enforcement communities (LEC) and the general public to better mitigate future ASI. According to the Department of Homeland Security's study, an active shooter is an "individual actively engaged in killing or attempting to kill people in a confined and populated area, typically through the use of firearms" (Department of Homeland Security, 2008). Despite the effort, the frequency of ASI has increased despite the LEC efforts to mitigate such events. According to the FBI (2016), the annual average of ASI rose from 7.4 (from 2000-2008) to 19.1 (from 2009-2016). Furthermore, the majority of shooters commit suicide before the police arrive on scene (Scott & Schwartz, 2014). Additionally, 69% of ASI ended within 5 minutes or less and 36 percent ASI ending in 2 minutes or less (Blair & Schweit, 2013). Finally, 41.5% of police arrived on scene between 11 to 60 minutes followed by 24.99% arrival on the scene between 6 to 10 minutes. (Maston & Klaus, 2011). The short duration of ASI that ends prior to LEC's arrival challenges the unarmed individuals and first responders.

2.2 Law Enforcement Communities Response to Active Shooter Incidents

After the Columbine shooting, the law enforcement community (LEC) had developed new tactics when responding to active shooter incidents (ASIs). The new tactics were necessary since the origin of threat during ASI was not stationary unlike the traditional emergencies such as fire, tornado, chemical leak, etc. For example, the school resource officers (SROs) are often considered to be the shooter's primary contact. However, to increase the officer's safety, some agencies require SRO to stand-by until the contact team is formed (Scott & Schwartz, 2014). The minimum requirement for the contact team is 3 to 4 officers which provide more than 180 degrees of the visual span. While the contact team's role is to apprehend the shooter, it is the rescue team's mission to assist the injured and/or uninjured to provide safety. In addition to the rescue operation, the rescue team also provide intelligence to the contact team and the incident command. Establishing incident command became a vital part of the ASI response. According to the Federal Emergency Management Agency (FEMA), the purpose of the incident command is to enable "incident managers to identify the key concerns associated with the incident" (2017). The operational integrity of the incident command during an ASI is time sensitive due to a short duration, unlike other emergency incidents. The current policies recommend the initial incident commander to either continue his or her role regardless of their rank until the end of the situation, or either transition the commander's role to a higher ranking officer upon arrival after full briefing of the situation. The LEC tactics and training method reiterates the importance of the contact teams' primary goal of apprehending the shooter.

In addition to the ASI policy development among the first responder communities, training offerings focusing in ASI were provided as well. The Advanced Law Enforcement Rapid Response Training (ALERRT) by Texas State University trains officers concentrating in ASI. The facility is recognized as the National Standard in Active Shooter Response Training where more than 105,000 officers have been trained since 2002 (ALERRT, n.d.). ALERRT also conducts research under the Criminal Justice Research Department to maintain concurrent training standards as new ASI emerge. The ALERRT also hosts the National Active Shooter Training Conference each year where LEC, fire and rescue and emergency medical service affiliates contribute their experience to "build local, regional, state and national active shooter response preparedness" (ALERRT, n.d.). The ALERRT not only provides ASI prevention and response procedures for the first responders but also conducts academic research approach on how to improve policies and tactics among multidisciplinary first responders.

2.3 Application of Unarmed Responses for Public and Private Sectors

The ALERRT also trains civilian response to ASI known as the AvoidDenyDefend™ (Texas State University, 2004). The AvoidDenyDefend™(ADD) response method gradually replaced the evacuate and shelter-in-place response, which was common during the pre-Columbine era. ADD can be used interchangeably among the three responses by the unarmed individuals' discretion to either avoid, deny or defend, whereas traditional responses only provided one option. ADD proactively encourages unarmed individuals to "avoid" the shooter by escaping from the threat while increasing awareness of his or her surroundings. If unable to avoid the shooter, "deny" the shooter by either seeking shelter in a secured location or barricade the entrance to deny the approach from the threat. If unable to deny the shooter, "defend" yourself by using any means necessary to deter the shooter's objective. Deterrence could be weapons sharp office supplies or throwing heavy books at the threat. ADD provides multiple options for the unarmed individuals which could be used interchangeably during an ASI based on the individuals discretion.

In 2012, the City of Houston developed the RUN.HIDE.FIGHT.® (RHF) unarmed response. The RHF method encourages unarmed individuals to "run" when an active shooter is in your vicinity by attempting to evacuate regardless of others consensus. "hide", if evaluation is not possible by physically removing yourself from the shooter's vicinity while minimizing noise that could reveal your location. Finally, "fight" the shooter as a last resort, and only if your life is in danger by improvising with weaponized objects to apprehend the shooter. RHF recommends similar approaches similar to ADD where the individual can choose the optimal response to increase the probability of survival during ASI.

The interchangeable unarmed responses like RHF are recommended by the federal government organizations. The Department of Homeland Security (DHS) has a three-step response known as “Evacuate”, “Hide Out”, and “Take Action”(2008). The *Evacuate* response recommends all personnel to move away from the threat by using “accessible escape path” and ”attempt to evacuate the premise” (DHS, 2008). The “Hide Out” is recommended when “evacuation is not possible” where you should “find a place to hide where the active shooter is less likely to find you”. Lastly, DHS recommends to “Take Action” against the active shooter which is reserved as a last resort to be used “when your life is in imminent danger”. DHS provides interchangeable options to ASI mitigation for unarmed individuals that is similar to ADD and RHF.

The state-level public safety organizations also recommend interchangeable ASI response for unarmed individuals. The Indiana State Police (ISP) recommends “Escape/Run”, “Lock-down/Hide”, or “Fight” (ISP, 2015). “Escape/Run” from the shooter by removing yourself and other from the shooter by taking the secured path to a predetermined or confirmed secured area while attempting to sound an alarm promote evacuation of others. “Lock-Down or Hide” if “a secure path or an exit site is not a certainty” by barricading the environment with larger furniture and objects. Finally, “Fight” when faced with imminent danger by taking lethal action to decapitate the shooter using nearby objects as weapons. The ISP’s Escape/Run, Lock-down/Hide or Fight can be used interchangeably, also similar to the ADD and RHF responses.

The non-public safety organizations began to implement unarmed response to mitigate ASI as recommended by the federal and the state level public safety organizations. The Department of Education (DOE) operates the Readiness and Emergency Management for Schools (REMS) program which recommends RHF application (2013). REMS also emphasize the importance of immediate response when threats are detected by referring how the delayed responses have increased the casualty rate during the 9/11 attack and the Virginia Tech. RMES recommends staff and students to be familiar with the infrastructure of their institution and run away from the shooter once the threat is detected without hesitation. Hide when unable to run by entering a location where the walls might be thicker and have fewer windows. Finally, fight if running or hiding from the threat is not possible. The REMS incorporates RHF to mitigate ASIs within the educational institutions. However, REMS also cautions the reader that RHFs "materials may or may not be relevant to the institution of higher education (IHE), as they are not for an IHE setting" (DOE, 2013). RMES recognizes potential implementation issues for RHF in IHE environment which may increase casualty rate.

The Santa Ana Unified School District (n.d.) has fully incorporated RHF as part of the ASI response. The district has created three RHF training videos in order to meet the level of understanding among students while guiding instructors on how to successfully lead students to safety. All three videos recommend RHF while emphasizing the importance of their instructors' leadership, especially in the elementary school environment. The district recommends to "hide" from the threat by either exiting the door or breaking the window while assessing the proximate distance from the shooter to the students. During the "hide" response, all personal belongings should be left behind and all individuals in the "hide" phase must keep advancing until they arrive in a secured area. Individuals must "hide" if instructed via public announcement and initiate lockdown procedures. The point of entry must be blocked with furniture, lights turned off, and seek refuge within the space until help arrives. The "fight" response is recommended as a last resort. The district recommends utilizing school supplies to apprehend the shooter. During these confrontational phases, the instructor must lead all students to run as far away from the shooter by using the escape routes. The district also recommends all schools apply RHF that best suites campus infrastructure to maximize the potential of RHF application. Despite the RHF's application within the school district, the individual students are not allowed to make decisions on whether to "hide", "hide" or "fight". The Santa Ana Unified School District uses RHF to mitigate ASI while emphasizing the importance of following instructions for students, and emphasizing the instructors' leadership.

2.4 Privatized Unarmed Responses

Private organizations provided ASI mitigation training which consisted of interchangeable response protocols similar to ADD and RHF. The ALICE (Alert, Lockdown, Inform, Counter, Evacuate) Training Institute is geared toward training school administrators and staff on how to respond and survive ASI (ALICE Training Institute, n.d.). The purpose of the “alert” mechanism in ALICE training is to share information via campus-wide alert system or by the public announcement. The primary focus of “alert” is to motivate individuals within the infrastructure to seek refuge from the shooter, “lock-downs”. Once physically separated from the threat by creating a barricade from the threat, “inform” the local authorities to help detect the shooter. ALICE recommends providing even the smallest detail to the police which could help to reduce the response time. If the shooter is able to make entry your location, “counter” the shooter by using objects or furniture to apprehend the shooter while attempting to “evacuate”. In addition to ADD and RHF response concept, ALICE provides training and certifies educational institutions by the ALICE instructor. ALICE training not only provides training to mitigate ASI for administrators and staff but also certifies schools to be ASI ready.

In contrast to responsive training as mentioned above, FASTER (Faculty/Administrator Safety Training and Emergency Response) Saves Lives is a proactive training course that not only focuses in personnel training but also the infrastructure of the institution. FASTER consists of five actions (1) take preventative measures, (2) harden the physical building, (3) develop the right mindset, (4) arm the school staff, and (5) learn trauma combat casualty care (FASTER Saves Lives, n.d.). The FASTER program primarily focuses on training teachers to conceal carry firearms to mitigate potential ASI as a deterrent to the shooters’ objectives. FASTER suggests the duration of training school staff is more efficient than training officers since the primary focus is to apprehend the shooter. Additionally, the training is conducted with individuals who are comfortable carrying weapons and willing to use the firearm to protect both themselves and the students from the shooter. FASTER training exemplifies ASI where a concealed carrier or an armed guard have successfully apprehended the shooter prior to the LEC arrival. FASTER promotes conceal carry of firearm training to the willing individuals within the educational environment to proactively apprehend the shooter with the deadly force.

2.5 Lack of Supporting Literature to Support the Effectiveness of RUN.HIDE.FIGHT.®

Despite the nationwide application of ASI response for both first responders and the civilians, there is limited literature and the quantitative research to support the effectiveness of the RUN.HIDE.FIGHT.® (RHF). The primary obstacle in researching unarmed response is the higher likelihood of violating research ethics. In order to gather the reliable ASI data, initiating a mock active shooter incident without notice would be an optimal solution. This would make the participants unaware of the situation where genuine responses such as evacuation delay, police response time, and the projected casualty rate could be collected. However, even the mock ASI presents a unique set of psychological challenges which could be presumed as an unethical research method. According to the DHS, victims of ASI may experience "post-traumatic stress disorder or other anxieties" where mental health counseling should be part of the recovery effort among ASI survivors (2017). The ethical research approach is the core challenge when gathering accurate research data. According to Briggs and Kennedy (2016) "it would be ethically impossible to create a true life-or-death situation in which individuals would response with potentially lethal force". Thus, there is a limited number of active shooter research. The characteristic of the ASI increases the possibility of the psychological trauma of the participants which limits the active shooter research.

In addition to the ethical issues, collecting reliable data during mock ASI is challenging since the repetitive tasks could change the participants' behavior. Behavioral changes due to repetitive task could decrease the action delay and increase the rate of proactive response which could add bias to the data. The behavioral change that occurs from doing consistently repetitive tasks is known as the demand characteristic. According to the Dictionary of Psychology, "an experimental situation that encourages certain types of behavior to form the research participants or subjects and can contaminate the result, especially when the behavior arises from research participants expectations or preconceptions or from their interpretations of the experimenters expectations" (Colman, 2015). The genuine response to the active shooter may differ since the demand characteristic would change the participating individuals' response. Finally, the vast majority of ASIs takes place in either commercialized or an academic environment, which is predominantly occupied by unarmed individuals. The daily use of these environments limits the opportunity for the first responders to conduct full-scale exercises that could accurately replicate an ASI.

2.6 Research Flexibilities of Agent-Based Modeling

The agent-based modeling (ABM) research method overcomes the ethical, psychological, and logistical challenges that the real-life exercise presents. The ABMs are conducted in a virtual environment where research ethics such as human rights violation or the Institutional Review Board's approval is not necessary. This would allow the researcher to collect data during hypothetical ASIs while the agents freely interact with one another under the sets of parameters. ABM benefits the researcher to validate the model by recreating a historical ASI, then manipulate the parameters to extract the data to assess the effectiveness of current policies. "A key to understand complex system such as human beahvior is using the computational modeling approach"(Ravandi & Mili, 2019). For example, parameters such as cognitive delay for the unarmed individuals, the probability of "hide", "hide" or "fight", the rate of fire of the shooter and the police response time could alter the agents' response. The ABM's virtual environment allows researchers to gather data while eliminating the ethical and human error issues are nonexistent.

The ABM is also capable of collecting social interactions among agents. Traditional models are equation-based which could illustrate dynamics of gases, fluids, or solid bodies (Balietti, 2012). Though these models are not suitable for collecting data based on human interactions, the ABM could customize its agents' "needs of resources", "perception", "emotions", and the tendency to have relationships with other agents (Helbing, 2012). The human and social factors are crucial in measuring the effectiveness of unarmed responses during ASI. Helbing states that the sociological modeling by ABM is capable of measuring how "individual respond to their own and other peoples future expectation" (2012). The ABMs ability to measure social and human interaction suggests ABM is suitable as a measuring tool to examine unarmed response for AIS.

The ABM can measure emergent phenomena, which are result from the interactions of individual entities (Bonabeau, 2002). Emergent phenomena in ABM allows researchers to collect data during ASI among the shooter and unarmed individual agents. Each agent will make its decision based on the sets of parameters that were implemented prior to starting the model. For example, if the number of active shooters is increased to 5 from 1, then the interaction between the unarmed individual and the shooter agent would change. Gathering data by allowing agents to freely interact with one another during the simulation and utilize space and obstacles are an effective research method which incorporates the situational uniqueness of active shooter incidents.

The ABM is capable of illustrating natural interactions among agents which could be used when describing and simulating a system composed of behavioral entities (Bonabeau, 2002). In one test run, natural interactions between the shooter and the unarmed individual agents are necessary to procure accurate data. Additionally, measuring natural interactions among agents within the sets of behavioral parameters such as evacuation speed or the shooter discharge range is more realistic than coding individual response among each agent. The natural interactions also illustrate congestion of population that would cause a delay in evacuation or decision making factors among civilians to determine whether to run, hide or fight based on the user's discretion. The ABM allows collecting ASI data by creating an environment where multiple agents could freely interact with one another under the parameters where making quantitative policy decisions could be made.

Finally, the agent-based model is “flexible” (Bonabeau, 2002) where the modification to the model can be easily made. Flexibility in models entail “behavior, degree of rationality, ability to learn and evolve, and rules of interactions can be made” (Bonabeau, 2002). The flexibility component could be applied to increase or decrease the discharge interval, the speed of the shooter, or the evacuation speed among unarmed individual agents. The flexibility of ABM allows the researcher to cross-compare different active shooter scenarios after the model validation within one model without needing to reconstruct the core components of the model.

2.7 Agent-Based Modeling Application in Active Shooter Research

Several quantitative research was conducted to recreate ASI using ABM. Hayes and Hayes used ABM to prove the effectiveness of Sen. Feinstein’s bill which bill was intended to limit the usage of assault weapons and high-capacity magazines (2015). This study suggests that ABM is effective to test the bill’s applicability since “each agent is chosen in random order and allowed to make an action” in accordance with the predetermined behavioral parameters (2015). In the model, the unarmed civilians’ parameters had the ability to escape to the nearest door once the shooting began while manipulating their escape velocity and consistently moving away from obstacles. The shooter’s parameters were set to aim at the nearest civilian, the amount of ammunition, and approach the next target. The study tested the indoor and outdoor models which had three agents: armed security guards, civilians and the shooter. The model terminates when the shooter is apprehended by the armed security guard or all civilians escape via the nearest exits. The research concluded that the bill did not address the rate of fire which was the highest contributing factor which increased the casualty rate. The modeling also suggested that banning high capacity magazines would only lower the discharge rate to 12 bullets per minute which is minimal in lowering casualty rate. The study suggests banning semi-automatic weapons and the detachable magazine would lower the rate of discharge rate. Hayes was able to test the effectiveness of Sen. Feinstein's bill by using agent-based modeling where the bill was predicted to make less impact in lowering casualties than intended.

Kirby (2015) used ABM to test the effectiveness of firearm countermeasures by the school resource officer and/or conceal carry individuals within the higher education system. The study used ABM since the modeling technique could best measure human systems (Anklam III et al., 2015). There were four total distinct scenarios: (1) a school with no physical security mechanisms such as access control and security protocols, (2) a school with 5 to 10 percent of the workforce carrying concealed firearms, (3) a school with an armed school resource officer, and (4) a school with a resource officer while 5 to 10 percent of the workforce conceal carrying a weapon. As mentioned in the Bonabeau's study, ABMs can be easily customized by adding parameters that would create user-friendly scenarios. Among all four models, the first scenario had the highest casualty rate. In contrast to the first scenario, the other three scenarios with firearm countermeasures decreased the casualty rate. The lowest casualty rate was 69.9 percent (Anklam III et al., 2015) compared to the first model. Kirbys model also found that the police response time is another contributing factor in decreasing the casualty rate. Kirby used ABM to examine the effectiveness of physical security, the firearm countermeasures from the instructor, and/or resource officer while emphasizing the correlation from police response time to lower casualty rate.

Briggs and Kennedy (**?**) used ABM to test unarmed resistance during active shooter incidents (ASI). The RHF response is fully implemented where the fighters, fleers and the shooter agents are naturally interacting in an open landscape. Once the shooter begins to discharge ammunition, the fighter agents approach the shooter while the fleeing agents attempt to escape. The models were repeated over 500 times with both "control and experimental conditions" (**?**). The research result states that the shooter was subdued 67 percent of the time by fighter agents while the mean casualty rate remained at 30. In contrast, the casualty rate rose from 30 to 63 on average when the shooter was not subdued. The Briggs and Kennedy research suggest that taking proactive action against the shooter could lower the casualty rate in contrast to all run method.

