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AGENT-BASED MODELING FOR CASUALTY RATE ASSESSMENT OF LARGE EVENT ACTIVE SHOOTER INCIDENTS

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ABSTRACT

The 1999 Columbine attack changed police response to the active shooter incidents (ASI) by the public and first responder's tactics and training. With FBI data suggesting ASI events increasing, this study offers an AnyLogic models to understand mitigation actions such as Run.Hide.Fight. Our model represents a general densely populated area, such as public transportation terminal or indoor arena. Model agents include civilians, police, and shooter agents interact with the following parameters: civilian evacuation time, the response of police, firearm discharge by the shooter and police. The casualty rates vary from 85 to 1 causalities when the shooter's rate of discharge was 1 to 60 seconds, respectively. The model as developed was shown to provide a method to evaluate and compare actions such as adequacy of training, introduction of technology into public buildings and the general design of public spaces to reduce the impact of ASI events.

1 INTRODUCTION

Active shooter incidents (ASI) is a common terminology that is frequently introduced to the general public since the 2000's. Despite the first responder and civilian communities' efforts to mitigate ASIs by developing new response tactics, the incident rate nor the casualty rate are seeing a decline (FBI 2014). According to the FBI (2014), 70% of reported ASIs between 2000 to 2016 have occurred in either areas of commerce 43.2% or educational environments 21.8%. These areas consist of large population density where over 60% of the incidents are terminated prior to the first responders' arrival (FBI 2014). Under these circumstances, it is vital to implement unarmed response strategies to lower civilian casualty rate.

The Run.Hide.Fight.® (RHF) unarmed response developed by the City of Houston in 2012 is implemented throughout the public and private sectors in the United States (Ready Houston 2012). However, there is a lack of policy and academic research data that supports the effectiveness of RHF in lowering casualties despite the nationwide implementation. Additionally, the application of RHF is limited during a large event active shooter incidents. A large event ASI such as the 2017 Las Vegas Shooting challenges civilians to *Run* from the shooter since the discharge rate was much faster than the previous ASI events. The *Hide* response of the RHF was also another challenge since the area was densely populated with lack of physical structures to seek adequate shelter. Finally, the civilians attempting to *Fight* the shooter may be exposed to the higher range of discharge which increases the possibility of casualty.

The AnyLogic agent-based modeling (ABM) was chosen as the modeling software to replicate the real-life ASI to improve logistical efficiency while minimizing human error. The AnyLogic supports discrete event, agent-based, and system dynamic methods that are compatible between model methods. The flexibility of AnyLogic permits the recreation of an open area's physical structure while implementing shooter, civilian, and police officer agents to meet the criteria of historic ASIs. The model consists of four manipulative parameters: evacuation delay, police response delay, tome to acquire active shooter, and active shooter agents. This study will examine the impact of the ASI casualty rates as a result of delays in event notification or police response.

2 BACKGROUND

2.1 Active Shooter Incident Overview

The active shooter terminology is familiar to the general public due to the increased rate of incident occurrences. According to the Department of Homeland Security (DHS 2017), 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". The Federal Bureau of Investigation data (FBI 2014) states that the annual average of active shooter incidents (ASI) were 6.4 incidents (2000-2006) to 16.4 incidents (2007-2013). The increasing rate of ASIs has challenged the mitigation strategies for the first responder and civilian communities.

2.2 Mitigation Strategies to Active Shooter Incidents for the First Responders

The first responders mitigation tactics changed to challenge each ASI's unique circumstances. Unlike the traditional emergency situations, the origin of the danger is not stationary. For example, during an active fire, civilians would leave the premise by evacuating away from the origin of the fire. However, the ASI presents a unique set of challenges where the threat actively seeks for their next target, and unlike a reaction to a structural fire, the victim's reaction is not as easily to replicate.

The law enforcement communities (LEC) have utilized the preexisting school resource officer (SRO) program to mitigate the shooter impact. The SRO's structural knowledge could be used to develop the mitigation and response tactics by sharing the shooter's status to the dispatcher. Additionally, active shooter training implements a *contact team* concept which may use at least three officers to apprehend the shooter. The purpose of a *contact team* is to increase awareness while minimizing blind spots during the search operation. The *contact team* could also assist the rescue operation as well as intelligence gathering by distributing roles among officers (Police Executive Research Forum 2014).

