ACTIVE SHOOTER MITIGATION FOR OPEN-AIR VENUES

by

Braiden M. Frantz

A Dissertation

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Doctor of Philosophy

Department of Technology

West Lafayette, Indiana

August 2021

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. J. Eric Dietz, Chair

Department of Computer and Information Technology

Dr. Joseph F. Pekny

Davidson School of Chemical Engineering

Dr. John A. Springer

Department of Computer and Information Technology

Dr. James E. Lerums

Department of Computer and Information Technology

Approved by:

Dr. Kathryne A. Newton

This dissertation is dedicated to my wife and children. Words cannot explain the patience, support and love provided to me during this journey. Without you, none of this would have been possible!

ACKNOWLEDGMENTS

Throughout life and my time serving our great country, I have come to realize that great accomplishments are not achieved alone. My parents demanded a strong work ethic at an early age and that has stuck with me through adulthood. Laying that foundational belief that anything is possible if you work hard enough developed my pursuit of greatness in all that I do. Without their guidance and tutelage, I would have never been successful in life. To this day, my father remains the single greatest mentor, idol and hero.

I would like to convey my deepest thanks and gratitude to my committee: Dr. James Lerums, Dr. Joseph Pekny, Dr. John Springer, and Dr. J. Eric Dietz. The past year has been hectic battling a worldwide pandemic, yet their enthusiastic support, counsel and insight kept my research on track. Together we found resourceful ways to overcome obstacles and conduct meaningful research while meeting all necessary benchmarks. Serving as my primary advisor and committee chair, Dr. J. Eric Dietz was instrumental to my success. He unselfishly adopted me into the Purdue Military Research Initiative, which has served as an extended family during the past three years. His innovative mindset, sincere care, and unconditional dedication to not only me, but my entire family has been a true blessing. Thank you from the bottom of my heart.

During my research, I had the overwhelming support and pleasure of working with Dr. James Lerums, Katie Reichart, Robert Bott, Krassimir Tzvetanov and Jae Yong Lee. I have learned so much from this academic network and established lifelong friendships. The absence of their assistance would not have properly prepared me to undertake this research project. Special thanks to Jae Yong Lee for his willingness to dedicate time and expertise to ensure refinement of the model used for this research project. Without his proactive counsel and countless hours of assistance throughout the past year, I would have never been able to complete data collection and analysis on time. His involvement in my life has proven invaluable and I am eternally grateful for his friendship.

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GLOSSARY

For the purpose of this study, the following research specific terms are used throughout the scope of this project.

- Active Shooter: Shooting incidents that possess the following qualities (Federal Bureau of Investigation, 2020)
    - Public spaces
    - Occur at more than one location
    - Shooter's actions were not result of another criminal act
    - Results in mass killing
    - Indication of spontaneity by the shooter
    - Shooter appeared to methodically search for potential victims
    - Shootings focused on injury to people, not buildings or objects
- Agent-Based Modeling: Computerized model used for the purpose of simulating autonomous agents based upon behavior built into model code.
- Discharge: Term to indicate a firearm has been successfully fired.
- Gimbal: Pivoting support, often attached to a mobile camera, that permits the user to rotate the object along a single axis. A three-axis design is common among cameras.
- Gunshot Triangulation: Systematic network of inter-connected sensors designed to positively identify the location of gunfire.
- Open-Air Venue: Outdoor event where patrons spend most of their time outside of permanent enclosed structures.
- Mass Shooting: Shooting where four or more people are shot, wounded, or killed, excluding the gunman (Holcombe, 2021).
- Pandemic: Epidemic that has spread to more than one continent, possibly impacting people on a world-wide scale.
- Reinforcement Learning: Associated with machine learning to develop agents capable of selecting actions based upon previous outcomes following a series of trial and error.
- RUN.HIDE.FIGHT®: Three tactics that can be applied to safeguard yourself and others during an active shooter event, regardless of location.

- Unmanned Aerial System: Unmanned airborne vehicle with equipment to control it:
    - Autonomous or human-operated control system found on the ground, ship or another aircraft
    - Unmanned aerial vehicle
    - Command and control system (European Commission, 2019)
- Unmanned Aerial Vehicle: Unmanned airborne vehicle that is either controlled remotely or operates autonomously.