Stewart (2017) used ABM to understand the impacts of the police response and civilian evacuation to lower the number of causalities. Three factors (cognitive delay, police response time and civilian response strategy) are implemented to determine the highest contributing factor that increases the casualty rate. ABM was used in Stewart's model since assessing various models with multiple agents could help determine the contributing factor in increasing casualty rate. This study suggests that the rapid police response time decreases the number of casualties among models. According to Stewart (2017), the "police response time has the largest impact on the number of casualties". The research also suggests the casualty rate is at the lowest between "30-seconds and 1-minute" of the police response time where it was compared to models with a 5-minute delay (Mackenzie, 2017). Finally, run or hide had the lowest casualty rate from either all run or all hide response for the unarmed individuals. Stewart used ABM to determine the contributing factor that lowers the casualty rate during an active shooter incident.

2.8 Summary

The purpose of this literature review is to review the ABM (agent-based modeling) research which concentrates on the active shooter incidents to lower the casualty rate by implementing interchangeable unarmed responses like RUN.HIDE.FIGHT.®. The study by Briggs and Kennedy (**?**) implements RHF response to ABM, however, the research is conducted in an open environment. The FBI's (2013) ASI report states that indoor infrastructures such as school or commercialized areas have the highest occurrence of ASI. The Briggs and Kennedy research implements RHF on ABM, however, the model set is an outdoor environment which contrasts this thesis' model. Stewart's study (2017) ABM is set in school infrastructure and only the part of the RHF response is implemented. The valid examination of RHFs effectiveness is not possible without the "fight" component. The "fight" component is missing in the model since attempting to apprehend the shooter could terminate the ASI in advance. Both Briggs and Kennedy (**?**) and Stewart's (2017) study used ABM to test the effectiveness of unarmed response during an ASI. Despite the presence of multiple quantitative research focusing on ASI via ABM to test the RHF's effectiveness, neither study meets the criteria of this thesis research objective.

CHAPTER 3. RESEARCH METHODOLOGY

This chapter provides the research methodology of physical infrastructure, agents location, model validation, and data collection by using agent-based modeling (ABM) with AnyLogic.

3.1 Active Shooter Mitigation Strategies

The purpose of this model is to compare the casualty rates of staff and student members from the events occurred in the library during the 1999Columbine High School shooting to the models with RUN.HIDE.FIGHT.® implementation. The RHF was created by the City of Houston in 2012 with strong similarities to the Avoid Deny Defend (ADD) that was created by the Texas State University in 2004. Despite the RHFs nationwide application in both the private and the public sector, the literature suggesting the effectiveness of RHF is limited. The practicality to lower casualty rates of ADD and RHF during ASIs are significant since unlike the traditional emergency response, such as Evacuate and "Shelter-In-Place", are no longer to be effective since the origin of danger is not stationary.

3.2 AnyLogic Software

The AnyLogic software was chosen for this research. The AnyLogic supports the discrete event, agent-based, and system dynamic capabilities that could be used interchangeably which increases diverse data output. The agent-based method of AnyLogic is predominantly used to recreate interactions among active shooter, staff, and student agents that takes action based on the actual events. For example, the Pedestrian Type agents from the Pedestrian Library individually take actions based on the default parameters from real events, and the RHF parameters such as evacuation delay, run probability, shooters movement speed and etc. To realistically recreate the shooter agents line of sight when discharging their weapons, a Rectangular Area from the

Presentation Palette was used to determine the location which limits who is and is not a potential target. The AnyLogic's flexibility to interchangeably use library offerings increases the models realism to the actual event and RHF what-if scenarios.

3.3 Physical Layout

The model layout created based on 42 incident diagrams published by the Jefferson County Sheriffs Office (SOURCE). The scale of this model was set to one foot equaling 3.75 pixels by assuming the width of the door is three feet. The physical barriers were implemented by Wall, Rectangular Wall, Rectangular Area, and Target Line markups from the Pedestrian Library. The Wall markups were used to create the walls to limit the agents access to a different space such as hallway and office areas. The Rectangular Walls were then used to create countertop, desks, seating furniture, and bookshelves. The Rectangular Area covers the whole library was used to place the Attractors for all agents location based on the diagrams. Finally, the Target Line markups were used as doors which could both be used for entrance and exit among agents.

3.3.1 Line of Fire Implementation

The model layout is divided into 83 Rectangular Area space markups as seen in Figure 3.1. The purpose of creating different areas is to realistically implement the limitations of the line of fire (LOF) due to the phsyical obsticals. Each area has a designated “Collection” that updates every .1 second by the “Event” both from the Agent Component of the Agent Library. For example, if an agent begins their journey from area 1, then the “Event” will add the agent to the area 1 collection. As soon as the agent leaves the area 1 and enters area 8, the event will remove the agent from the area 1 collection, and add to area 8 collection which applies to all agents in the model.

There are two separate collections in the model to implement the line of fire. The first collection consists of the qualifying areas that are part of the life of fire. For example, the area 22

LOF collection will have area 5, 11, 17, 22, 28, 33, and 40. The area 10 LOS collection will have area 1, 2, 3, 8, 9, 10, 13, 14, 15, 21, 26, 32, and 38 in the collection. The second collection consists of all agents that are part of the line of fire area. For example, the agent collection for the area 22 will consist of agents from 5, 11, 17, 22, 28, 33, and 40.

Table 3.1.: Line of Fire Area Collections per Area

Area	**LOS Collection**
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10 , 13, 14, 15, 24, 31, 35, 44, 48, 56, 61, 69, 76
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, 20
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, 20, 26, 32, 38
4	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
5	1, 2, 3, 4, 5, 6, 7, 11, 17, 22, 28, 33, 40
6	1, 2, 3, 4, 5, 6, 7, 11, 12
7	1, 2, 3, 4, 5, 6, 7, 11, 12, 19, 23, 30, 34, 43, 47, 55, 60, 68, 75, 83
8	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 20, 24, 31, 35, 44, 48, 56, 61, 49, 76
9	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 20, 21
10	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 20, 21, 26, 32, 38
11	4, 5, 6, 11, 17, 22, 28, 33, 40
12	6, 7, 12, 18, 19, 23, 30, 34, 43, 47, 55, 60, 68, 75, 83
13	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 25, 31, 35, 36, 44, 48, 56, 61, 69, 76
14	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21
15	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21, 26, 32, 38
16	8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22
17	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23
18	11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23

Continued on next page.

Table 3.1 – continued from previous page

Area	LOS Collection
19	7, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23, 30, 34, 43, 47, 55, 60, 68, 75, 83
20	1, 2, 3, 4, 8, 9, 10, 13, 14, 15, 16, 20, 24, 25, 31, 35, 36, 44, 48, 56, 61, 69, 76
21	3, 10, 14, 15, 16, 21, 25, 26, 27, 32, 38
22	5, 11, 16, 17, 18, 22, 27, 28, 29, 33, 40
23	7, 12, 18, 19, 23, 29, 30, 34, 43, 47, 55, 60, 68, 75, 83
24	1, 8, 13, 20, 24, 25, 26, 27, 28, 29, 30, 31, 35, 44, 48, 56, 61, 69, 76
25	20, 21, 24, 25, 26, 27, 28, 29, 30, 31, 32
26	3, 10, 15, 21, 24, 25, 26, 27, 28, 29, 30, 32, 38
27	21, 22, 24, 25, 26, 27, 28, 29, 30, 32, 33
28	5, 11, 17, 22, 24, 25, 26, 27, 28, 29, 30, 33, 40
29	22, 23, 24, 25, 26, 27, 28, 29, 30, 33, 34
30	7, 12, 19, 23, 24, 25, 26, 27, 28, 29, 30, 34, 43, 47, 55, 60, 68, 75, 83
31	1, 8, 13, 20, 24, 25, 35, 36, 44, 48, 56, 61, 69, 76
32	3, 10, 15, 21, 25, 26, 27, 32, 37, 38, 39
33	5, 11, 17, 22, 27, 28, 29, 33, 39, 40, 41
34	7, 12, 19, 23, 30, 34, 43, 47, 55, 60, 68, 75, 83
35	1, 8, 13, 20, 24, 31, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 48, 56, 61, 69, 76
36	31, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44
37	32, 35, 36, 37, 38, 39, 40, 41, 42, 43
38	3, 10, 15, 21, 26, 32, 35, 36, 37, 38, 39, 40, 41, 42, 43
39	32, 33, 35, 36, 37, 38, 39, 40, 41, 42, 43
40	5, 11, 17, 22, 28, 33, 35, 36, 37, 38, 39, 40, 41, 42, 43
41	33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43
42	34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 46, 47, 53, 54, 55, 60

Continued on next page.

Table 3.1 – continued from previous page

Area	LOS Collection
43	7, 12, 19, 23, 30, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 46, 47, 53, 54, 55, 60, 68, 75, 83
44	1, 8, 13, 20, 24, 31, 35, 36, 48, 49, 50, 51, 56, 57, 58, 61, 62, 63, 64, 49, 70, 71, 72, 76, 77, 78, 79
45	36, 37, 38, 48, 89, 50, 51, 56, 57, 58, 61, 62, 63, 69, 70, 71, 76, 77, 78
46	7, 12, 19, 23, 30, 34, 41, 42, 43, 46, 47, 53, 54, 55, 60
47	7, 12, 19, 23, 30, 34, 41, 42, 43, 46, 47, 53, 54, 55, 60, 68, 75, 83
48	1, 8, 13, 20, 24, 31, 35, 44, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 61, 62, 63, 64, 69, 70, 71, 72, 76, 77, 78, 79
49	44, 45, 48, 49, 50, 51, 52, 53, 54, 55,, 56, 57, 58, 64, 62, 63, 64, 69, 70, 71, 72, 76, 77, 78, 79
50	36, 37, 38, 45, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 61, 62, 63, 64, 69, 70, 71, 72, 76, 77, 78, 79
51	37, 45, 48, 49, 50, 51, 52, 53, 57, 55
52	48, 49, 50, 51, 52, 53, 54, 55, 59, 65, 73, 80
53	46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 59
54	42, 43, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 59, 60
55	41, 42, 43, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 60, 68, 75, 83
56	1, 8, 13, 20, 24, 31, 35, 44, 45, 48, 49, 50, 51, 56, 57, 58, 61, 62, 63, 64, 69, 70, 71, 72, 76, 77, 78, 79
57	44, 45, 48, 49, 50, 56, 67, 58, 61, 62, 63, 64, 69, 70, 71, 72, 76, 77, 78, 79
58	37, 44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 69, 70, 71, 76, 77, 78
59	51, 52, 53, 59, 64, 65, 66, 71, 72, 73, 74, 77, 78, 79, 80, 81, 82
60	42, 43, 46, 47, 54, 55, 60, 67, 68, 75, 83

Continued on next page.

Table 3.1 – continued from previous page

Area	LOS Collection
61	1, 8, 13, 20, 24, 31, 35, 44, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83
62	44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81
63	37, 44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
64	56, 57, 58, 59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
65	52, 59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
66	59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81
67	61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80
68	7, 12, 19, 23, 30, 34, 43, 47, 55, 60, 61, 62, 63, 64, 65, 66, 67, 68, 75, 83
69	1, 8, 13, 20, 24, 31, 35, 44, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
70	35, 44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 79, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
71	44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
72	44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81
73	52, 56, 57, 58, 61, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82

Continued on next page.

Table 3.1 – continued from previous page

Area	LOS Collection
74	56, 67, 58, 59, 61, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82
75	7, 12, 19, 23, 30, 34, 43, 47, 55, 60, 67, 68, 75, 82, 83
76	1, 8, 13, 20, 24, 31, 35, 44, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83
77	44, 45, 48, 49, 80, 56, 57, 58, 61, 62, 63, 64, 65, 66, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83
78	37, 44, 45, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 69, 70, 71, 72, 73, 76, 77, 78, 79, 80, 81, 82, 83
79	44, 48, 49, 50, 56, 57, 58, 61, 62, 63, 64, 65, 66, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83
80	52, 56, 57, 58, 59, 61, 62, 63, 64, 65, 66, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83
81	56, 57, 58, 59, 61, 62, 63, 64, 65, 66, 69, 70, 71, 72, 73, 74, 76, 77, 78, 79, 80, 81, 82, 83
82	69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83
83	7, 12, 19, 23, 30, 34, 43, 47, 55, 60, 68, 75, 76, 77, 78, 79, 80, 81, 82, 83

3.4 Variables and Parameters

Table 3.2 pertains the data output once each iteration is completed. Each iteration consists of 1,000 replications. The Output Title of Table 3.2 is the column headers of the output data. The Data Type is the data type of each column headers. The Description describes the origin of data generated from the model.

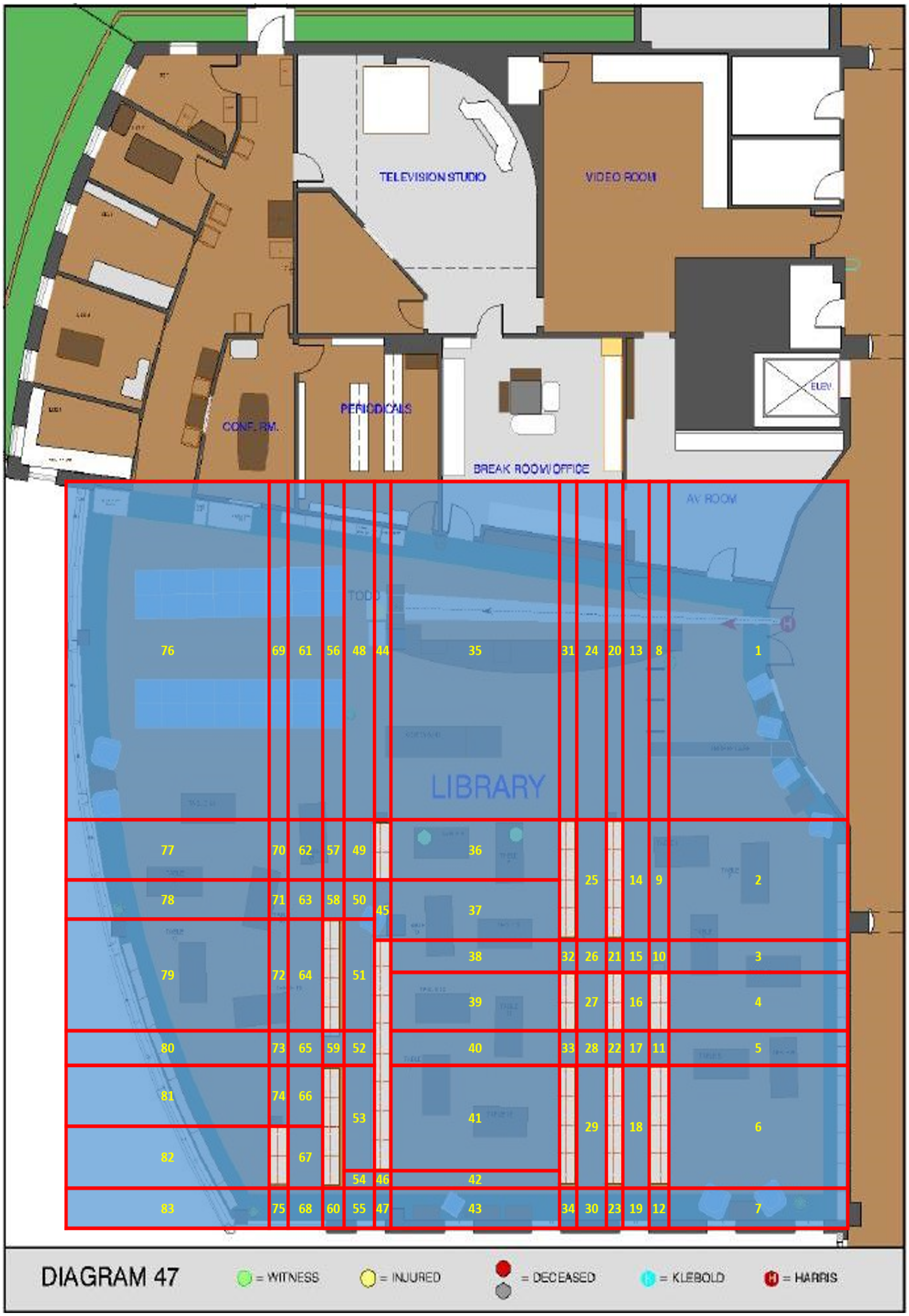

Figure 3.1. Columbine High School Library Area Division

Table 3.2.: Model Parameter and Data Type Overview

Output Title	Data Type	Description
duration_total	Double	The total model duration in seconds.
event_timer	Double	The total duration from Diagram 47 until the simulation stops.
action_delay	Double	The delay for staff and student agents to enter Phase 1 in seconds.
as_continue	Boolean	Returns True or False based on TBD.
ui_alive	Integer	The total number of staff and student agents that were in the State of Alive when the simulation stops.
ui_all_in_place	Boolean	Returns True or False based on all staff and student agents arriving at the assigned attractor based on actual events.
ui_death_before_trigger	Integer	The total number of staff and student agents that were in the State of either injured or dead when RHF is initiated by the action_delay.
ui_injured	Integer	Total number of staff and student agents that were in the State of Injured when the simulation stops.
ui_dead	Integer	Total number of staff and student agents that were in the State of Death when the simulation stops.
ui_casualty	Integer	The total number of staff and student agents that were in the State of either injured or dead when the simulation stops.

Continued on next page.

Table 3.2 – continued from previous page

Output Title	Data Type	Description
ui_potential_target	Integer	The total number of staff and student agents that were in the alive state when Run.Hide.Fight is initiated by the action_delay.
run_prob0	Double	The “Run”probability in Phase 1.
hide_prob0	Double	The “Hide” probability in Phase 1.
fight_prob0	Double	The “Fight” probability in Phase 1.
run_prob1	Double	The “Run” probability in Phase 2.
hide_prob1	Double	The “Hide” probability in Phase 2.
fight_prob1	Double	The “Fight” probability in Phase 2.
run_prob2	Double	The “Run” probability in Phase 3.
hide_prob2	Double	The “Hide” probability in Phase 3.
fight_prob2	Double	The “Fight” probability in Phase 3.
ui_run_sucess	Integer	The total number of staff and student agents that were in the State of alive that have completed the “Run” logic of Phase 1.
ui_run_casualty	Long	The total number of staff and student agents that were in the State of rhf_casualty during the “Run” logic of Phase 1.
ui_hide_total	Integer	The total number of staff and student agents that were in the State of alive that have completed the “Hide” logic of Phase 1.
ui_hide_total_casualty	Long	The total number of staff and student agents that were in the State of rhf_casualty during the “Hide” logic of Phase 1.

Continued on next page.