The incident command system (ICS), along with mutual-aid agreements, were improved to react to ASI challenges. The application of traditional command and communication among first responders during the Columbine Massacre was recognized as needing policy improvements to meet the challenges with ASI reaction concurrent with a mass casualty event which increased the casualty rate. The role of the incident command stands to "identify the key concerns associated with the incident" (Federal Emergency Management Agency). The key concerns of ICS during an ASI would be the location of the shooter, coordination among the first responders, and mutual aid organizations. Most importantly, maintaining lines of open communication among participating responders has proven vital when operating an ICS due to the threat's reactivity over a short duration.

The active shooter preparedness also changed the first responders' training. The Advanced Law Enforcement Rapid Response Training (Advanced Law Enforcement Rapid Response Training 2004) by Texas State University trains law enforcement officers (LEO) to apprehend the shooter by taking proactive measures. ALERRT also hosts the National Active Shooter Training Conference to share "local, regional, state and national active shooter response preparedness" among police, fire & rescue, and emergency medical service (EMS).

2.3 Mitigation Strategies to Active Shooter Incidents for the Civilians

The traditional emergency responses such as *Evacuate* and *Shelter-In-Place* are not effective for ASI due to the mobility of the threat. The Avoid, Deny, Defend™ (ADD) unarmed response was developed in 2004 (Advanced Law Enforcement Rapid Response Training), which incorporates the traditional response while initiating the potential victims to take proactive measures against the threat as a last resort. This method instructs civilians to *Avoid* the shooter by moving away from the threat. If unable to *Avoid*, *Deny* the shooter by physically barricading yourself and others from the threat. As a last resort, *Defend* yourself from the shooter by using any means necessary to deter the shooter, such as utilizing surrounding objects as weapons.

The Run.Hide.Fight.® (RHF) unarmed response was introduced in 2012 by the City of Houston (Ready Houston 2012). Similar to ADD, the RHF recommends civilians to *Run* away from the shooter regardless of the consequences. When running away from the shooter is no longer an option, *Hide* from the shooter by physically removing yourself from the threat. If unable to run or hide, *Fight* the shooter when your safety is at risk by improvising surrounding objects as weapons. The RHF recommends strategies similar to ADD during the ASI for civilians. In summary, ADD and RHF both pertain to defensive measures which are similar to Evacuate and Shelter-In-Place. Both responses also recommend offensive measures to the threat by utilizing surrounding objects as weapons. The three steps measures of ADD and RHF can be used interchangeably depending on the civilians' discretion.

The ADD or RHF unarmed responses are implemented in both private and all levels of public sectors. The four branches of the U.S. military use RHF for unarmed personnel response in an instance of ASI. The Department of Homeland Security (DHS) recommends *Evacuate, Hide Out,* and *Take Actions* (DHS 2008) in the active shooter handbook. The Department of Education's (DOE) Readiness and Emergency Management for Schools (REMS) recommends RHF application in order to meet the individual campus infrastructure. The REMS emphasizes the importance of immediate evacuation and the necessity to follow instructors' command to lower casualties. The Indiana State Police recommends Escape/Run, Lockdown/Hide or Fight (ISP 2015). The Santa Ana Unified School District also recommends RHF through instructional videos for elementary, middle, and high school students. The application of RHF and RHF-like responses encompasses all level of public and private organizations.

3 ACTIVE SHOOTER RESEARCH

3.1 Previous Active Shooter Research

Hayes and Hayes (2014) tested the effectiveness of Senator Feinstein's bill to regulate assault weapons and magazine capacity. This study used agent-based modeling (ABM) since "each agent is chosen in random order and allowed to make an action" (Hayes and Hayes 2014). An indoor and outdoor models were created with three types of agents: civilians, security guards, and one shooter. The civilians are programmed to escape at a higher velocity to the nearest door once the shooting begins. The shooter chooses the nearest individual as the primary target and moves on to the next nearest target. The model terminates when either the shooter is apprehended by the security guards or all civilians escape through the nearest exits. The study found that Senator Feinstein's bill is less likely to be effective in lowering casualty rates during an ASI. In contrast, the study found that the rate of discharge is the primary factor that increased the casualty rate.