LIST OF ABBREVIATIONS

ABM	Agent-based Model
AGDS	Acoustic Gunshot Detection System
AGLS	Acoustic Gunshot Location System
ALERRT	Advanced Law Enforcement Rapid Response Training
ASI	Active Shooter Incident
CSB	Community Services Board
DHS	Department of Homeland Security
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Agency
FERPA	Family Educational Rights and Privacy Act
HCM	High Capacity Magazine
HDOE	High Density Outdoor Event
JAMA	Journal of American Medical Association
LCM	Large Capacity Magazine
LiPo	Lithium Polymer
LVMPD	Las Vegas Metropolitan Police Department
NASRO	National Association of School Resource Officers
NFPA	National Fire Protection Association
RHF	Run. Hide. Fight
RL	Reinforcement Learning
SWAT	Special Weapons and Tactics
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
VTPD	Virginia Tech Police Department

ABSTRACT

This dissertation examines the impact of active shooters upon patrons attending large outdoor events. There has been a spike in shooters targeting densely populated spaces in recent years, to include open-air venues. The 2019 Gilroy Garlic Festival was selected for modeling replication using AnyLogic software to test various experiments designed to reduce casualties in the event of an active shooter situation. Through achievement of validation to produce identical outcomes of the real-world Gilroy Garlic Festival shooting, the researcher established a reliable foundational model for experimental purposes. This active shooter research project identifies the need for rapid response efforts to neutralize the shooter(s) as quickly as possible to minimize casualties. Key findings include the importance of armed officers patrolling event grounds to reduce response time, the need for adequate exits during emergency evacuations, incorporation of modern technology to identify the shooter's location, and applicability of a 1:548 police to patron ratio.

CHAPTER 1. INTRODUCTION

1.1 Introduction to the Problem

Active shooter events are a plague within the United States, gaining national attention from the horrific loss of life associated with each tragedy. The shooting that took place within Columbine High School in 1999 took the lives of 13 people which prompted change to active shooter response tactics employed by first responders across the United States. Tactics employed by first responders through the 1990s involved establishing a secure perimeter around the scene while waiting on a Special Weapons and Tactics (SWAT) team to arrive. This technique relied on the specialized training conducted by SWAT team members that was not rehearsed by other members of law enforcement. The result was a system rife with delays in interdicting active shooters to prevent unnecessary loss of life. The shooters at Columbine High School exploited the protocol in place by first responders and led to sweeping changes in active shooter response measures. The establishment of both Advanced Law Enforcement Rapid Response Training (ALERRT) and RUN.HIDE.FIGHT® (J. Y. Lee, 2019) stem from the Columbine massacre, addressing actions to be taken during an active shooter incident by both victims and first responders.

Early development of post-Columbine active shooter training focused upon enclosed spaces. Responding officers trained to migrate toward the sound of gunfire to interdict the shooter as quickly as possible (Blair et al., 2013). Officers no longer wait outside a structure for SWAT members to arrive, but rather move directly toward the location of gunfire to minimize firing time by the shooter. This is important in minimizing the amount of damage that can be inflicted by an active shooter over a short period of time. A Federal Bureau of Investigation (FBI) study analyzed over 160 active shooter events spanning from 2000-2013, with 69.8% of the events ending in less than five minutes (Department of Justice, 2017). The FBI study highlights how quickly an active shooter can mount casualties. Every second saved during active shooter response and shooter neutralization could prevent further casualties or streamline administration of first aid to those critically injured by gunfire.

Active shooter response and training standards have evolved over the past two decades, but shooters have also adjusted, targeting victims at non-traditional locations. Places of worship, festivals and concert venues have all seen an uptick in active shooting events, with many taking place in open air locations that offer little to no protection from a potential shooter. While some open-air venues like amusement parks are in the same location year-round, many are typically pop-up style, which are not permanent and only in place for a short period of time. This poses a unique problem set for event planners in regard to protection from a potential active shooter attack. Many open-air venues lack permanent structures that could shield victims from shooter gunfire and patrons will be unfamiliar with all available exits. This increases the likelihood of victim stacking at main exits due to limited throughput capability, making patrons more vulnerable to shooter engagement. In some situations, like the one at the Route 91 Harvest Music Festival in Las Vegas, all options of RUN.HIDE.FIGHT® may be compromised. The shooter was in an elevated location adjacent to the festival, canceling out the Fight option (Alsup, 2018). The Run and Hide options were also not ideal due to the lack of cover within the festival site to shield victims from gunfire. Open-air venues strain RUN.HIDE.FIGHT® response options and not all scenarios perfectly align with one of the responses, creating a need for additional means to protect victims.