Table 3.2 – continued from previous page

Output Title	Data Type	Description
ui_fight_total	Integer	The total number of staff and student agents that were in the State of alive that have completed the "Fight" logic of Phase 1.
ui_fight_total_casualty	Long	The total number of staff and student agents that were in the State of rhf_casualty during the "Fight" logic of Phase 1.
ui_rh_casualty	Integer	The total number of staff and student agents that were in the State of rhf_casualty when the simulation stops.
ui_fight_range	Double	The range from the staff and student agents to the shooter to send the String message.
as_alive	Integer	The total number of shooter agents that were in the State of alive when the simulation stops.
shooter_exit	Integer	The total number of shooter agents that have exited the model by completing all actual events.
as_dead	Integer	The total number of shooter agents that were in the State of dead when the simulation stops.
as_range	Double	The shooter agents discharge range.
shooter_speed	Double	The speed of the shooter agents speed in feet per second.
discharge_scope	Double	The discharge scope of the shooter agents in degrees.
discharge_interval	Double	The discharge interval of the shooter.
as_hide_range	Double	The distance from the shooter to the staff and student agent to cancel from Phase 1.

Continued on next page.

Table 3.2 – continued from previous page

Output Title	Data Type	Description
as_fight_range	Double	The distance from the shooter to the staff and student agent to cancel from Phase 2.

3.5 Model Agents

This section discusses the agent populations' placement, movement during an actual event and RHF implementation.

3.5.1 Agents Population

The Pedestrian Type from the Pedestrian Library were used to create 2 shooter, 4 staff, and 52 student agents.

3.5.2 Agents Placement

The Attractor from the Pedestrian Library was placed within the Rectangular Area that works as the current or future destinations points per diagram. The Ped Source, and Ped Wait blocks from the Pedestrian Library were used to inject and place the agents at attractors. Once the staff and student agents arrive at their attractors, the 240 seconds delay begins where the agents remain stationary. The 240 seconds were the duration of staff agent dialing 911(Diagram 29) in the library to where Shooter A injures student agent (Diagram 47). The witnesses which were marked as a green oval among diagrams were placed to the model environment as part of the model totaling in 56 potential targets.

(a) (b)

Figure 3.2. (a) Diagram 47 by the Jefferson County Sheriff's Office (b) Diagram 48 by the Jefferson County Sheriff's Office

3.5.3 Agents Movement During Actual Events

The staff and student agents remain stationary at their assigned Attractor except for the two student agents. The first agent seeks shelter behind the front counter after obtaining injuries from the shooter as illustrated in Diagram 47 and 48 in Figure 3.2. The shooter and the student agents are initially placed to their designated attractors based on Diagram 47 by Ped Source and Ped Wait blocks from the Pedestrian Library. Once the student agent obtains injuries from the shooter, both agents advances to their next attractors initiated by Ped Wait based on Diagram 48. The agents' movement progression was initiated by the Event once all Boolean variables per Diagram returned true.

The purpose of the Boolean variable is to ensure all actions illustrated in each diagram such as INJURED, DECEASED, and the agents arrival to the assigned attractor is accomplished. For Diagram 47, three Boolean variables are set to False for one shooter agent's location, one student agent's location and state. The Boolean variable changes to Ture once the student agent obtains injuries, the student and the shooter agent arrive at their attractor. Then the Event component cancels the Ped Wait for the student and the shooter agent transitioning their location from Diagram 47 to 48. The similar logic applies to the rest of the logic which requires all actions to take place before progressing to future diagrams until Diagram 89 where the incidents covered in this thesis is terminated.

3.5.4 Staff and Student Agents Movement During RHF

The RUN.HIDE.FIGHT.® could be initiated after all the staff and student agents are in place which is when the 240 seconds delay from Diagram 29 to Diagram 47 begins. All agents could cancel from their block from either Ped Wait or Ped Go To connected from Diagram 47 to Diagram 89 to enter the Phase 1 of the RHF logic. The RHF logic is divided into three phases to fully represent the RHF programs suggestion. The program suggests to initially Run from the shooter, Hide from the shooter if not possible to Run, and Fight if not possible to Hide (source). Table 3.3 describes the default probabilities that are set on each phase.

Table 3.3. Default Run, Hide, and Fight Probability per Phase

Parameter	Phase 1 Probability	Phase 2 Probability	Phase 3 Probability
Run	1.0	0	0
Hide	0	1.0	0
Fight	0	0	1.0

Each phase begins with Select Output 5 block from the Process Modeling Library where the agents next action to either “Run”, “Hide”, or “Fight” is determined based on the probability set by the Parameter from the Agent components. Figure 3.3 illustrates the agents actions based on the run, hide, and fight.

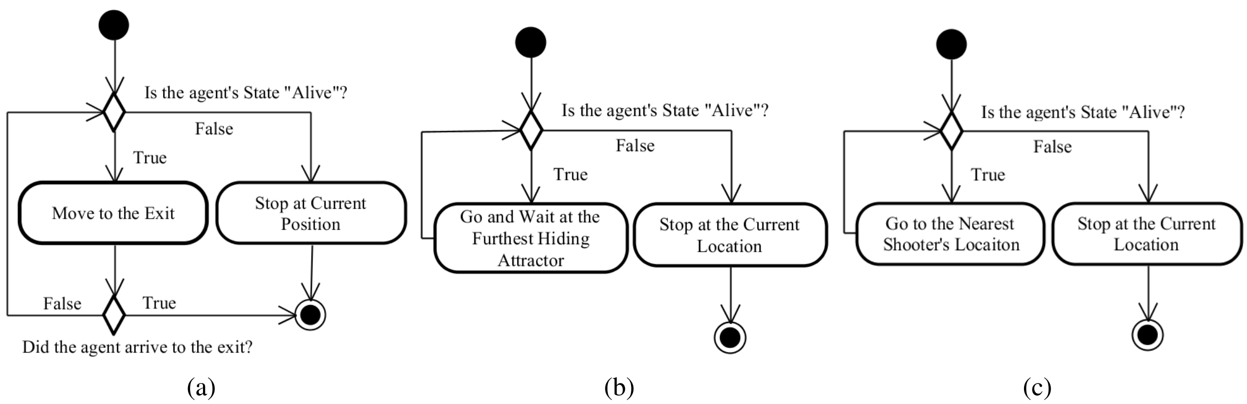

Figure 3.3. (a) Activity Diagram for the Run Logic. (b) Activity Diagram for the Hide Logic. (c) Activity Diagram for the Fight Logic.

The staff and student agents will all “Run” once the agents enter Phase 1 as RHF is initiated. The inability to run from the shooter is determined by the “as_hide_range” from the shooter to individual agents. If the agent is within the “as_hide_range”’s range, the agents cancel from Phase 1 and enter to Phase 2 to hide from the shooter. As the agents enter the Hide logic, the agents will move to the designated hide location located at the south east corner of the library. Finally, if the hiding agents are discovered by the shooter, the agent will fight the shooter by entering Phase 3 triggered by the “as_fight_range””. The fighting agents will charge at their nearest shooter by the Java Function that calculates the shortest distance from individual agents to the shooter agents that are in the Alive state. The nearest shooters location is updated per second.

3.5.5 Shooter Agents Movement During RHF

The shooter agents will approach their nearest potential targets among staff and student agents by a Java function. This function calculates the nearest distance from the individual shooter agent, to the rest of agents that are a potential target. To be considered as a potential target, the agents would have to be in the “Alive” state during the RHF implementation. Once the potential target is selected, the individual shooter agent will approach their target. The potential targets location is updated by one second.

3.6 Agents State

All agents are illustrated by an oval shape with the diameter of one foot. The color of the oval changes depending on the agent’s state. For example, all staff and student agents are colored black when in the “Alive” state. During the model runtime based on the actual events, the agent changes its color to either yellow (injured) or red (death). For the injuries or deaths occurred during the RUN.HIDE.FIGHT.® implementation, the staff, and student agents turns to the cyan color after receiving casualty from the shooters discharge. The casualty includes either injuries or death which sets the agent to remain at their location until the simulation is finished. The table below is the color variation of all agents based on the agents state.

Table 3.4. Default Agent Color by State per Agent

Agent	Not a Target	Alive	Injured	Death	Casualty (RHF)
Shooter A	NA	Red	NA	NA	Green with red outline
Shooter B	NA	Blue	NA	NA	Green with blue outline
Staff	Black	Black	Yellow	Red	Cyan
Student	Black	Black	Yellow	Red	Cyan

The Statechart Entry Point, State, and Transition from the Statechart Library were used to change the state of each agents. The staff and student agents enter the model in the state of Not a Target. Once all agents arrive in their location based on the diagrams created by the Jefferson County Sheriffs Office, the four minutes delay begins which was the duration of staff agent dialing 911 in the library to the point of Shooter A and Shooter Bs entering the library. After the four minutes delay, the agent changes their state from “Not A Target” to “Alive”.

3.7 Offensive Logic

3.7.1 Shooter Discharge Logic during Actual Events for Shooter Agents

A Java function was created to model the shooter agents firearm discharge to the staff and student agents. The for-loops were coded within this function that sends out String messages per .1 second that are within the discharge range. For example, if an agent were to obtain an injury from the shooter agent, then the “Injured String message would be sent out. Whereas if the target has died from the shooter agent, both the “Injured and “Death String messages are sent out to the targeted agent. These String messages change the state for staff and student agents from Alive to either Injured or Death during an actual event.

3.7.2 Shooter Discharge Logic During RHF for Shooter Agents

There are three different for-loops within the RHF discharge function. The first for-loop cancels the staff and student agents that are in Phase 1 as the agents Run toward the exit based on “as_hide_range”. The second for-loop cancels the staff and student in Phase 2 where the agents are hiding from the shooter by the “as_fight_range”. The third for-loop sends the String message of rhf to one selected agent among all potential target that is within the Arc at a random choice, not the nearest distance. The Arcs range and scope are determined by the “as_range” and “discharge_scope parameters”.

3.7.3 Fight Logic for Staff and Student Agents

The logic of the Fight Java function for staff and students are similar in concept with the shooter agents discharge logic. Since the close proximity is required to initiate Fight, the String message was delivered to the nearest shooter agent once within the “ui_fight_range”.

3.8 Conditions of Simulation Stop

The following conditions below will stop the simulation:

- The shooters complete all necessary tasks from diagram 47 to 89.
- The state of both shooters is dead.
- The total number of staff and student agents that have successfully escaped, and in the state of Casualty are 56.

3.9 Learning the Shooter Agent's Parameters based on Actual Events

The Parameter Variation experiments were conducted to learn the minimum value to recreate historical events within the 420 seconds of the "event_timer" which is the duration from Diagram 47 to 89. The following parameters below were manipulated for this experiment. Each iteration within each experiment consists of 1,000 replications.

3.9.1 Learning the Minimum Speed of the Shooter Agents

The first experiment consists of 9 iterations that increment the "shooter_speed" speed by 1 from 1 to 9. The agents speed that is the slowest will be chosen among "shooter_speed" that meets the "event_time" near the 420 seconds as the minimum agent speed. The second experiment consists of 10 iterations with .1 increment to the -1 of the experiment one output. For example, if the output value for experiment one is 3, then the experiment two will increment by .1 from 2 to 3. The third experiment consists of 10 iterations with .01 increment from a -.1 of the experiment two output. After the third experiment, the shooter agents' speed to the nearest hundredth is chosen as the "shooter_speed" parameter as a default. The "shooter_speed" will be used as the default speed to learn the discharge range and the scope. Table 3.5 describes the shooter agents' parameters after third experiment.

Table 3.5. Default Parameters for Experiment 1 to 3.

Output Title	Data Type	Default
shooter_speed	Double	Experiment 3
as_range	Double	100
discharge_interval	Double	.1
discharge_scope	Double	360

3.9.2 Learning the Minimum Range of the Shooter Agents

The fourth experiment consists of 10 iterations that increment the shooter agents discharge range by 10 from 10 to 100. Upon completion, the range that outputted the lowest range that meets the "event_time" equaling the 420 seconds will be initially chosen as the minimum discharge range. The purpose of choosing the lowest range is by assuming that there were additional range points that exist between the 10 step increments. The fifth experiment consists of 10 iterations that increments by 1 from the -10 of the experiment four output. Similar to the fourth experiment, the lowest range range for the fifth experiment will be chosen for the sixth experiment. The sixth experiment consists of 10 iterations that increments by .1 from the -1 of experiment five's output. The seventh experiment consist of 10 iterations that increments by .01 from the -.1 of experiment six output. After the seventh experiment, a double value with the nearest hundredth is chosen as the "as_range parameter".

Table 3.6. Default Parameters for Experiment 4 to 7.

Output Title	Data Type	Default
shooter_speed	Double	Experiment 3
as_range	Double	Experiment 7
discharge_interval	Double	.1
discharge_scope	Double	360

3.9.3 Learning the Discharge Interval of the Shooter Agents

As seen in Table 3.7, the Shooter A and Kelbold's total number of discharged rounds were 34 and 27 within the library. To determine the average discharge interval, the total number of discharged rounds were divided by 420 which is the total duration of two shooters in the library. As a result as seen in Table 3.8, the discharge interval for Shooter A is one round per 12.35 seconds, and Shooter B at one round per 15.56 seconds.

Table 3.7. Shots Fired by the Shooter A and B in the Library

Ammunition Type	Shooter A	Shooter B	Total
Shotgun Rounds	21	6	27
9MM Rounds	13	21	34
Total Fired	34	27	61
Discharge Interval within 420 Seconds	12.35	15.56	

3.10 Learning the Shooters' Parameters based on Experiment 3, 7 and the Discharge Interval

The parameter variation experiments were conducted to learn the minimum parameters to cause casualty rates from the historical events within the 420 seconds of the "event_timer". While the student and staff agents remain at their historical location, the shooter agents seek their target based on the targets' proximity. Each iteration within each experiment consists of 1,000 replications.

3.10.1 Learning the Discharge Scope of the Shooter Agents

The "shooter_speed", "as_range", and "discharge_interval" parameters were used to discover the discharge scope. The eighth experiment consists of 10 iterations that increment the shooter agents discharge scope by 10 from 0 to 90 degrees. Upon completion, the discharge scope that resulted in the nearest "event_time" to 420 seconds will be chosen as the experiment eighth's output. The ninth experiment consists of 10 iterations with 1 increment from -10 of the eighth experiment. The tenth experiment consist of 10 iterations with .1 increment from -1 of the ninth experiment. The eleventh experiment consist of .01 increment from -.1 of the tenth experiment. The final outcome of the eleventh experiment will be chosen as the "discharge_scope" parameter.

Table 3.8. Default Parameters for Experiment 8 to 10.

Output Title	Data Type	Default
shooter_speed	Double	Experiment 3
as_range	Double	Experiment 7
Shooter A's discharge_interval	Double	12.35 Seconds
Shooter B's discharge_interval	Double	15.56 Seconds
discharge_scope	Double	Experiment 11

3.11 Implementing Mitigation Tactics during Actual Events by Distance

A total of 10 parameter variation experiments that manipulates the "as_hide_range" and "as_fight_range" were conducted to assess the effectiveness of RUN.HIDE.FIGHT.® (RHF). The "as_hide_range" triggers the student and staff agents to hide by canceling their run activity from phase 1 based on their proximity to the shooter. Similarly, the "as_fight_range" triggers the student and staff agents to fight by canceling their hide activity from phase 2 based on their proximity.

The 12th experiment consisted of 11 iterations that increments the "as_hide_range" by 10 from 0 to 100 while "as_fight_range" is set to 0. The "as_hide_range" set to 0 resulted in the all "Run" scenario and 100 will result in all Hide scenario where the student and staff agents move toward the south east corner of the library. The RHF will be initiated at 240 of the model duration which is when two shooters enters the library based on the actual event. The shooter agents' discharge interval increment from Interval A to D as seen in Table 3.9 to examine the casualty rate changes based on the discharge interval.

Table 3.9. Discharge Interval Variation by the Shooter A and B in the Library

Agent	Interval A	Interval B	Interval C	Interval D (Historical)
Shooter A	1.00	4.78	8.57	12.4
Shooter B	1.00	5.83	10.7	15.6

The The National Physical Fitness Award's One-Mile Run data were used to average the evacuation speed of the staff and students among participants over the age of 14 to 17. The data set represent the 50th percentile based on the 1985 School Population Fitness Survey" (Source). Table 3.10 illustrates the Female and Male individuals over the age of 14 to 17 average duration per second to complete the one mile run. 528 seconds were the average duration to complete the one mile run, which converts to 6.82 miles per hour equalling 10.0 foot per second.

Table 3.10. Staff and Student Agents Run Speed in Foot per Second

Age	14	15	16	17	Seconds per Mile
Female	606	598	631	622	614
Male	464	450	430	424	442
Seconds per Mile	535	524	531	523	528

The 13th experiment consists of 10 iterations that increments the "as_hide_range" by 10 from 0 to 90 while "as_fight_range" is set to 10.

The 14th experiment consists of 9 iterations that increments the "as_hide_range" by 10 from 0 to 80 while "as_fight_range" is set to 20.

The 15th experiment consists of 8 iterations that increments the "as_hide_range" by 10 from 0 to 70 while "as_fight_range" is set to 30.

The 16th experiment consists of 7 iterations that increments the "as_hide_range" by 10 from 0 to 60 while "as_fight_range" is set to 40.

The 17th experiment consists of 6 iterations that increments the "as_hide_range" by 10 from 0 to 50 while "as_fight_range" is set to 50.

The 18th experiment consists of 5 iterations that increments the "as_hide_range" by 10 from 0 to 40 while "as_fight_range" is set to 60.

The 19th experiment consists of 4 iterations that increments the "as_hide_range" by 10 from 0 to 30 while "as_fight_range" is set to 70.

The 20th experiment consists of 3 iterations that increments the "as_hide_range" by 10 from 0 to 20 while "as_fight_range" is set to 80.

The 21th experiment consists of 2 iterations that increments the "as_hide_range" by 10 from 0 to 10 while "as_fight_range" is set to 90.

The 22th experiment consists of 1 iterations that sets the "as_hide_range" to 0 while "as_fight_range" is set to 100.

3.12 Chapter Summary

This chapter covered the research framework of model layout, parameters, agent movement logic, agent action logics, model validation, and experiments and answer the research question.

CHAPTER 4. ANALYSIS AND RESULTS

This chapter provides the data output summary per Experiment in tables and figures first to learn the minimum shooter agents' minimum movement speed, discharge range, and the discharge scope. Second, these three parameters for the shooter agents were then implemented to examine the effectiveness of the RUN.HIDE.FIGHT.® in lowering the casualties of the staff member and student agents than the historical 22 casualties.

4.1 Experiments to Learn the Shooter Agent's Minimum Speed

The experiments from 1 to 3 determined the minimum shooter agent's speed to accomplish all events that have occurred in the library of 1999 Columbine High School shooting at 420 seconds. The shooter agent's default parameters for the discharge range is set to 100 feet, discharge interval at 0.1 per second and discharge scope at 360 degrees as seen in Table 3.5. Each experiment will consist of a table illustrating the shooter agent's speed in feet per second, the number of successful replications per speed, the average and the standard deviation of the incident duration based on the speed. Each experiment will also have a figure illustrating the experimented shooter agent's speed in feet per second on the x-axis, and the event time on the y-axis. The 420 seconds will be marked on the y-axis for all experimented speed.