Anklam (2014) researched the effectiveness of armed school security guards and instructors with conceal carry weapons during an ASI. Anklam used ABM since the modeling best reproduces the "human systems" (2014). The following scenarios were tested: school without physical security mechanism, school with 5-10% of the workforce using conceal carry weapons, school with an armed guard, and the school with armed guards with 5-10% of the workforce utilizing conceal carry weapons. The model with no security mechanisms had the highest casualty rate. In contrast, models with armed guard and/or instructors' with conceal carry had lower casualty rate. This study also emphasizes the importance of law enforcement's timely response.

Briggs and Kennedy (2016) have implemented RHF by using ABM in an open area. The fighters, fleers, and the shooter agents are set to naturally interact with the model's runtime. Once the shooting begins, the fighters will approach the shooter, and the fleers will try to escape the threat. This study found that proactive measures such as fighting the shooter will lower the average casualty rate to 30 casualties compared to the average casualty rate of 63 casualties when the shooter is not subdued. The research suggests that taking proactive actions against the shooter will decrease the overall casualty rate. However, the individuals who take proactive measures will be at a higher risk of casualty.

Stewart (2017) researched the effectiveness of run, hide, or run and hide to lower the casualty rate while manipulating the cognitive delay and the police response delay. Stewart used ABM to create the model which resembled an academic environment to determine the contributing factors which increase the casualty rate. The police response time of 5 minutes delay had the most impact on the casualty rate compared to 30 and 60 seconds delay. Stewart's research found that the run and hide scenario had the lowest casualty rate when response time was increased by police response or notifications delays.

3.2 Limitations of Active Shooter Research

The ASIs presents unique challenges for not only the general public and first responders but also the researchers. There have been fewer active shooter incidents compared to the traditional emergency management responses where the standardized response measures are yet to be implemented. In order to gather accurate data to prove the effectiveness of unarmed responses, participation of civilians, police officers, and a mock shooter would be necessary. The logistical challenges and human error outweigh the benefit of conducting such exercises to collect data.

Conducting a mock active shooter incident to test the effectiveness of the unarmed response had limitations. The exercise would have to be conducted without notice to test the element of cognitive delay, which was one of the problems during the Columbine Massacre. According to the Department of Homeland Security (DHS 2017), the element of surprise could cause mental health concerns such as PTSD or anxiety. Additionally, Briggs and Kennedy (2016) emphasize that "it would be ethically impossible to create a true life-or-death situation in which individual would response with potential lethal force". The unique circumstances of the ASI creates research limitations to gather data in a traditional research method by simply recreating mock ASIs.

4 RESEARCH METHOD

4.1 Agent-Based Modeling

An agent-based modeling (ABM) was an optimal solution to gather active shooter research data. The ABM allowed the researcher to create hypothetical situations, such as ASIs in commercial and educational environments. The shooter, police officer, and unarmed individual agents could be added to the environment. Unlike equation-based modeling, ABM was capable of capturing the emergency phenomena which is based on the "result from the interactions of individual entities" (Bonabeau 2002). The *emergent phenomena* would capture the differences in casualty rate based on evacuation delay, police response delay, and the civilians determination on whether run, hide, or fight. The ABM was capable of recreating ASIs using the flexible nature of the modeling to capture natural interactions among agents under the certain sets of rules.

4.2 AnyLogic Software

The AnyLogic modeling software supports discrete event, agent-based, and system dynamic configurations within a model that could be used interchangeably. The agent-based method of AnyLogic provided the user with the ability to create and customize the behavior of the agent. The discrete event enabled the user to manipulate parameters such as rate of fire by the shooter or the accuracy of the police officers' firearm. The system dynamic component would be used to represent the evacuation delay by adding parameters such as the bystander effect or the cognitive delay. Finally, AnyLogic allowed the user to use all three components interchangeably which increases flexibility from the traditional equation-based modeling.