4.1.1 Experiment 1:Incident Duration by Shooter Agent's Speed from 1 to 9 Feet Per Second

The 1st experiment determined the minimum shooter agent's speed at the nearest ones by running the Parameter Variation experiment of the shooter_speed. During the first experiment, five additional experiment attempts were made to finish the experiment with 1000 replication attempts. However, the experiments have failed due to the run-time error that has continued when the shooter speed was set to 9 feet per second resulting in the average replication in the 200's output 1,000 attempts. The researcher suspects the out of bound has occurred due to the compact environment of physical barriers that throughput the shooter agent into these barriers resulting the agent to not reach their designated destination.

Table 4.1. Experiment 01 Output Summary

shooter_speed	Total	Mean	Standard Deviation
1	NA	NA	NA
2	221	587.55	44.83
3	274	404.76	14.03
4	287	374.56	11.70
5	280	398.76	13.57
6	237	432.86	18.55
7	205	473.76	33.32
8	234	511.62	25.87
9	NA	NA	NA

Figure 4.1 illustrates the incident duration from 2 to 8 feet per second. The 3 to 5 feet per second duration have output the mean duration that was below the 420 seconds. The 2 to 3 and 6 to 8 feet per second have exceeded the 420 seconds incident duration. The 3 feet per second were chosen as the test variable for Experiment 2 since it has outputted the average incident duration at 404.76 seconds which was nearest to the 420 seconds.

4.1.2 Experiment 2:Incident Duration by Shooter Agent's Speed from 2 to 3 Feet Per Second

The 2nd experiment determined the minimum shooter agents speed at the nearest tenth by running the Parameter Variation experiment from 2 to 3 feet per second of the shooter_speed based on the test variable from the 1st experiment. The number of replication per speed was higher since the run-time error has not occurred. However, as seen in table 4.2, the shooter speed at 2.0 had the 845 replications whereas the speed from 2.1 to 3.0 was in the mid to upper 900's.

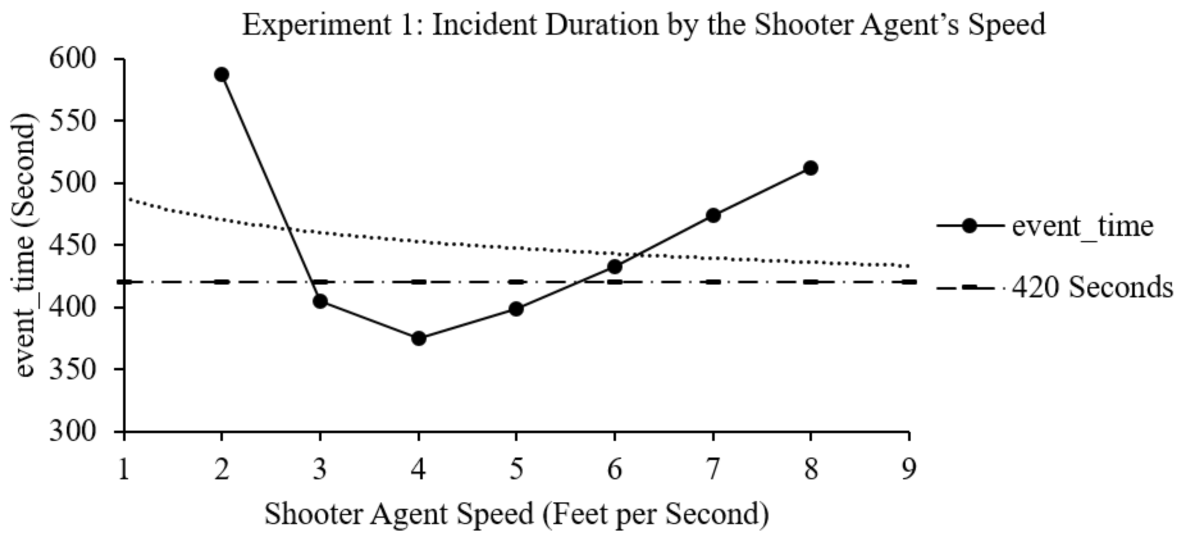

Figure 4.1. Experiment 01: The event_time by the shooter_speed from 1 to 9

Table 4.2. Experiment 02 Output Summary

shooter_speed	Total	Mean	Standard Deviation
2.0	845	574.74	28.34
2.1	948	545.52	27.67
2.2	968	517.96	26.81
2.3	982	499.56	23.84
2.4	991	479.39	24.44
2.5	990	461.66	19.73
2.6	993	445.75	18.72
2.7	991	432.54	17.07
2.8	990	423.05	15.07
2.9	993	413.73	16.59
3.0	994	404.16	14.02

Figure 4.2. illustrates the shooter_speed that were successfully executed from 2 to 3 based on the 2nd experiment. The speed between 2.9 and 3 feet per second have outputted the incident duration below 420 seconds. The rest of the speed from 2 to 2.8 feet per second have outputted the average incident duration that has exceeded the 420 seconds. The minimum speed of 2.9 feet per second was chosen as the test variable for the 3rd experiment.

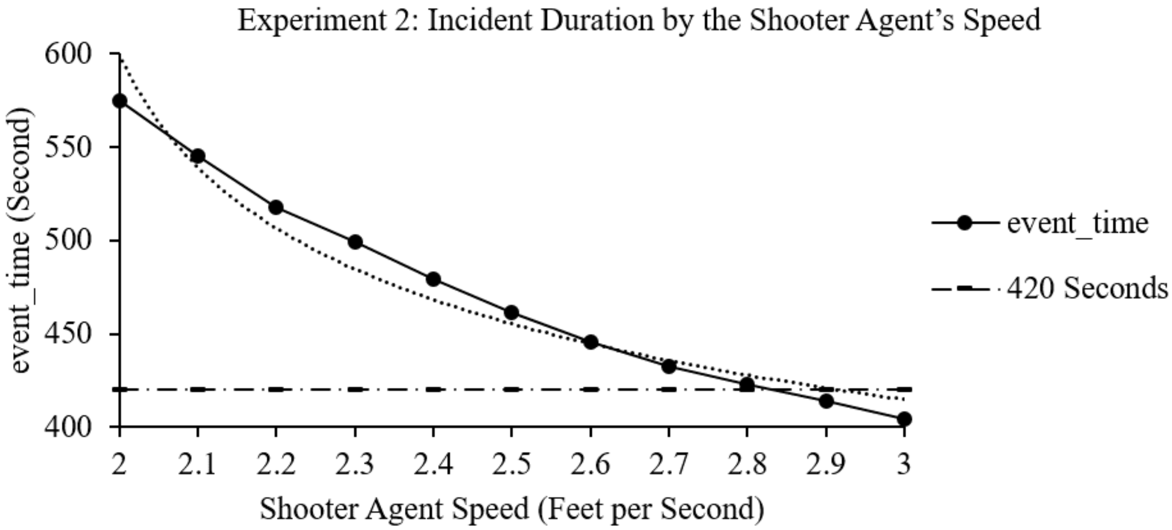

Figure 4.2. Experiment 02: event_time by the shooter_speed from 2 to 3

4.1.3 Experiment 3:Incident Duration by Shooter Agent's Speed from 2.8 to 2.9 Feet Per Second

The 3rd experiment determined the closest shooter agents speed at the nearest tenth by running the Parameter Variation experiment for the shooter_speed from 2.8 to 2.9. The successful replications were in 990s out of 1,000 attempts with the standard deviation in the mid-teens.

Table 4.3. Experiment 03 Output Summary

shooter_speed	Total	Mean	Standard Deviation
2.80	993	421.98	14.78
2.81	991	421.77	14.73
2.82	992	421.23	15.38
2.83	993	419.63	13.82
2.84	994	419.11	15.23
2.85	995	418.75	14.39
2.86	992	417.31	15.78
2.87	991	416.72	17.54
2.88	991	415.65	14.76
2.89	996	414.57	16.59
2.90	993	413.71	19.02

Figure 4.3 illustrates the average shooter_speed that were successfully executed from 2.8 to 2.9 based on the third experiment. The speed from 2.83 to 2.90 feet per second have sufficed the incident duration that was below 420 seconds whereas the speed from 2.80 to 2.82 feet per second have outputted the average incident duration that was above 420 seconds. Among all speed, the 2.83 have outputted the average incident duration of 419.63 seconds that was nearest to 420 seconds among all duration. The 2.83 feet per second was selected as the shooter agent's default speed for the rest of the experiments.

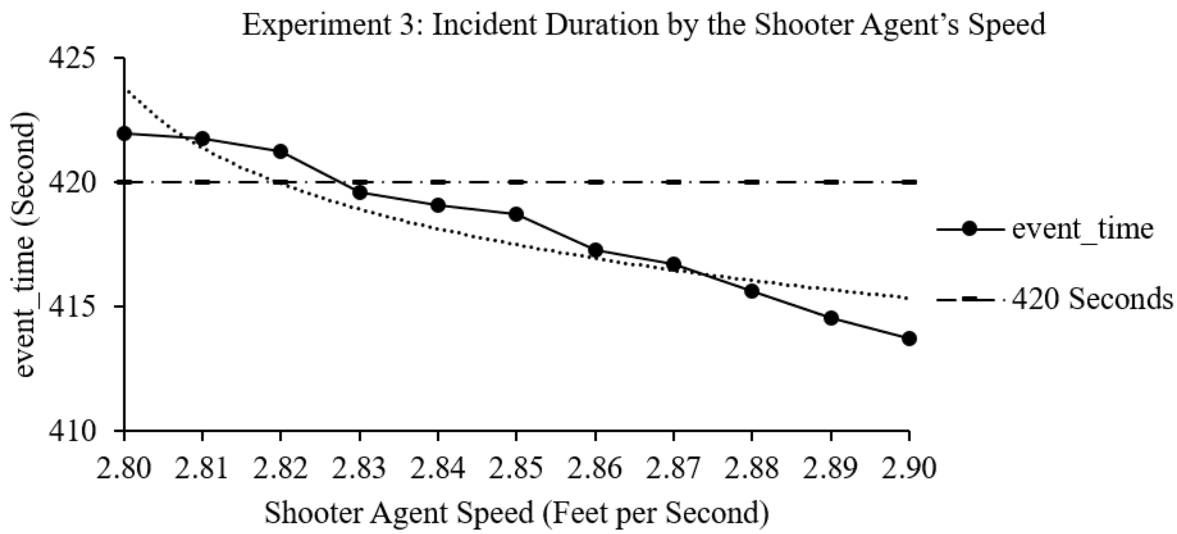

Figure 4.3. Experiment 03: event_time by the shooter_speed from 2.8 to 2.9

4.2 Experiments to Learn the Shooter Agent's Discharge Range

The experiments 4 to 7 determined the minimum shooter agent's discharge range at the nearest hundredth to accomplish all events that have occurred in the library of 1999 Columbine High School shooting at 420 seconds. The shooter agent's default parameters for the speed is 2.83 feet per second, discharge interval at 0.1 per second and discharge scope at 360 degrees as seen in Table 3.6. Each experiment will consist of a table illustrating the shooter agent's discharge range in feet, the number of successful replications per speed, the average and the standard deviation of the incident duration based on the range. The figures will illustrate the experimented shooter agent's discharge range in feet on the x-axis, and the event time on the y-axis. The 420 seconds will be marked on the y-axis of the incident duration for all experimented discharge range.

4.2.1 Experiment 4: Incident Duration by Shooter Agent's Discharge Range from 10 to 100 Feet

The 4th experiment determined the minimum discharge range at the nearest tens by running the Parameter Variation experiment for the as_range variable from 10 to 100. The as_range from 10 to 50 feet have not fully executed the completion requirement since the discharge range was not met. The successful iterations were seen from 60 to 100 feet of the discharge range have outputted in the lower 990's out of 1,000 attempts with the standard deviation in the upper teens.

Table 4.4. Experiment 04 Output Summary

as_range	Total	Mean	Standard Deviation
10	NA	NA	NA
20	NA	NA	NA
30	NA	NA	NA
40	NA	NA	NA
50	NA	NA	NA
60	990	420.12	14.18
70	992	420.64	17.36
80	992	420.25	16.55
90	993	419.77	15.56
100	991	420.81	18.00

Figure 4.4. illustrates the as_range that were successfully executed from 10 to 100. The discharge ranges from 60 to 100 are between 419.5 to 421 seconds. The minimum range that has sufficed the experiment requirement was 60 feet of the discharge range which resulted in 420.12 seconds chosen as the test variable for the 5th experiment.

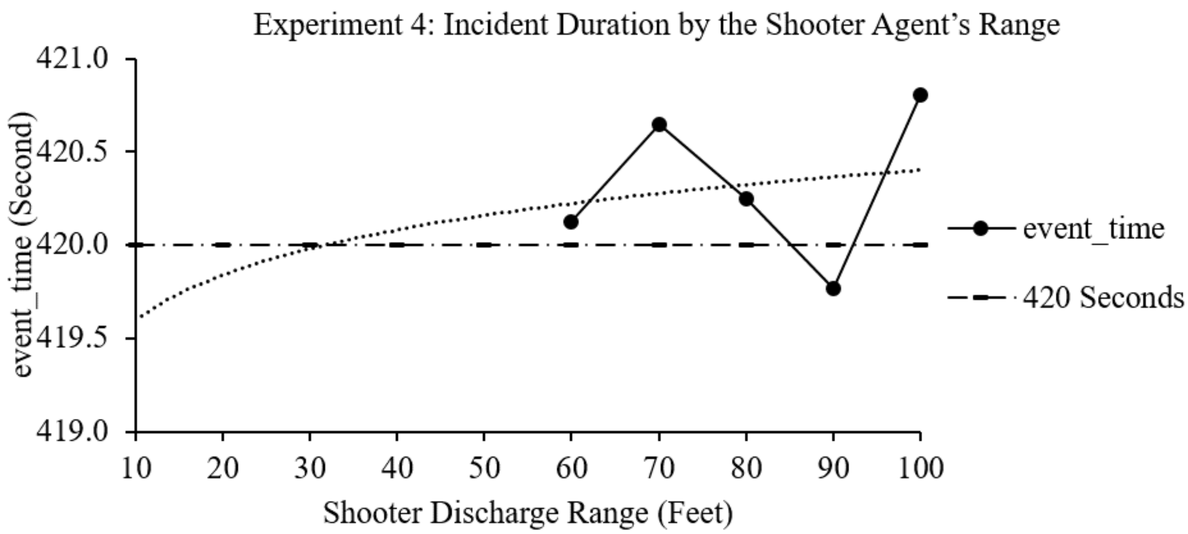

Figure 4.4. Experiment 04: event_time by the as_range from 10 to 100

4.2.2 Experiment 05: Incident Duration by Shooter Agent's Discharge Range from 50 to 60 Feet

The 5th experiment determined the minimum discharge range for the shooter agents at the nearest ones by running the Parameter Variation experiment for the as_range from 50 to 60. The discharge range of 50 to 51 feet has not met the completion requirement, while the range of 52 to 60 feet has outputted the successful replications in the 990s out of 1,000 attempts with the standard deviation in the upper teens.

Figure 4.5. illustrates the as_range that were successfully executed from 50 to 60 feet. The discharge ranges from 52 to 60 feet are between 419.5 to 421 seconds. The minimum range that has sufficed the experiment requirement was 52 feet of the discharge range which resulted in 421.04 seconds chosen as the test variable for the 6th experiment.

4.2.3 Experiment 06: Incident Duration by Shooter Agent's Discharge Range from 51 to 52 Feet

The 6th experiment determined the minimum discharge range for the shooter agents at the nearest ones by running the Parameter Variation experiment for the as_range from 51 to 52 feet.

Table 4.5. Experiment 05 Output Summary

as_range	Total	Mean	Standard Deviation
50	NA	NA	NA
51	NA	NA	NA
52	993	421.04	16.67
53	990	419.90	15.53
54	993	420.67	16.49
55	990	420.41	15.89
56	986	421.26	16.86
57	992	419.81	14.84
58	993	420.32	16.37
59	994	420.26	16.88
60	992	420.26	14.81

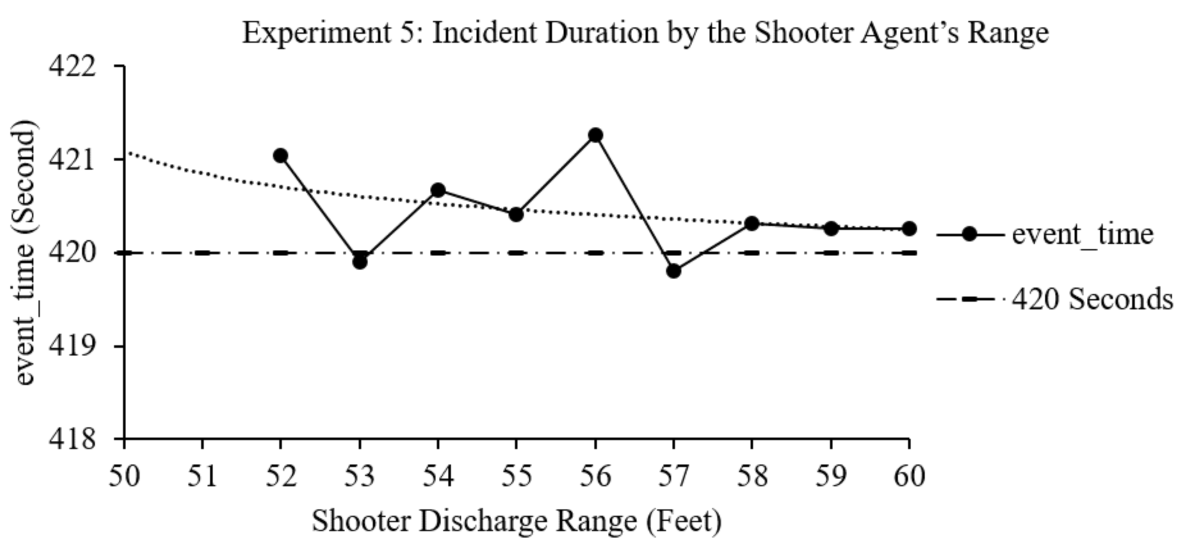

Figure 4.5. Experiment 05: event_time by the as_range from 50 to 60

The discharge range of 50 to 51.1 feet have not met the completion requirement, while the range of 51.2 to 52 feet has outputted the successful replications in the 990s out of 1,000 attempts with the standard deviation in the upper teens.

Figure 4.6. illustrates the as_range that were successfully executed from 51 to 52 feet. The discharge ranges from 51.2 to 52 feet were between 419.5 to 420 seconds. The minimum range

Table 4.6. Experiment 06 Output Summary

as_range	Total	Mean	Standard Deviation
51.0	NA	NA	NA
51.1	NA	NA	NA
51.2	991	419.80	17.98
51.3	990	420.01	17.58
51.4	995	419.93	15.81
51.5	989	419.78	16.94
51.6	991	419.84	18.75
51.7	997	419.74	15.60
51.8	991	419.67	17.53
51.9	991	419.75	16.82
52.0	993	419.69	17.86

that has sufficed the experiment requirement was 51.2 feet of the discharge range which resulted in 419.80 seconds chosen as the test variable for the 7th experiment.

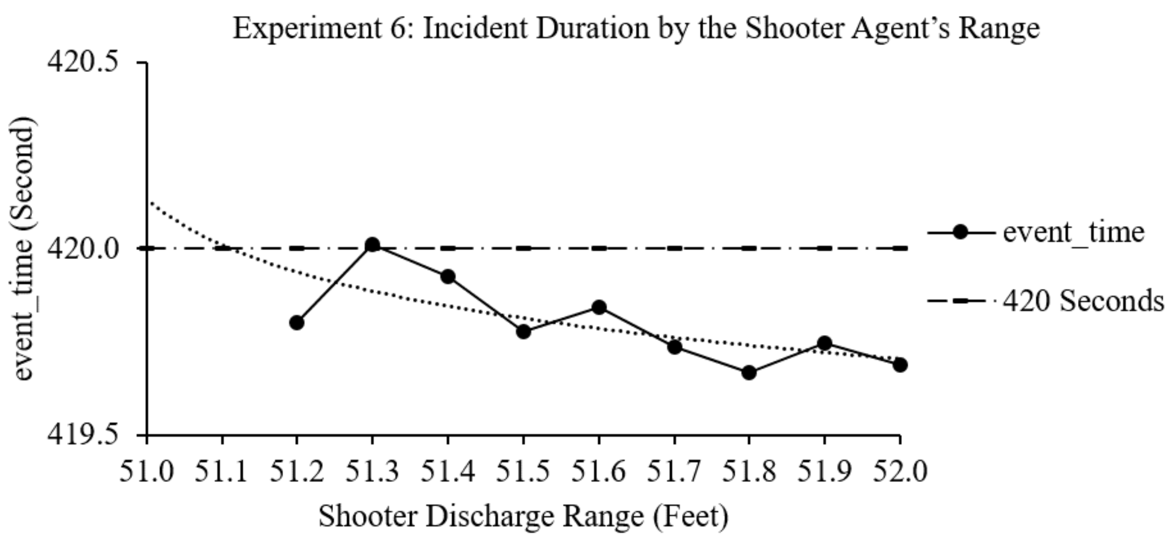

Figure 4.6. Experiment 06: event_time by the as_range from 51 to 52

4.2.4 Experiment 07: Incident Duration by Shooter Agent's Discharge Range from 51.10 to 51.20 Feet

The 7th experiment determined the minimum discharge range for the shooter agents at the nearest ones by running the Parameter Variation experiment for the as_range from 51.1 to 51.2 feet. The discharge range of 51.10 to 51.11 feet have not met the completion requirement, while the range of 51.12 to 52.20 feet have outputted the successful replications. However, unlike the previous experiments, the discharge range from 51.12 to 51.13 has resulted in the successful replications that were below 200. The 51.14's successful replications were in their 881 while the range from 51.15 to 51.20 has resulted in the replications in the 900's with standard deviation at the upper teens.

Table 4.7. Experiment 07 Output Summary

as_range	Total	Mean	Standard Deviation
51.10	NA	NA	NA
51.11	NA	NA	NA
51.12	2	418.00	2.38
51.13	179	418.23	11.12
51.14	881	420.75	17.07
51.15	900	420.36	17.61
51.16	901	421.68	18.38
51.17	645	421.01	16.83
51.18	962	420.70	16.02
51.19	987	420.14	14.41
51.20	987	421.49	16.88

Figure 4.7. illustrates the as_range that were successfully executed from 51.1 to 51.2. The minimum range that has sufficed the experiment requirement was 51.12. However, the discharge range at 51.19 foot that resulted in the highest number of replications, with an average of 420.14 seconds duration with 14.41 standard deviation which was the closest output to the 420 seconds. The shooter agent's default discharge range was set to 51.12 feet.

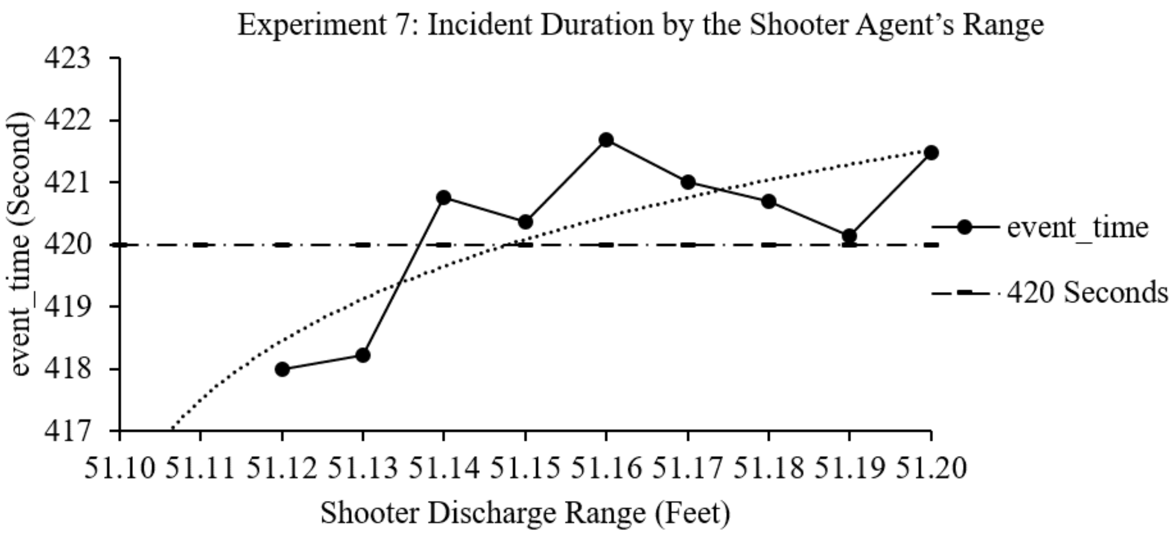

Figure 4.7. Experiment 07: event_time by the as_range from 51.1 to 51.2

4.3 Experiments to Learn the Shooter Agent's Discharge Scope

The experiments 8 to 11 determined the minimum shooter agent's discharge scope at the nearest hundredth to accomplish all events that have occurred in the library of 1999 Columbine High School shooting at 420 seconds. The shooter agent's default parameters for the speed is 2.83 feet per second, discharge interval to 51.12 feet, the discharge interval for Shooter A at 12.35 seconds, and for shooter B at 15.56 seconds. discharge interval at 0.1 per second and discharge scope at 360 degrees as seen in Table 3.8. Each experiment will consist of a table illustrating the shooter agent's discharge scope in degrees, the number of successful replications per speed, the average and the standard deviation of the incident duration based on the range. The figures will illustrate the experimented shooter agent's discharge scope in feet on the x-axis, and the event time on the y-axis. The 420 seconds will be marked on the y-axis of the incident duration for all experimented discharge scope.

4.3.1 Experiment 08: Incident Duration by Shooter Agent's Discharge Scope from 10 to 90 Degrees

The 8th experiment determined the minimum discharge scope for the shooter agents at the nearest tens by running the Parameter Variation experiment for the discharge_scope from 10 to 90 degrees. All tested discharge scope have completed the event requirements while 10 degrees was the only duration that was above 420 seconds. The discharge scope 20 and 30 degrees have resulted in the event duration in the 300s in seconds. The 40 to 90 degrees have resulted in the event duration in the 200s in seconds.

Table 4.8. Experiment 08 Output Summary

discharge_scope	Total	Mean	Standard Deviation
10.00	980	504.13	74.45
20.00	996	366.40	42.41
30.00	996	323.31	30.58
40.00	998	297.13	27.58
50.00	997	279.01	22.17
60.00	993	267.88	18.47
70.00	997	260.91	14.10
80.00	998	256.55	14.26
90.00	999	252.56	14.05

Figure 4.8. illustrates the discharge_scope that were successfully executed from 10 to 90. As seen in the figure, the event duration is maintained at the upper 200's making a lesser impact in the duration once the discharge scope is above 40 degrees. The minimum range that has sufficed the experiment requirement was 20 of the discharge_scope which will be the test variable for the 9th experiment.

4.3.2 Experiment 09: Incident Duration by Shooter Agent's Discharge Scope from 10 to 20 Degrees

The 9th experiment determined the minimum discharge scope for the shooter agents at the nearest ones by running the Parameter Variation experiment for the discharge_scope from 10 to 20

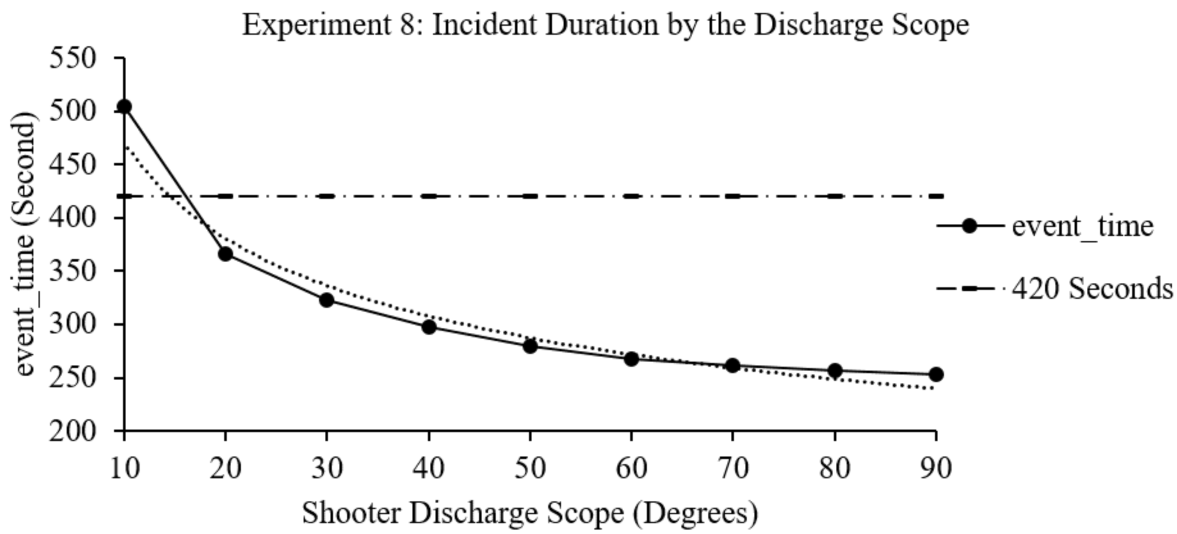

Figure 4.8. Experiment 08: event_time by the discharge_scope from 10 to 90

degrees. All tested discharge scope have completed the event requirements while 10 to 14 degrees had a duration that was above 420 seconds. The discharge scope 15 to 20 degrees have resulted in the event duration that was below 420 seconds.

Table 4.9. Experiment 09 Output Summary

discharge_scope	Total	Mean	Standard Deviation
10	971	503.21	74.43
11	990	475.95	69.03
12	991	458.91	67.17
13	997	441.41	61.74
14	995	424.76	57.28
15	994	413.75	55.74
16	996	404.75	52.41
17	996	394.98	48.96
18	992	385.41	46.37
19	994	376.18	44.83
20	995	367.93	43.91

Figure 4.9. illustrates the discharge_scope that were successfully executed from 10 to 20. The figure illustrates the discharge range between 14 and 15 has passed through the 420 seconds of event duration. 15 degrees was set as the test variable for the 10th experiment.

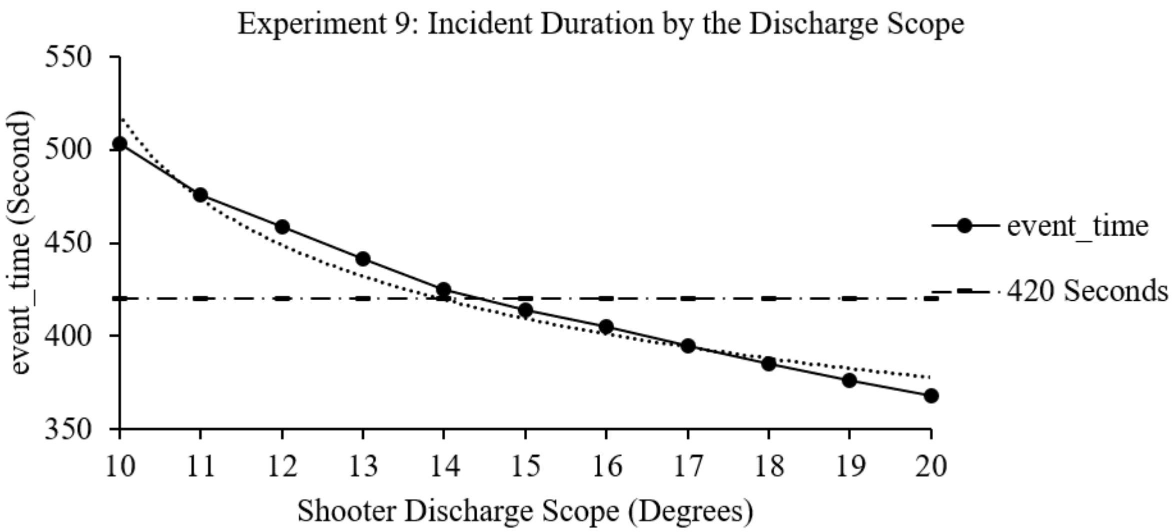

Figure 4.9. Experiment 9: event_time by the discharge_scope from 10 to 20

4.3.3 Experiment 10: Incident Duration by Shooter Agent's Discharge Scope from 14 to 15 Degrees

The 10th experiment determined the minimum discharge scope for the shooter agents at the nearest tenth by running the Parameter Variation experiment for the discharge_scope from 14 to 15 degrees. The tested discharge scope has all resulted in successful model execution accomplishing all necessary tasks. The discharge scope from 14 to 14.3 have outputted the average duration that was higher than 420 seconds. 14.4 have outputted the average duration of 420.57 which was the closest to 420 seconds, while 14.5 to 15 were below were in their upper 410's. Therefore, 14.4 degrees were chosen as the test variable for the 11th experiment.

The Figure 4.10. illustrates the discharge_scope that were successfully executed from 14 to 15 degrees. The minimum range that has sufficed the experiment requirement was 14.5 degrees. However, since the 14.4 degrees average duration only has exceeded the 420 seconds by

Table 4.10. Experiment 10 Output Summary

discharge_scope	Total	Mean	Standard Deviation
14.0	997	430.52	59.11
14.1	998	425.81	58.81
14.2	996	424.51	57.78
14.3	995	422.89	57.71
14.4	997	420.57	57.76
14.5	991	417.64	55.03
14.6	997	418.18	57.08
14.7	997	415.94	56.55
14.8	989	417.70	55.95
14.9	995	415.54	54.84
15.0	996	413.33	55.57

0.57 seconds. The 14.5 degrees was chosen as the test variable for the 11th experiment to consider the standard deviation.

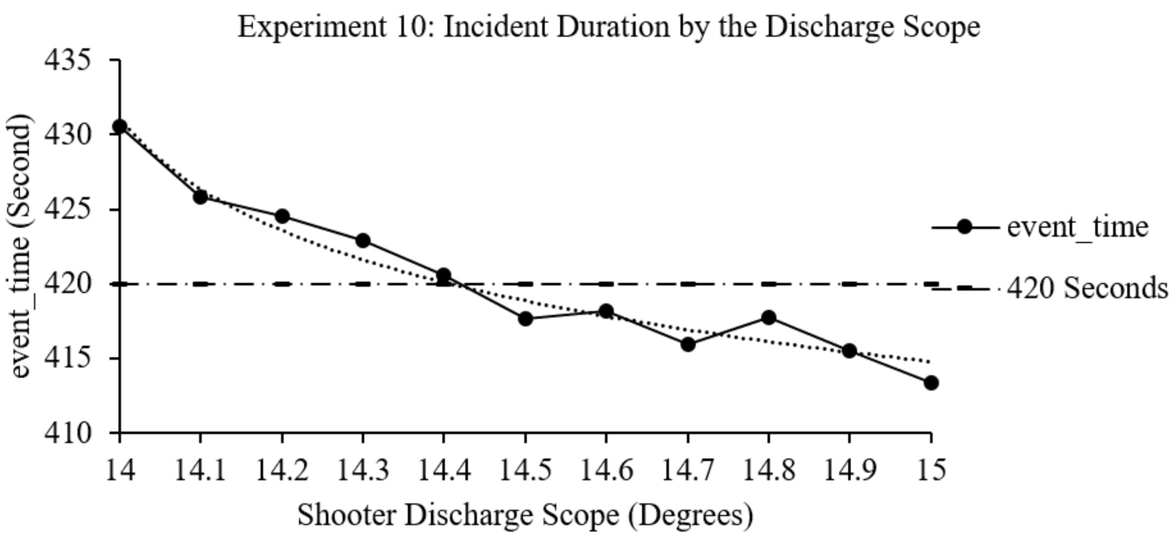

Figure 4.10. Experiment 10: event_time by the discharge_scope from 14 to 15

4.3.4 Experiment 11: Incident Duration by Shooter Agent's Discharge Scope from 14.3 to 14.4 Degrees

The 11th experiment determined the minimum discharge scope for the shooter agents at the nearest tenth by running the Parameter Variation experiment for the discharge_scope from 14.3 to 14.4 degrees. The tested discharge scope has all resulted in successful model execution accomplishing all necessary tasks. Unlike the 9th and 10th experiments, the event duration fluctuates sporadically without any particular trend defined by the event duration.

Table 4.11. Experiment 11 Output Summary

discharge_scope	Total	Mean	Standard Deviation
14.30	996	424.72	58.15
14.31	994	420.58	58.55
14.32	997	422.18	54.56
14.33	997	424.91	58.46
14.34	995	424.28	56.91
14.35	994	422.69	56.78
14.36	997	423.44	56.40
14.37	997	422.25	56.95
14.38	995	421.67	55.46
14.39	998	419.26	57.64

Figure 4.11. illustrates the discharge_scope that were successfully executed from 14.3 to 14.4. The minimum range that has sufficed the experiment requirement was 14.31 degrees which will be used as the default discharge_scope.