4.3 Model Assumption

One assumption is that this model greatly simplifies human behaviors to allow for study of active shooter incident (ASI) research in terms of key actions and the impact of such incidents.

4.3.1 Physical Layout Assumptions

The physical layout has been simplified into a rectangle which represents a large public infrastructure with a common area located at the center. The dimension of the rectangle is 300 feet by 500 feet.

4.3.2 Agent Assumptions (Unarmed Individuals, Active Shooter, Police Officers)

All agents assumptions were 5 feet per second velocity before the shooting, 7 feet per second velocity after the shooting, the police officers will respond 5 seconds after the shooter's discharge, the civilians will evacuate 10 seconds after the shooter's discharge, the discharge range of the officers and the shooter are both 100 feet with 100% target acquirement.

4.4 Agent and Structural Layout

The model consists of three agents: civilians, police officers, and an active shooter. The model replicates a large open area which does not exist in reality but to resemble a terminal, public transit, auditorium, etc. The open area was 500 by 300 feet. The model consisted of one common area, four physical barricades, police checkpoints, and four exits. Figure 1 displays the model runtime overview.

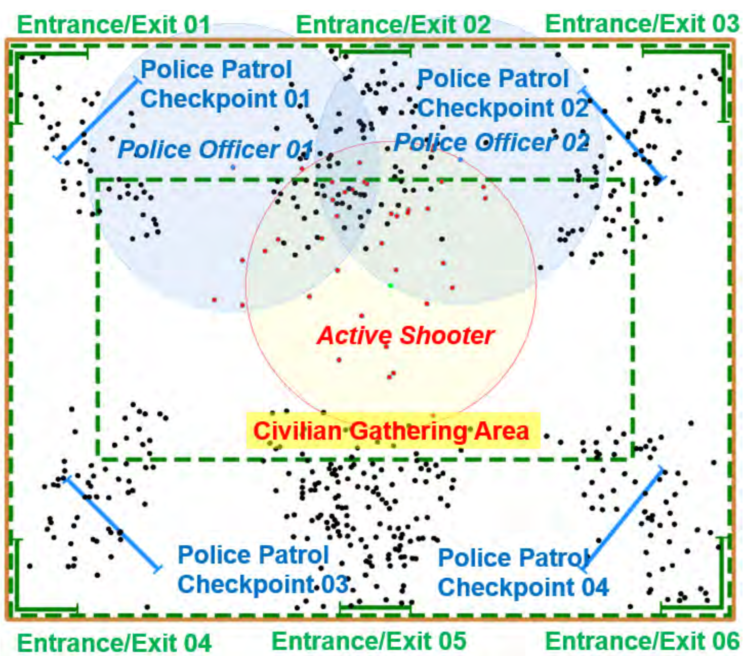

Figure 1: Model runtime image after active shooter discharge.

4.5 Model Logic Prior to the Active Shooter's Discharge

The civilian agents randomly entered the model by the entry/exit points. Upon entry, the civilian agent either moved to the randomly selected entry/exit or to the center location of the open area to simulate the waiting civilians. The wait duration was set from 30 to 40 minutes where the civilian agent moves to the randomly selected entry/exit upon wait time expiration. The civilian agent exited the model when it reaches one of four entries/exits

The police officer (PO) agents entered the model by one of four entry/exit points. Upon entry, the PO agents patrols toward one of four checkpoints located on the edges of the center waiting area. The checkpoints were randomly chosen by the PO agents while continuously moving toward the next randomly chosen checkpoint. The PO agents would continue their patrol until the end of the model.

The active shooter (AS) agent entered the model by the random selection of four entry/exits. The AS agent moves to the open area and disguises as a civilian agent. The civilian agent was dismissed from the open area after 30 to 40 minutes and exited the model by choosing one of four entry/exits. If the AS agent reached the entry/exit, the agent exits the model.