4.4 Experiments to Learn the Shooter Agent's Discharge Scope

The Experiment 12 to Experiment 22 examined the casualties by implementing RUN.HIDE.FIGHT.® (RHF) for the staff member and student agents at 1129 (Mountain Daylight Time) which is when two shooters enter the library. Upon the two shooters entry, all staff member and student agents make a run to the exit located at the upper left corner of the

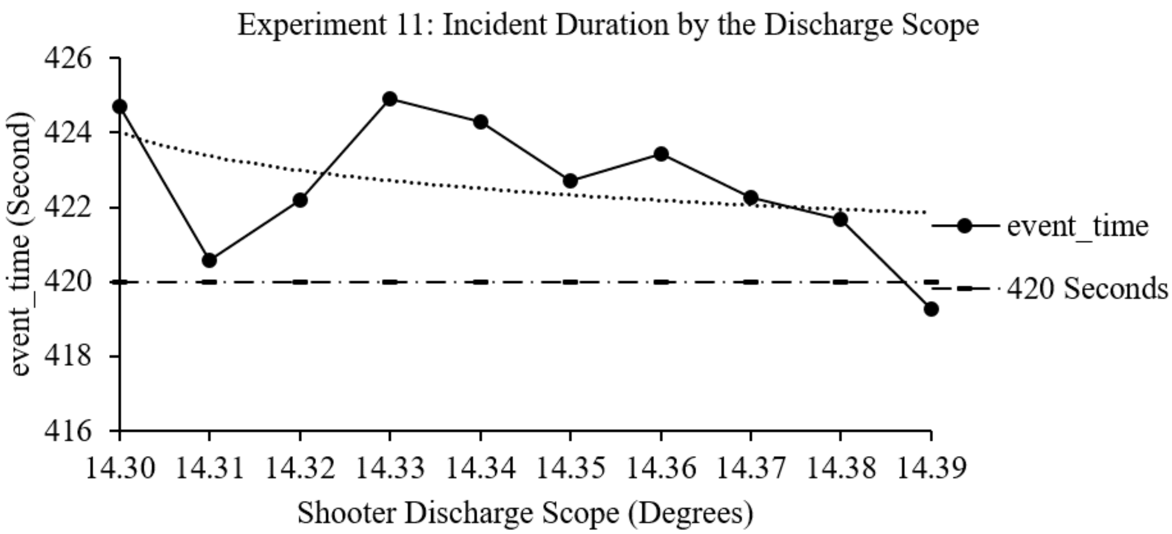

Figure 4.11. Experiment 11: event_time by the discharge_scope from 14.3 to 14.4

diagram. The escapees will hide from the shooter based on proximity set by the ui_hide_range as they move towards the designated hiding area located at the bottom right corner of the library. The hiders will fight the shooter based on another proximity set by ui_fight_range as they move toward their nearest shooter. Per hide and fight range, four different discharge intervals were experimented as seen in Table 3.9 while maintaining the default parameters for the speed, range, and scope from previous experiments. The two shooters will move toward their nearest staff or student agents to cause casualties.

Each experiment has a table output illustrating the hide, and fight range variation per iteration with the number of average survival rate and the casualties by the interval A, B, C, and D. The acronym SRVL stands for Survived, and CAS stands for Casualties in each table. Additionally, each experiment will come with a figure illustrating the casualties per iteration by the interval A to D per hide range increment.

4.4.1 Experiment 12: Hide Range from 0 to 100 Feet with 0 Feet Fight Range

The 12th experiment compared the difference in casualties among student and staff agents with 10 step increment of the as_hide_range from 0 to 100 feet while as_fight_range is set to 0 feet. Per iteration, the shooter agents discharge interval is set from A to D as described in Table 3.9. The casualties differ by the intervals when the hide and fight range is both set to 0 feet where all staff member and student agents run away from the shooter.

The diversity in casualty decreases when the hide range increments by 10 feet. During the all run scenario, there are additional 9 casualties on the average for interval A than the interval B, C and D. At 10 feet set for the hide range as seen in table 4.12, the average casualties remains at 14 individuals for the interval A, and 13 individuals for interval B, C, and D. Similarly from 20 to 50 feet hide range, the differences among casualties are under 0.5. As seen in figure 4.12, the average casualties were between 55 to 56 individuals during the 60 to 100 feet. The average casualty difference from interval A to B was 1.3, 0.76 for interval B to C, and 0.66 for interval C to D. The result suggests that the discharge interval has a lesser impact in casualties when more individual hides from the shooter without the offensive measure.

Table 4.12. Experiment 12 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
0	0	38.8	17.2	46.9	9.1	49.8	6.2	51.6	4.42
10	0	42.3	13.7	43.1	12.9	43.4	12.6	43.5	12.5
20	0	36.1	19.9	39.6	16.4	39.5	16.5	39.3	16.7
30	0	23.6	32.4	23.6	32.4	23.9	32.1	24.2	31.8
40	0	18.9	37.1	18.7	37.3	18.8	37.2	18.8	37.2
50	0	4.49	51.5	4.90	51.1	4.16	51.8	5.08	50.9
60	0	0.38	55.6	0.67	55.3	0.52	55.5	0.55	55.5
70	0	0.00	56.0	0.00	56.0	0.48	55.5	0.64	55.4
80	0	0.00	56.0	0.00	56.0	0.00	56.0	0.00	56.0
90	0	0.00	56.0	0.00	56.0	0.00	56.0	0.00	56.0
100	0	0.00	56.0	0.00	56.0	0.00	56.0	0.94	55.1

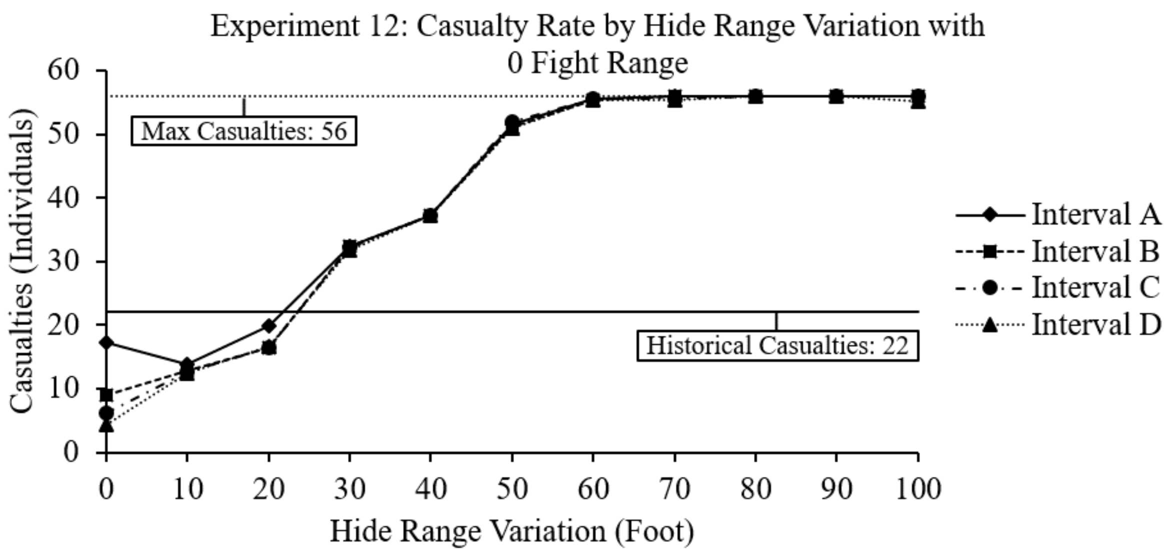

Figure 4.12. Experiment 12: Casualty Rate by Hide Range Variation with 0 Fight Range

4.4.2 Experiment 13: Hide Range from 10 to 100 Feet with 10 Feet Fight Range

The 13th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 10 to 100 while as_fight_range is set to 10. For interval A as seen in table 4.13, the casualties remains under 22 casualties from 10 to 40 feet hide with 10 feet fight range. The casualties exceed 22 but remain under 27 individuals from 50 to 100 hide feet. For interval B, C, and D, the casualties remain under 10 casualties throughout the experiment regardless of the hide range incrementation. Unlike the 12th experiment, the casualties have not reached between 55 to 56 individuals for the hide range from 60 to 100 feet. As seen in figure 4.13, the average differences of casualties from interval A to B were 16.15 casualties, interval B to C at 1.81 casualties, and interval C to D 0.9 casualties. The average causalities have decreased by 30.53 individuals from Experiment 12 to 13 which suggests the inclusion of offensive measure increases the survivability among staff member and student agents.

Table 4.13. Experiment 13 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
10	10	40.3	15.7	51.4	4.57	54.1	1.94	54.7	1.32
20	10	40.8	15.2	47.6	8.43	49.2	6.76	51.0	5.02
30	10	34.2	21.8	49.1	6.87	51.7	4.28	53.5	2.54
40	10	35.6	20.4	50.1	5.86	51.5	4.47	52.6	3.45
50	10	28.9	27.1	50.4	5.56	52.7	3.26	53.7	2.31
60	10	33.2	22.8	51.0	4.96	52.3	3.75	52.7	3.31
70	10	33.7	22.3	51.3	4.75	52.3	3.69	52.8	3.19
80	10	31.6	24.4	50.1	5.93	52.1	3.90	53.5	2.53
90	10	29.7	26.3	50.9	5.07	52.8	3.16	52.6	3.40
100	10	33.5	22.5	51.0	4.99	52.3	3.72	53.2	2.85

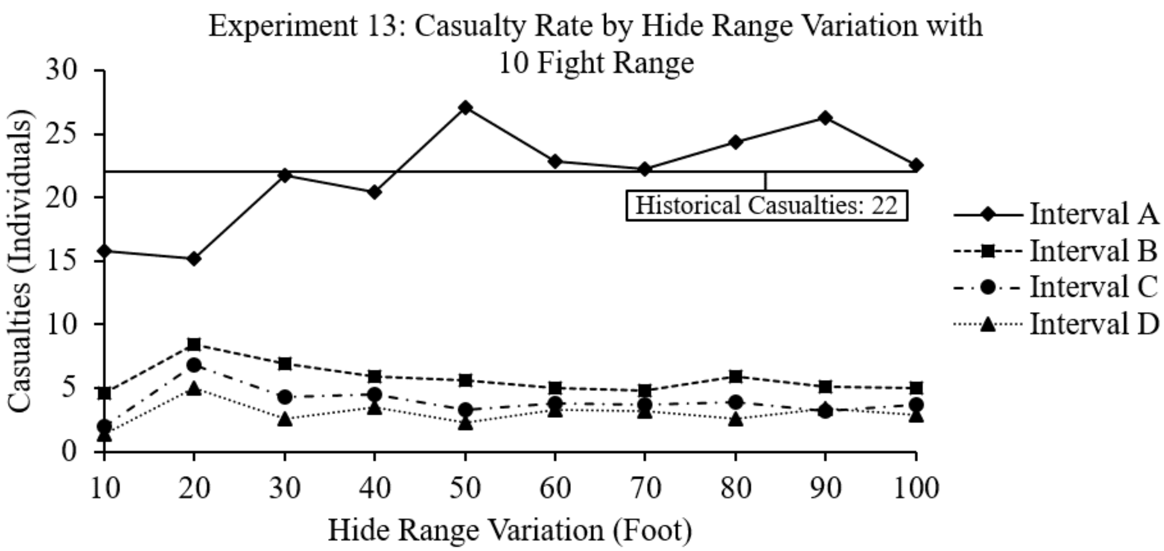

Figure 4.13. Experiment 13: Casualty Rate by Hide Range Variation with 10 Fight Range

4.4.3 Experiment 14: Hide Range from 20 to 100 Feet with 20 Feet Fight Range

The 14th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 20 to 100 while as_fight_range is set to 20. Unlike the 13th experiment as seen in figure 4.14, the hide range from 20 to 30 had casualties under 22 individuals where 40 to 100 were between 22 to 26 casualties. For the interval B, C, and D, the casualties output were similar to the 13th experiment where the average difference was

0.66 individuals. The average differences of casualties from interval A to B were 18.35 casualties, interval B to C at 2.32 casualties, and interval C to D 0.63 casualties. The total casualties difference were .08 from the previous experiment which suggests that that the long fight range has less impact in further lowering casualties.

Table 4.14. Experiment 14 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
20	20	38.3	17.7	52.0	4.02	53.9	2.12	54.7	1.31
30	20	35.2	20.8	51.2	4.80	52.3	3.75	52.4	3.63
40	20	33.5	22.5	50.0	6.04	52.3	3.71	52.9	3.14
50	20	29.4	26.6	50.1	5.86	52.9	3.08	53.4	2.58
60	20	28.9	27.1	50.7	5.33	53.4	2.63	53.9	2.11
70	20	32.8	23.2	50.6	5.38	53.3	2.68	54.1	1.92
80	20	31.6	24.4	50.5	5.55	53.3	2.74	54.4	1.62
90	20	29.0	27.0	50.7	5.31	52.9	3.06	53.8	2.16
100	20	32.7	23.3	51.0	5.02	53.3	2.66	53.7	2.31

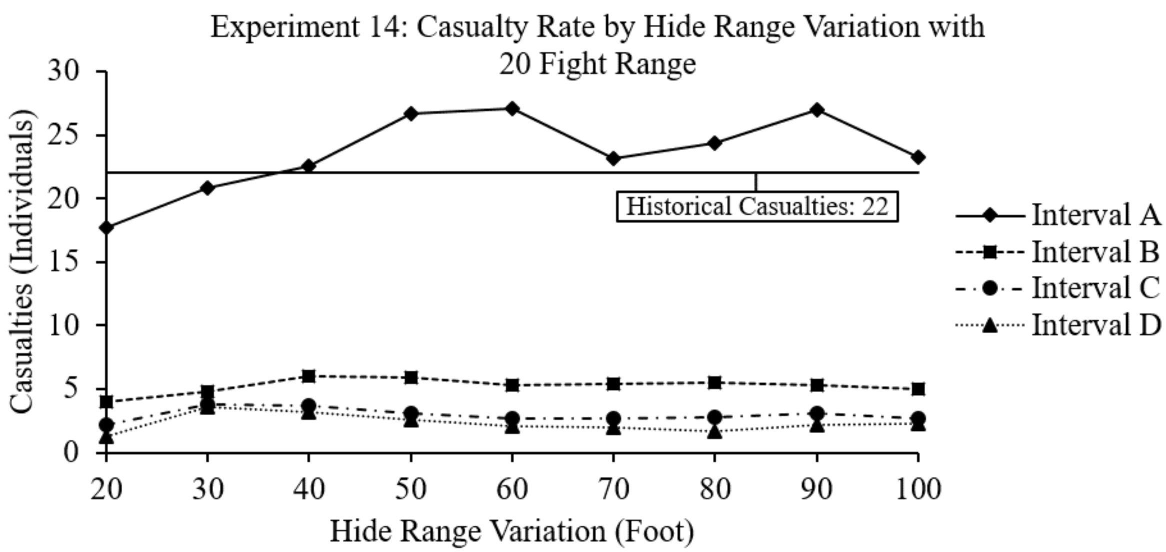

Figure 4.14. Experiment 14: Casualty Rate by Hide Range Variation with 20 Fight Range

4.4.4 Experiment 15: Hide Range from 30 to 100 Feet with 30 Feet Fight Range

The 15th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 30 to 100 while as_fight_range is set to 30. For all intervals, the average differences of casualties were 0.6 suggesting the higher fight range has less impact in decreasing casualties than the interval rate. The average differences of casualties from interval A to B were 20.95 casualties, interval B to C at 1.74 casualties, and interval C to D 0.72 casualties. The 15th experiment suggests that the higher number of casualties are impacted by the discharge interval than the increased fight range.

Table 4.15. Experiment 15 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
30	30	33.0	23.0	51.4	4.59	53.6	2.39	54.4	1.57
40	30	30.1	25.9	52.2	3.82	53.8	2.25	54.7	1.33
50	30	32.4	23.6	52.4	3.63	54.2	1.84	54.5	1.53
60	30	28.4	27.6	52.6	3.35	54.1	1.94	54.9	1.09
70	30	32.2	23.8	52.9	3.08	54.1	1.86	54.8	1.19
80	30	29.6	26.4	52.5	3.49	54.2	1.84	54.8	1.21
90	30	31.9	24.1	52.0	4.01	54.0	1.99	54.9	1.06
100	30	32.9	23.1	52.1	3.92	54.1	1.88	54.8	1.21

4.4.5 Experiment 16: Hide Range from 40 to 100 Feet with 40 Feet Fight Range

The 16th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 40 to 100 while as_fight_range is set to 40. The average difference in the casualties were 0.41 from the previous experiment with 7.51 average casualties. The average differences of casualties from interval A to B were 18.64 casualties, interval B to C at 1.97 casualties, and interval C to D 0.75 casualties. Experiment 16 suggests that the rapid discharge interval has resulted in higher casualty differences than the longer fight range.

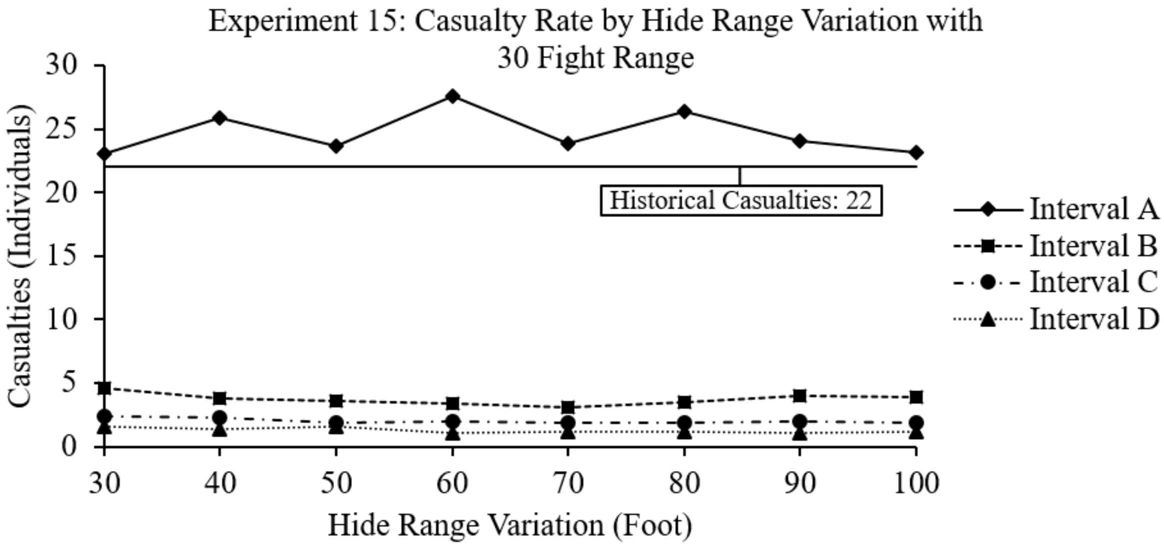

Figure 4.15. Experiment 15: Casualty Rate by Hide Range Variation with 30 Fight Range

Table 4.16. Experiment 16 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
40	40	34.9	21.1	51.4	4.65	53.9	2.13	54.5	1.49
50	40	33.0	23.0	51.9	4.15	53.9	2.11	54.8	1.23
60	40	29.8	26.3	51.4	4.61	54.3	1.75	54.8	1.23
70	40	34.0	22.0	52.3	3.70	53.7	2.30	54.9	1.13
80	40	31.4	24.6	52.5	3.47	54.0	1.97	54.6	1.37
90	40	34.7	21.3	52.7	3.32	53.9	2.05	54.7	1.34
100	40	35.5	20.5	51.7	4.29	53.9	2.08	54.7	1.31

4.4.6 Experiment 17: Hide Range from 50 to 100 Feet with 50 Feet Fight Range

The 17th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 50 to 100 while as_fight_range is set to 50. The average differences of casualties from interval A to B were 18.31 casualties, interval B to C at 1.63 casualties, and interval C to D 0.57 casualties. The average casualties were 7.13 which was 0.38 lower than the previous experiment. The 17th experiment suggested that the increased fight range from the previous experiment in lowering casualties.