4.6 Model Logic After the Active Shooter's Discharge

The active shooter (AS) agent entered the shooting logic when the number of civilian agent reaches 500 agents in the waiting area. One of civilian and PO agents were selected within the AS agent's discharge range of 100 feet. If there are no potential targets within discharge range, the AS agent begins to search again for a new target. Upon target selection, the AS agent notifies a word message per second to the target. Once the target agent received the message which occurs immediately, the target agent changed its color to represent casualty. If there is no target, then the target search logic restarted after a one second expiration.

The PO agents received the AS agent's location immediately after the first discharge and respond to the AS agent after 5 seconds to represent response delay. The PO agents had the discharge range of 100 feet where the only target is the AS agent. The PO agents discharged to the target every 10 seconds. Once the AS agent was apprehended, the PO agents remained at their location. The message exchange between police and active shooter agents represent exchange of fire during active shooter incident.

The UI agents began to evacuate the model 10 seconds after discharge. The agents would enter the evacuation logic. The agents would choose the nearest entry/exit points from the origin of evacuation. Table 1 displays the default parameters of agents prior to the active shooter's discharge. Table 2 displays the additional parameters with increased rate of agent speed to simulate the urgency to evacuate and respond.

Table 1: Default parameter values of model agents prior to discharge.

Default Parameters	Active Shooter (AS)	Police Officer (PO)	Civilian
Number of Agents	1 agent	2 agents	500 agents
Agent Speed	5 Feet per Second	5 Feet per Second	5 Feet per Second

Table 2: Default parameter values of model agents during discharge.

Default Parameters	Active Shooter (AS)	Police Officer (PO)	Civilian
Agent Speed	7 Feet per Second	7 Feet per Second	7 Feet per Second
Action Delay	0 Seconds (Discharge)	5 seconds (Response)	10 seconds (Evacuation)
Discharge Rate	10 Seconds	10 Seconds	Not Available

4.7 Manipulative Parameters

Table 3 represents the evacuation delay of the civilian agents ranging from the immediate evacuation, up to 120 seconds of evacuation delay. Similar to table 3, table 4 represents the response delay ranging from immediate response to 30 seconds. The table 5 and 6 represents the discharge delays from both the active shooter and the police officer agents. For example, if model 2 from table 5 is implemented, the active shooter will cause casualty every 5 seconds.

Table 3: Evacuation delay parameters for civilian agents (civilian reaction time to evacuate).

Test Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Civilian Evacuation Delay	0 second	10 seconds	30 seconds	60 seconds	120 seconds

Table 4: Response Delay Parameters for Police Officer Agents (Police Response Time).

Test Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Police Response Delay	0 second	2 seconds	5 seconds	10 seconds	30 seconds

Table 5: Rate of discharge parameters for active shooter agents.

Test Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Active Shooter Discharge Rate	1 second	5 seconds	10 seconds	30 seconds	60 seconds

Table 6: Rate of shooter acquirement parameters for police officers agents.

Test Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
Police Officer Discharge Rate	1 second	5 seconds	10 seconds	30 seconds	60 seconds

4.8 Data Collection Process

Using a random starting point, the model was ran 100 times on each test parameters under the following conditions: civilians' evacuation delay, police officers' response delay, the rate of one casualty per *x* seconds by police officer and active shooter agents. Only one parameter was manipulated per model while the remaining were set to default.

5 RESULTS

Table 7 represents casualty rate increase for civilian and police officer agents as the civilian evacuation time increases. Table 8 represents casualty rate increase for civilian and police officer agents as police response time increases. Two graphs on Figure 2 illustrates the casualty rate increase of the civilian agents as the evacuation and the police response time increases. Table 9 represents casualty rate decrease for civilian and police officer agents as the shooter agent's rate of accuracy decreases. Table 10 represents casualty rate increase for civilian and police officer agents as police agents rate of accuracy decreases. The first graph on Figure 3 illustrates the civilian casualty rate decrease as the shooter's rate of accuracy decreases. The second graph on Figure 3 illustrates the civilian casualty rate increase as the police officer's accuracy rate decreases. The one casualty per second rate of active shooter agent recorded the highest number of average casualties for both the civilian and the police office (PO) agents. The UI casualties were 85.3. The second highest UI casualties was one casualty per 5 seconds accuracy rate where 28.66 casualties. The lowest UI casualty rate was .53 casualties where the shooter's accuracy was set at one casualty per 60 seconds. The second lowest was 1.3 casualties where the accuracy rate was one casualty per 30 seconds by the active shooter. Among all parameters, the accuracy rate was the highest contributing factor during model runtime for civilian and police officer agents.