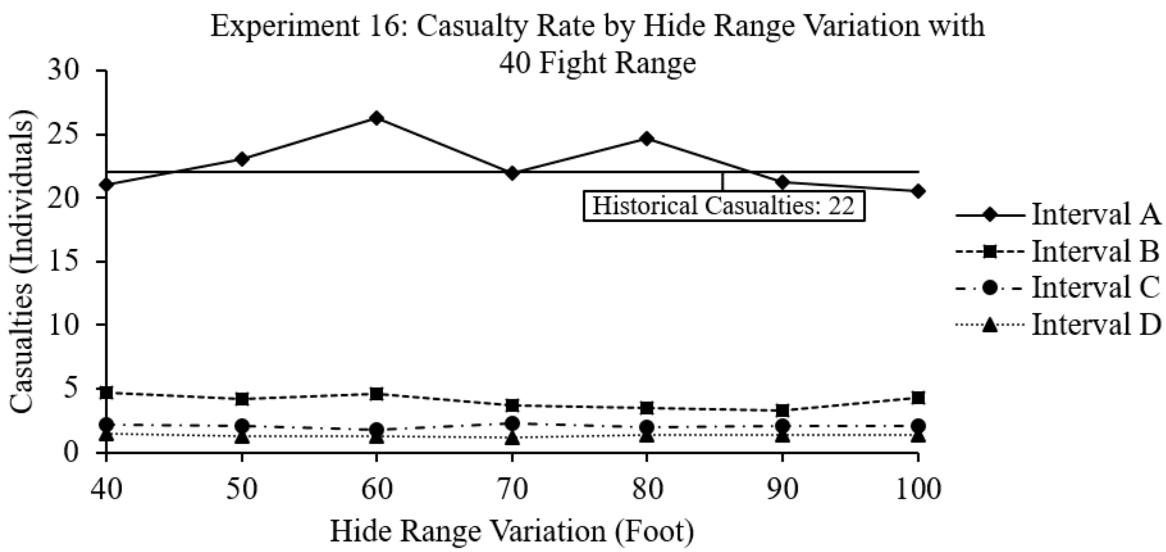

Figure 4.16. Experiment 16: Casualty Rate by Hide Range Variation with 40 Fight Range

Table 4.17. Experiment 17 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
50	50	35.0	21.0	52.6	3.44	54.2	1.76	54.7	1.31
60	50	33.5	22.6	52.8	3.24	54.1	1.94	54.8	1.23
70	50	35.5	20.5	52.1	3.94	54.4	1.58	54.6	1.44
80	50	34.5	21.5	52.5	3.51	53.8	2.18	54.7	1.35
90	50	32.6	23.4	52.4	3.64	54.1	1.89	54.8	1.20
100	50	34.1	21.9	52.7	3.29	54.1	1.91	54.7	1.31

4.4.7 Experiment 18: Hide Range from 60 to 100 Feet with 60 Feet Fight Range

The 18th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 60 to 100 while as_fight_range is set to 60. The average differences of casualties from interval A to B were 18.87 casualties, interval B to C at 1.58 casualties, and interval C to D 0.62 casualties. The casualties have increased by 0.19 from the previous experiment resulting in 7.32 average casualties. The 18th experiment suggested that the long fight range has not impacted the casualties than the previous experiments.

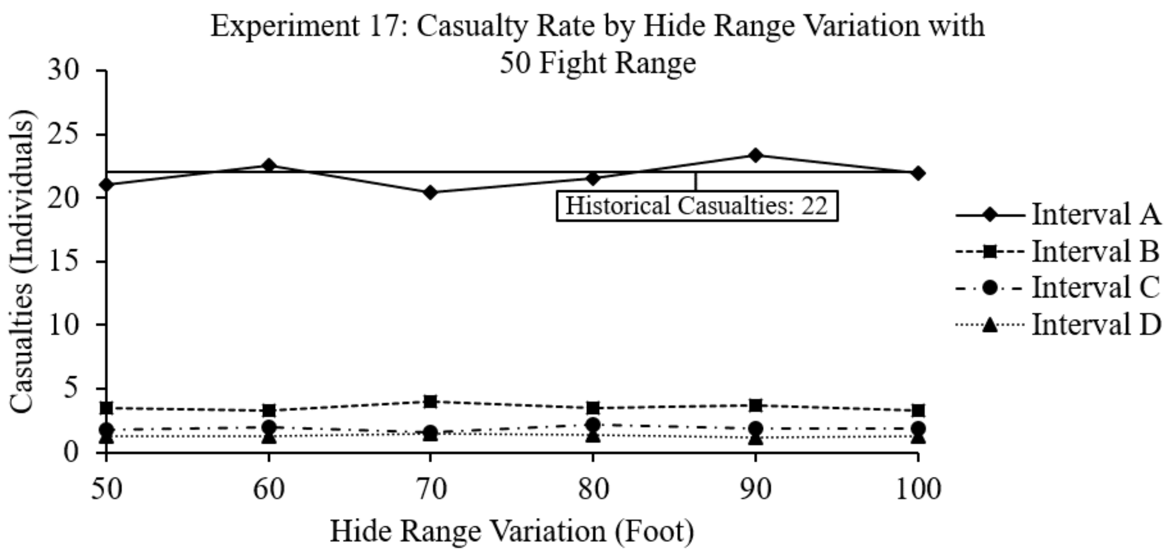

Figure 4.17. Experiment 17: Casualty Rate by Hide Range Variation with 50 Fight Range

Table 4.18. Experiment 18 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
60	60	35.4	20.6	52.7	3.28	53.9	2.13	54.7	1.26
70	60	34.9	21.1	52.6	3.43	54.1	1.95	54.6	1.36
80	60	33.4	22.7	52.1	3.89	54.1	1.93	54.6	1.39
90	60	33.4	22.7	52.6	3.36	54.0	1.96	54.7	1.31
100	60	30.9	25.1	52.2	3.78	54.1	1.89	54.6	1.43

4.4.8 Experiment 19: Hide Range from 70 to 100 Feet with 70 Feet Fight Range

The 19th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 70 to 100 while as_fight_range is set to 70. The average differences of casualties from interval A to B were 17.20 casualties, interval B to C at 1.69 casualties, and interval C to D 0.71 casualties. The average casualties were 7.05 with 0.27 decrease in casualties from the previous experiment. The 19th experiment suggests the early offensive measures will increase the average casualties by 1.46 individuals.

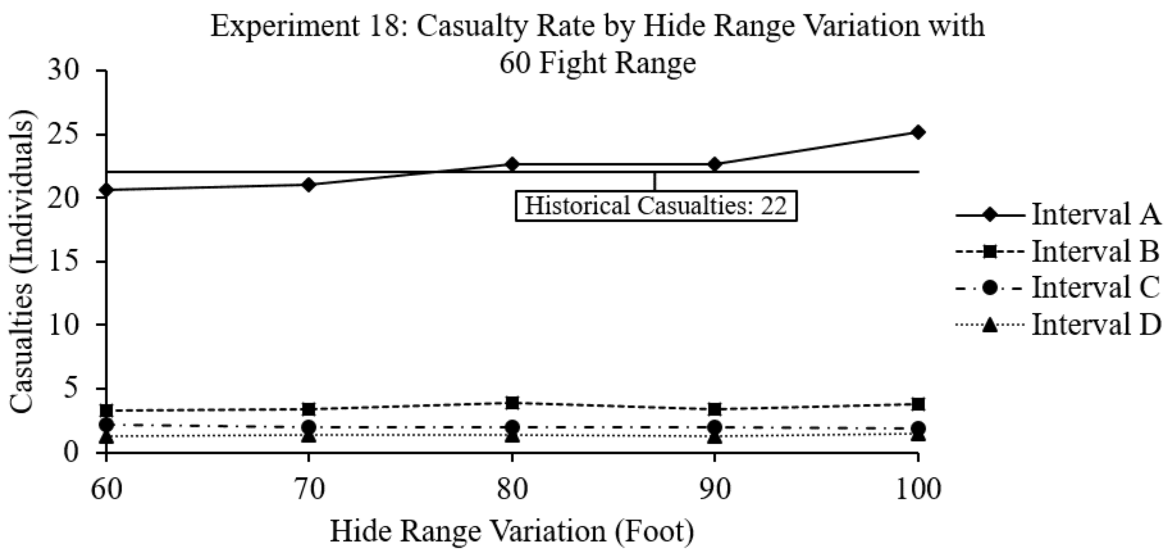

Figure 4.18. Experiment 18: Casualty Rate by Hide Range Variation with 60 Fight Range

Table 4.19. Experiment 19 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
70	70	35.5	20.5	51.9	4.14	53.8	2.21	54.4	1.57
80	70	33.8	22.2	52.1	3.94	53.9	2.08	54.9	1.10
90	70	37.3	18.7	52.4	3.60	54.0	2.03	54.7	1.29
100	70	33.5	22.5	52.6	3.39	54.0	1.99	54.5	1.51

4.4.9 Experiment 20: Hide Range from 80 to 100 Feet with 80 Feet Fight Range

The 20th experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 80 to 100 while as_fight_range is set to 80. The average differences of casualties from interval A to B were 16.89 casualties, interval B to C at 1.61 casualties, and interval C to D 0.51 casualties. The average casualties were 6.75 which is 0.3 casualties lower than the previous experiment. The 20th experiment suggests longer fight range has less impact on the decrease in casualties.

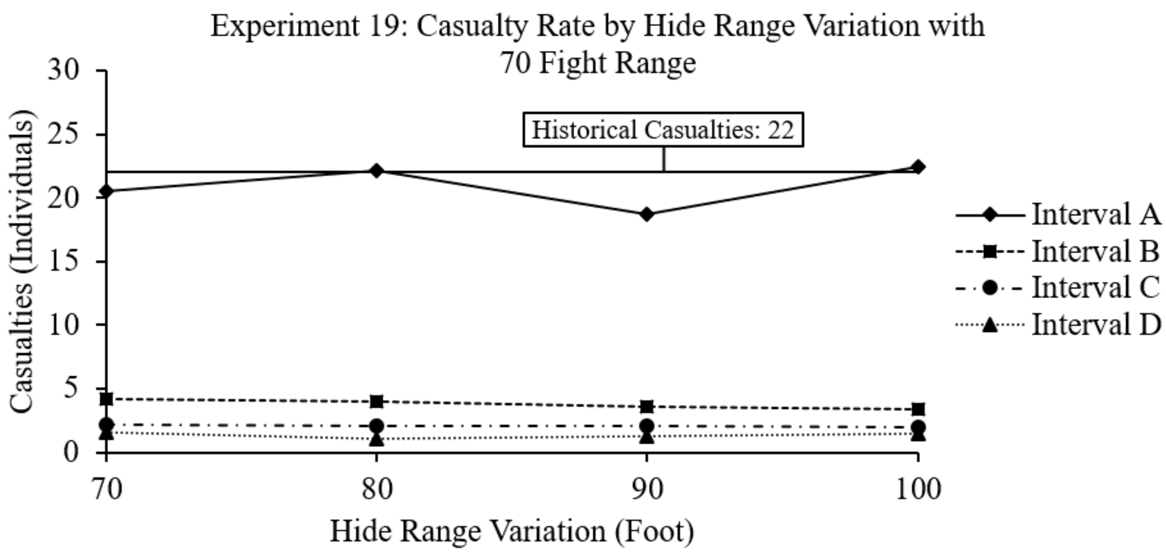

Figure 4.19. Experiment 19: Casualty Rate by Hide Range Variation with 70 Fight Range

Table 4.20. Experiment 20 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
80	80	35.5	20.5	52.6	3.41	54.4	1.65	54.7	1.33
90	80	36.8	19.2	52.7	3.33	54.1	1.92	54.5	1.48
100	80	34.7	21.3	52.4	3.64	54.0	1.99	54.8	1.21

4.4.10 Experiment 21: Hide Range from 90 to 100 Feet with 90 Feet Fight Range

The 21st experiment compared the casualty rate difference among student and staff agents with 10 step increment of the as_hide_range from 90 to 100 while as_fight_range is set to 90. The average differences of casualties from interval A to B were 16.68 casualties, interval B to C at 1.23 casualties, and interval C to D 1.02 casualties. The average casualties were 6.17 with 0.58 decreased casualties than the previous experiment. The 21st experiment suggests that the discharge range had less impact on increasing survivability.

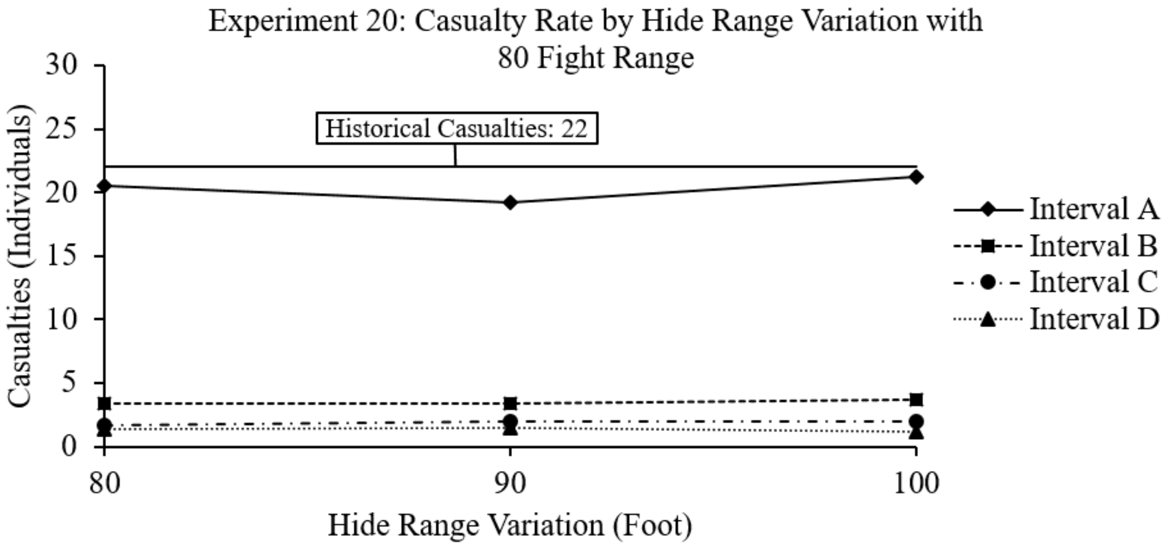

Figure 4.20. Experiment 20: Casualty Rate by Hide Range Variation with 80 Fight Range

Table 4.21. Experiment 21 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
90	90	35.6	20.4	52.2	3.76	54.0	1.98	54.8	1.24
100	90	37.3	18.7	54.0	1.98	54.7	1.30	56.0	0.00

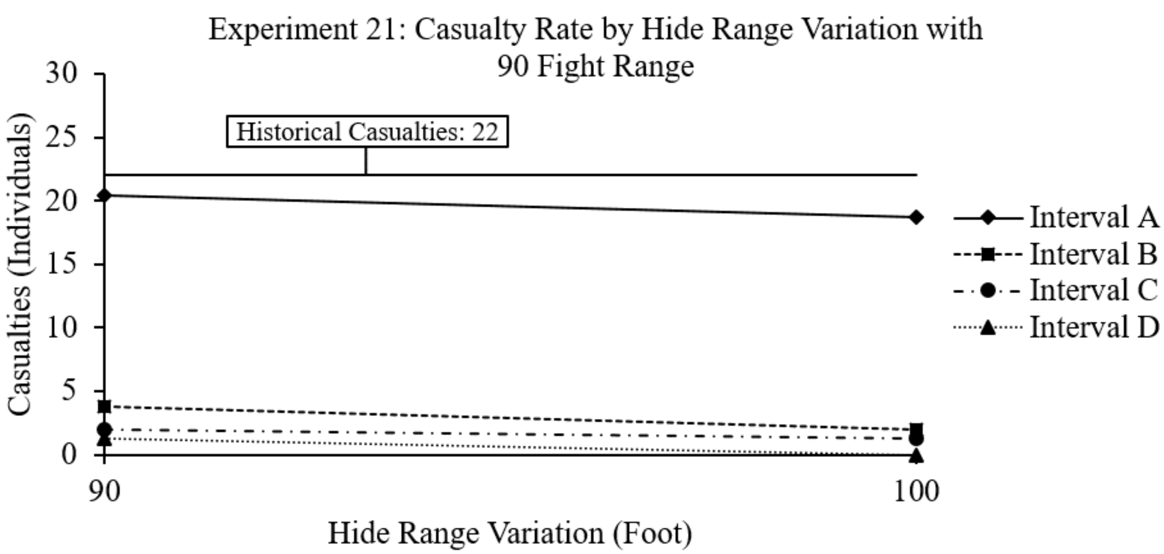

Figure 4.21. Experiment 21: Casualty Rate by Hide Range Variation with 90 Fight Range

4.4.11 Experiment 22: Hide Range to 100 Feet with 100 Feet Fight Range

The 22nd experiment compared the casualty rate difference among student and staff agents at as_hide_range to 100 while as_fight_range to 100. The average differences of casualties from interval A to B were 16.47 casualties, interval B to C at 1.55 casualties, and interval C to D 0.71 casualties. The average casualties were 6.78 individuals which are the increase of 0.61 from the previous experiment. The 22nd experiment suggests that when all staff and student agents fight the shooter, the number of casualties will remain below 22 individuals.