Table 7: Casualty rate per evacuation delay.

Model Agent	Model 1	Model 2	Model 3	Model 4	Model 5
Civilian Evacuation Delay	0 second	10 seconds	30 seconds	60 seconds	120 seconds
Civilian Casualty	5	12	14	13	17
Police Officer Casualty	1	1	1	1	1

Table 8: Casualty rate per evacuation delay.

Model Agent	Model 1	Model 2	Model 3	Model 4	Model 5
Police Response Delay	0 second	2 seconds	5 seconds	10 seconds	30 seconds
Civilian Casualty Rate	4	7	11	16	20
Police Officer Casualty Rate	0	1	0	1	1

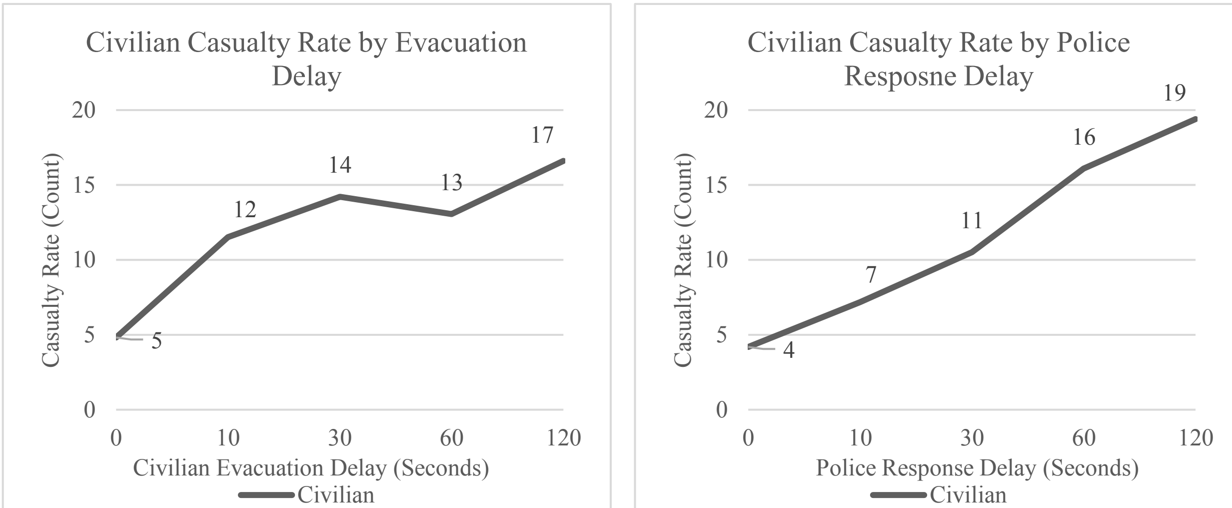

Figure 2: Civilian casualty rate difference by evacuation, and police response delay.

The PO agent recorded the highest number of casualties when the shooter's accuracy rate was one casualty per second recording 1.93 casualties on average. The second highest rate was 1.77 casualties during one casualty per 6 seconds casualty rate by the police officers. The lowest casualty rate was .09 casualties with shooters accuracy rate of one casualty per 60 seconds. The second lowest was .2 casualties when the shooter's rate was one casualty per 30 seconds.