Table 4.22. Experiment 22 Output Summary

Range		Interval A		Interval B		Interval C		Interval D	
Hide	Fight	SRVL	CAS	SRVL	CAS	SRVL	CAS	SRVL	CAS
100	100	35.9	20.1	52.4	3.62	53.9	2.07	54.6	1.36

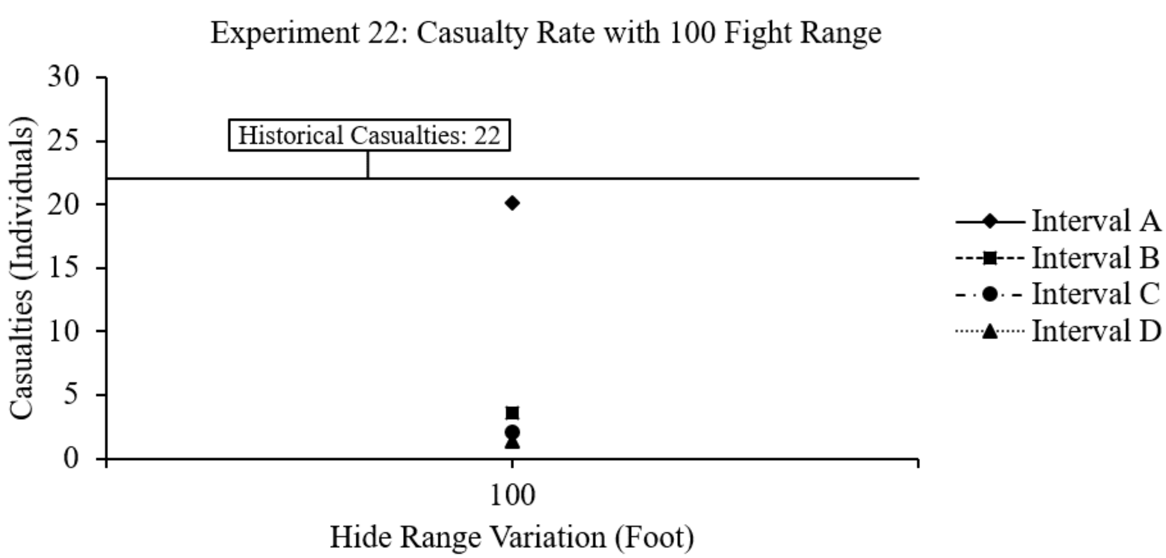

Figure 4.22. Experiment 22: Casualty Rate with 100 Fight Range

4.5 Summary

This chapter described the data output summary with a table and a figure per experiment that was conducted for two main goals. The first goal was to learn the minimum parameter for the shooter agent's minimum movement speed, discharge range, and the discharge scope. The results suggest the minimum movement speed is at 2.83 feet per second, minimum discharge range at 51.12 feet, and the 14.31 degrees as the minimum discharge scope. Among the discovered parameters, experiment 12 to 22 were conducted with the following hide range variation by set fight range. These parameters were used to test the effectiveness of the RUN.HIDE.FIGHT.® with hide and fight range from 0 to 100 feet incremented by 10 steps s seen in Table 4.23.

Table 4.23. Experiment Iteration Overview

Experiment	Iteration	Hide Range (Variation)	Fight Range
12	11	0 - 100	0
13	10	10 - 100	10
14	9	20 - 100	20
15	8	30 - 100	30
16	7	40 - 100	40
17	6	50 - 100	50
18	5	60 - 100	60
19	4	70 - 100	70
20	3	80 - 100	80
21	2	90 - 100	90
22	1	100	100

As seen in Figure 23, the number of average casualties for all intervals were similar for Experiment 11. The highest number of casualties for Experiment 11 occurred where there were no offensive measures among staff and student agents. In contrast, experiments with offensive measures resulted in 46% fewer casualties for Interval A, 90% less for Interval B, 94% less of Interval C and 96% less for Interval D on average.

Table 4.24 to 4.25 shows the survival and casualty probability of the historical discharge interval from Experiment 12 to Experiment 22. The highest survival probability was 100% during Experiment 21 where hide range set to 100 feet, and fight range set to 90 feet. The lowest survival

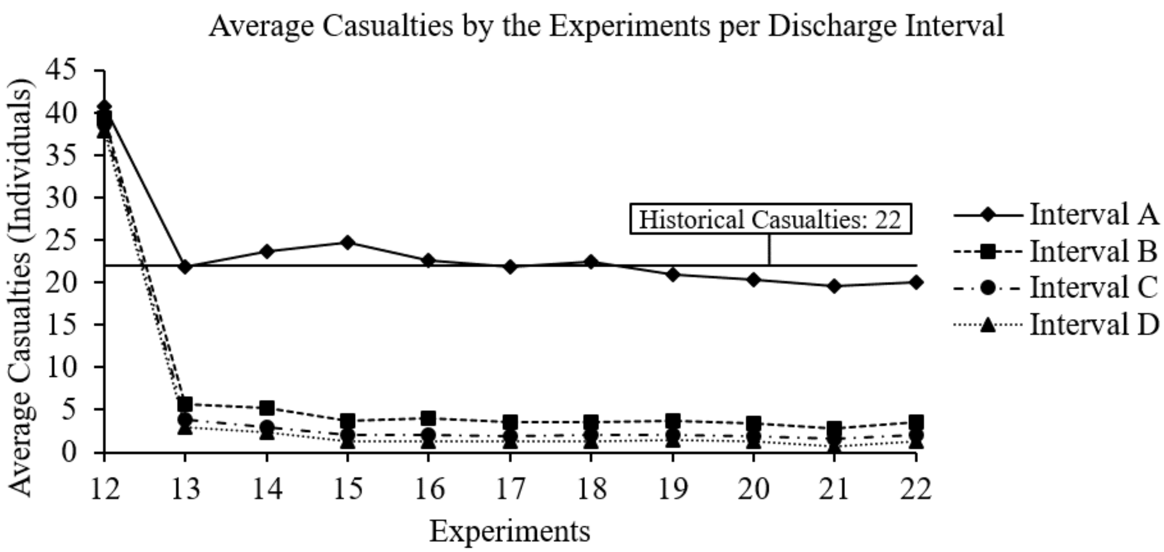

Figure 4.23. Average Casualties by the Experiments per Discharge Interval

probability was 3.07% during Experiment 11 where the hide range set to 90 feet, and fight range set to 0 feet.

Table 4.24. Survival Probability from Experiment 12 to 17 during the Historical Discharge Interval (Interval D) by the Model Output

	12	13	14	15	16	17
Unit: Foot	Fight: 0	Fight: 10	Fight: 20	Fight: 30	Fight: 40	Fight: 50
Hide: 0	92.1%					
Hide: 10	77.7%	97.6%				
Hide: 20	70.1%	91.0%	97.7%			
Hide: 30	43.9%	95.5%	93.5%	97.2%		
Hide: 40	34.1%	93.8%	94.4%	97.6%	97.3%	
Hide: 50	11.6%	95.9%	95.4%	97.3%	97.8%	97.7%
Hide: 60	7.70%	94.1%	96.2%	98.1%	97.8%	97.8%
Hide: 70	4.59%	94.3%	96.6%	97.9%	98.0%	97.4%
Hide: 80	5.13%	95.5%	97.1%	97.8%	97.6%	97.6%
Hide: 90	3.07%	93.9%	96.1%	98.1%	97.6%	97.9%
Hide: 100	5.16%	94.9%	95.9%	97.8%	97.7%	97.7%

Figure 4.24 illustrates the average survival and casualty probability per experiment based on historical events that occurred with RHF initiation at 11:29 AM. As seen in Figure 4.24, Experiment 11's survival probability was 32.28% which was 28.43% less than the historical

Table 4.25. Survival Probability from Experiment 18 to 22 during the Historical Discharge Interval (Interval D) by the Model Output

	18	19	20	21	22
Unit: Foot	Fight: 60	Fight: 70	Fight: 80	Fight: 90	Fight: 100
Hide: 60	97.7%				
Hide: 70	97.6%	97.2%			
Hide: 80	97.5%	98.0%	97.6%		
Hide: 90	97.7%	97.7%	97.4%	97.8%	
Hide: 100	97.4%	97.3%	97.8%	100%	97.6%

survival probability of 60.71%. The survival probability during Experiment 12 was 94.66% and Experiment 13 was 95.88%. These probabilities differ from Experiment 14 to Experiment 21 where the average survival probability was 97.79% with a standard deviation of 0.45. The results suggest that the higher the fight range, the higher the survival probability.

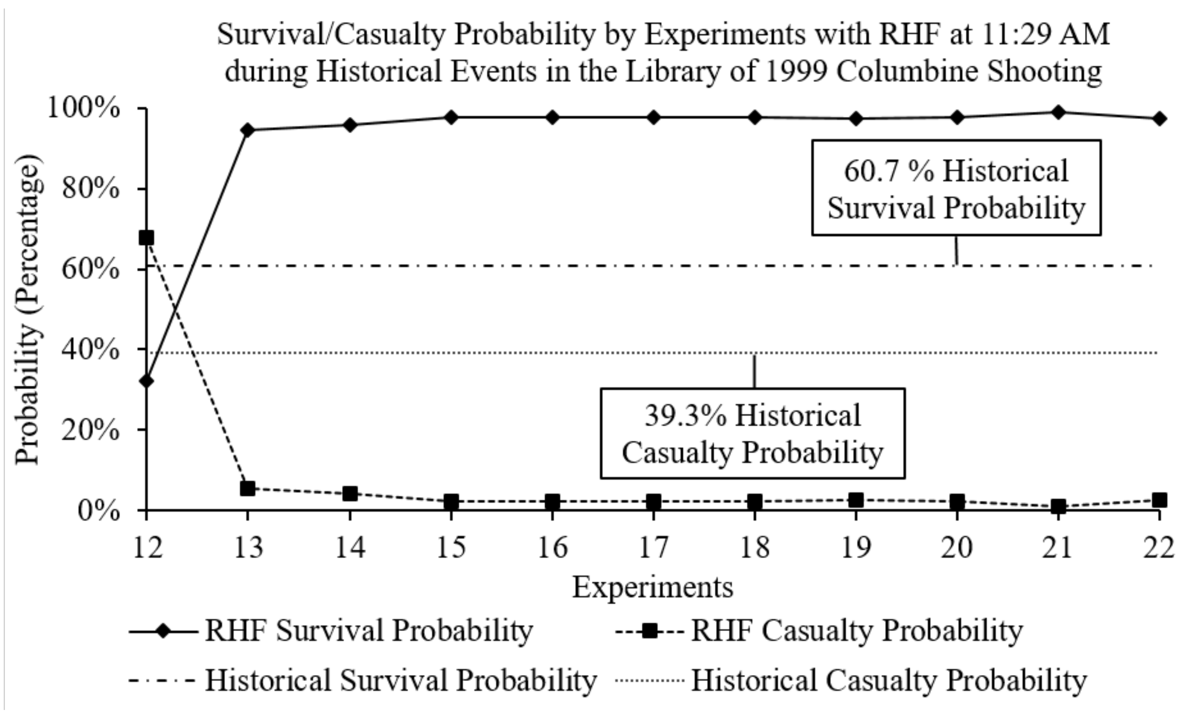

Figure 4.24. Survival/Casualty Probability by Experiments with RHF at 11:29 AM during Historical Events in the Library of 1999 Columbine Shooting

CHAPTER 5. SUMMARY AND FUTURE PLAN

This research examined the effectiveness of RUN.HIDE.FIGHT.® (RHF) by comparing the casualties based on the historical events that have occurred in the library of 1999 Columbine High School shooting with AnyLogic. The research was divided into five different phases as listed below.

- Phase 1: Procure data (images, reports, illustrations) to realistically model the incidents that have occurred in the library during the day of the shooting.
- Phase 2: Model the Columbine High School's library based on Phase 1 focusing on physical infrastructure and agent (student, staff, shooter) placement.
- Phase 3: Implementation of agent-specific logic in physical behavior for historical and RHF actions.
- Phase 4: Learning the minimum parameters of the shooter (movement speed, discharge range, discharge scope) based on the historical model.
- Phase 5: Assessing the effectiveness by manipulating the hide and fight range that initiates the agent to complete the RHF process based on their proximity to the shooter.

The Experiment 1 to 11 (Phase 4) suggest that the minimum shooter agent's speed was 2.83 feet per second, discharge range at 51.12 feet, and discharge scope at 14.31 degrees to complete all events within 420 seconds. The 420 seconds were the duration of the shooters stay in the Columbine High School library from 11:29 AM to 11:36 AM. These leanings from Phase 4 were set as defaults in Phase 5. Based on the default parameters, Experiment 12 to 22 (Phase 5) suggests that students and staff agents with the offensive measures during the historical discharge interval (Interval D) increased the survival probability by 36.57% on average. In contrast, Experiment 11 (no offensive measure) has a decrease in survival probability by 24.43%.

Additionally, the discharge interval did impact the casualties throughout Phase 5 except Experiment 11. This experiment did not have fighting capability where the differences among casualties were minor from experiments with fighting capabilities. During Interval D, the historical interval, the average casualties for experiments with offensive measures have outputted the 1.76 casualties on average. This equates to 93.71% lower casualty probability than the historical 22 casualties. In contrast, Interval A where the shooter agents discharge every second produced average casualties of 22.44 individuals, a 1.96% higher casualty probability than the historical casualties. The research outcome suggests the initiation of RUN.HIDE.FIGHT.® at 11:29 AM, April 20, 1999, as the shooter enters the library will increase survival probability by 36.57%.

5.1 All Run Scenario

The first iteration of Experiment 12 has 0 feet set for both the hide and the fight range resulting in an all run scenario. This scenario outputted the survival probability of 92.1% suggesting that at least 51 out of 56 individuals will survive the incident achieving 30.4% higher survival probability than the historical event. To maximize the potential of the all run scenario requires active shooter specific training to achieve evacuation latencies.

The first objective to achieving evacuation latencies is active shooter detection. Similar to fire alarms, an individual may attempt to evacuate, dial 911, or pull the fire alarm when they see smoke or fire. These actions are instinctual resulting from the early and continuous training occurs in a in society. Being trained to detect firearm discharge could prevent delayed response in evacuation and notifying emergency services. For example, the Purdue University's Emergency Communication Plan 2019 uses ALERTUS, a collection of multilayered communication capabilities. The alerts include text messages, emails, twitters, desktop popup alerts, and alert beacons to maximize the notification reached. In addition to the human capabilities, discharge detection tools by sound and/or visual could detect and approximate the location of the shooter.

The second objective is the location-specific path for safety based on the shooter's location. To maximize survival probability, civilians would have to run away from the shooter. This reasoning is why shooter detection becomes significant. Unlike traditional emergencies, active shooter incidents are fluid where the location of the threat is highly volatile. Therefore, the facilitation of several escape routes is necessary to execute an all run scenario.

5.2 All Hide Scenario

The 11th iteration of Experiment 12 has a 100 feet hide and 0 feet fight range resulting in an all hide scenario. This scenario outputted the survival probability of 5.16% suggesting that at least 2 out of 56 individuals will survive the incident. This is a 57.1% lower survival probability than the historical event. For Experiment 12, the historical casualty was replicated once the hide range was above 20 feet at 19.9 average casualties to 30 feet at 32.4 average casualties. From 60 to 100 feet, there were 55.6 casualties with the standard deviation of 0.41. The Experiment 11 results suggest that individuals who hide instead of run without fighting will have 86.9% less survival probability of surviving.

Defensive measures such as in-class ballistic shelter and even doors with locks could increase the survival probability during an all hide scenario. The purpose of these defensive measures is to prevent individuals from becoming targets by providing challenges to the shooter. The all hide scenario is crucial since elementary schools or individuals with disabilities may not be able to run. Seeking shelter in an in-class ballistic panels will naturally increase survival probability. Additionally, Purdue University installed campus-wide door locks after a homicidal active shooter incident. The purpose of installing the door locks was to obscure a shooter's target point.

5.3 All Fight Scenario

The first iteration of Experiment 22 has a 100 feet hide and fight range resulting in an all fight scenario. This scenario outputted a survival probability of 97.6% suggesting that at least 54 out of 56 individuals will survive the incident. This input results in a 35.7% higher survival probability than the historical event, and 5.46% higher than the all run scenario. The fight logic has all student and staff agents move toward the nearest shooter. The shooter becomes a casualty once the shooter is one foot away from the agent while remaining alive. The model simulation shows a swarm covers the two shooters that obstructs their ability to fire.

A real-life example of a successful fight scenario is the 2015 Thalys train attack (Karimi, 2018) in France where the passengers have willingly apprehended the shooter. Another example is in 2018, a science teacher from Noblesville, Indiana (Martin, Herron, Fittes, Cook, & Hays, 2018) has tackled a student with a firearm on campus to prevent an active shooter incident. The common factor of these two events is the deployment of the physical offenses against an individual with a firearm. The action of these brave individuals suggest that the necessity of firearm to fight the shooter is not required which supports the model output achieving the highest survival probability of 97.6%. However, the impact of the offensive measure will have a higher probability of shooter apprehension that could be accomplished in a longer distance while maintaining their protective posture.

5.4 Policy Recommendations

The initiation of RUN.HIDE.FIGHT.® (RHF) at full scale was crucial in decreasing casualties. As seen in the results, the casualties increased above the historical 22 casualties when offensive measures were missing. Repetitive training to fully incorporate RHF, especially among the population who cannot execute offensive tactics (elementary school students, disabled populations) will require alternatives.

The RHF was successful in decreasing the casualties for the staff and students that were seeking shelter in the library during the 1999 Columbine High School shooting. However, lowering casualties may not be seen depending on the circumstances of active shooter incidents. To better understand the impact of RHF during an active shooter incident, the researcher recommends the following.

- Step 1: Recreate the institution's infrastructure with agents in a modeling environment during the hours of operations.

  Example: Model your school based on floor plans with student, staff and school resource officer agents. Allow the agents to move based on the institution's schedule.

- Step 2: Validate the model's data output by comparing it to similar historical data that an institution possesses.

  Example: Run the parameter experiments to accomplish all tasks such as students arriving at their next class within the break period, or lunchtime movement to better recreate the flow of populations.

- Step 3: Allow the shooter to enter at randomized entry points without any response policies such as RHF to procure natural casualty data.

- Step 4: Allow the shooter to enter at randomized entry points with any response policies such as RHF to procure the influenced casualty data.

- Step 5: Compare the data of each scenario to customize policies for an institution's needs.

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