6 CONCLUSION AND FUTURE WORK

The mitigation strategies cannot prevent active shooter incidents from occurring but mitigation actions would by definition decrease the impact or severity of a disaster event. However, immediate evacuation could decrease the casualty rate, as could the rapid and well directed deployment of first responders with high precision discharge abilities. A firearm discharge alert system could proactively evacuate civilians to safety due to the general public's unfamiliarity with the discharge sound. Police officers carefully prepositioned at a vantage point during a large event could also decrease delays in locating the shooter. Finally, improving the police officers' shooting accuracy rate also decreases the civilian casualty rate. Immediate evacuation of civilians, early detection of the shooter, and the rapid deployment of first responders are contributing factors in decreasing casualty rate for civilians and police officers during an active shooter incident. Future research pertains to validating large event active shooter incidents by using the current model's rubric. This study is limited in data validation since the current model's data is based on historical active shooter incidents such as the 1999 Combine Massacre and the 2016 Orlando Nightclub Shooting. Full-scale modeling of the 2017 Las Vegas Shooting by applying the current model's rubric would provide opportunities to validate the integrity of the model. Once the model output data successfully validated by the Vegas shooting outcome, parameters among civilian, police officer, and active shooter agents will be manipulated to determine the greatest contributing factor of increasing the casualty rates of civilians and police officers. The future study's goal is to better make policy decisions to implement applicable active shooter mitigation plan during a large event.

Table 9: Casualty rate per active shooter discharge delay (rate of discharge).

Model Agent	Model 1	Model 2	Model 3	Model 4	Model 5
AS Discharge	1 second	5 seconds	10 seconds	30 seconds	60 seconds
Civilian Casualty Rate	85	29	11	1	1
Police Officer Casualty Rate	2	2	1	0	0

Table 10: Casualty rate per active shooter discharge delay (rate of discharge).

Default Parameters	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
PO Discharge Rate	1 second	5 seconds	10 seconds	30 seconds	60 seconds
Civilian Casualty Rate	4	7	12	20	22
Police Officer Casualty Rate	0	1	1	2	2

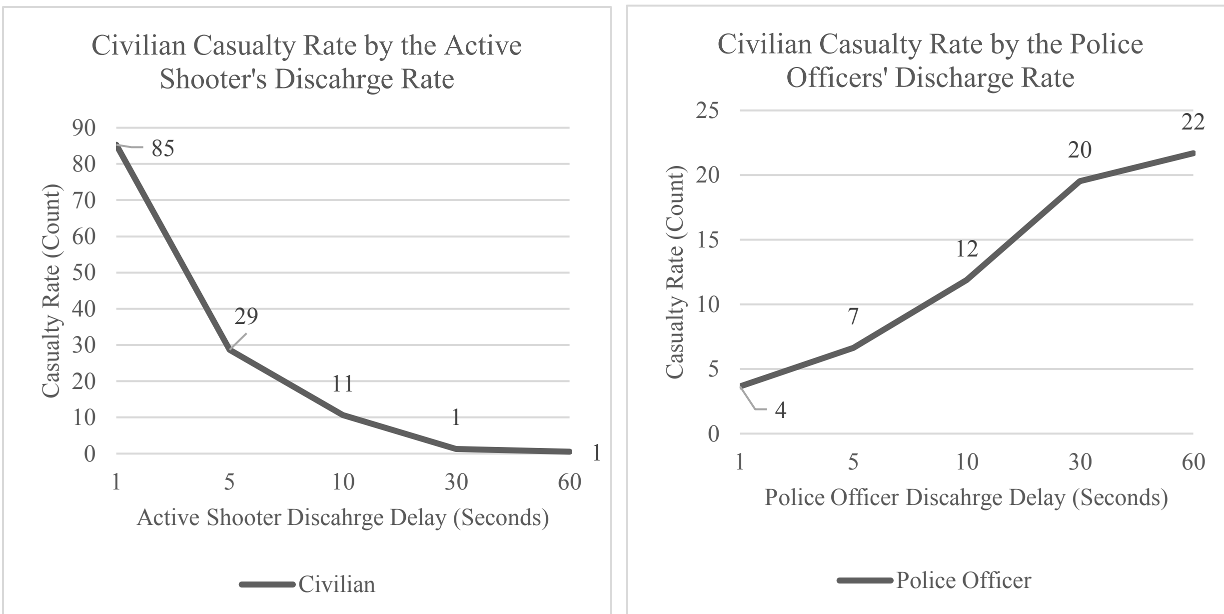

Figure 3: Civilian casualty rate difference by police officer (po) and active shooter (as) agents' rate of discharge.

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