1.1.1 Open-Air Concept

To narrow the focus of the problem, this research focuses upon the infrastructure supporting an outdoor festival venue. With limitless outdoor entertainment venues available, it is not feasible to incorporate all variations into this study. However, many of the suggestions stemming from this research project apply to all outdoor open-air venues. The open-air concept applies to any type of event that take place outside of permanent structures. Permanent structures may be present, such as attractions within an amusement park, restroom facilities or restaurants, but open-air applies when patrons spend the majority of their time outdoors while at the venue. Examples of open-air include concert venues, festivals, fairs, auto races, sporting events, and amusement parks. Layout and footprint variation at each location makes it difficult to identify standard response procedures that would be applicable to every open-air site, so it is imperative that event planners map out a custom-tailored active shooter response plan.

Open-air locations have largely been overlooked in terms of required active shooter drills and safety protocols. Unlike buildings, which can restrict access and offer quick protection from a potential shooter in the form of locked doors or interior walls, outdoor venues are limited in makeshift cover and concealment. Shooters have freedom of movement at outdoor locations and can pursue fleeing victims much easier than within buildings. Active shooter events that took place at the Las Vegas Route 91 Harvest Music Festival in 2018, Gilroy Garlic Festival in 2019 and Dayton's Oregon District in 2019 are examples of shooters that took advantage of mass groups of people in the open, expending a high volume of rounds in a short period of time. Recent shooters have exploited a vulnerability at open-air sites and steps must be taken to implement safety protocols for patrons to minimize casualties in the event of an active shooter.

1.2 Statement of the Problem

The problem addressed by this study is the susceptibility of many outdoor open-air event venues to an active shooter event. Since 2000, the United States have averaged one active shooter event per month (Mallonnee, 2017). More recently, there have been 147 mass shootings (four or more casualties) in the United States during the first four months of 2021, with 45 taking place between March 16, 2021 – April 18, 2021 (Holcombe, 2021). Many of these shootings have taken place at smaller gatherings, whether work, home or public businesses. The COVID-19 pandemic restricted large gatherings for over a year, which may skew the data available on attacks upon locations with masses of people present. With such a high number of shooting events taking place, it is logical that potential shooters will again seek out unconventional locations to spread their terror as pandemic restrictions begin to loosen. Over recent years, there have been attacks upon patrons attending various outdoor events, with no venue type specifically targeted by gunmen. Many outdoor venues are pop-up or used infrequently throughout the year, so there is not an established, robust security system in place to rapidly locate potential shooters. Due to the open-air space environment, outdoor venues lack the established infrastructure present at indoor spaces to expedite evacuations. Low budget solutions that minimize potential casualties during an active shooter event, regardless of venue, are lacking but necessary to combat the growing trend of outdoor shooters.

1.3 Significance

Through recent decades, active shooters have increased activity throughout the United States (Federal Bureau of Investigation, 2019). Spreading terror by targeting innocent civilians with firearms has unfortunately become commonplace in modern day society. Shooters seek out densely populated areas or structures to carry out their agenda, seeking to inflict as many casualties as possible in a short period of time. Schools seem to gain a high amount of national attention due to children being targeted, but they are not the only locations seeing a significant number of active shooting events. Places of worship, supermarkets, post offices, movie theaters, concert venues and festivals have all been targeted by shooters. All of these examples appeal to potential attackers due to patron density, giving gunmen endless targets to engage prior to the arrival of first responders. Since nearly 70% of active shooter incidents end in five minutes or less (J. Y. Lee, 2019), shooters understand they have limited time to operate prior to being engaged by armed first responders.

Indoor examples listed typically do not have metal detectors present, which facilitates the masking of firearms. Concert venues and larger festivals often have some sort of metal detector on site, seemingly serving as a deterrent to potential shooters. However, recent shootings in Gilroy and Las Vegas saw the gunmen circumvent gate security to engage patrons. The shooter in Las Vegas used an elevated position in an adjacent building to fire upon the crowd (Dolliver & Kearns, 2019) while the perpetrator at Gilroy cut a locked fence to gain access to the festival grounds (Rosen, 2020). The similarity shared by these two events were shooter cognizance of bypassing security to target innocent civilians. Additionally, these sites were both wide open spaces void of permanent structures offering cover from gunfire. The crowds were placed in a dilemma where traditional RUN.HIDE.FIGHT® response actions were ineffective. This research project seeks to identify supplemental response tactics to employ in case of an active shooter situation aboard an open-air venue.

1.4 Research Questions

The following research questions are central to this research project:

1. Where is the best place to position first responders at open-air venues to minimize attack time by a potential active shooter?
2. Does the total number of available exits at open-air venues impact casualties during an active shooter event?

1.5 Purpose

The purpose of this research was to develop and test low budget baseline safety protocols for implementation throughout large open-air event venues. Both the development and refinement of an AnyLogic model based upon the Gilroy Garlic festival location provided realistic data points for analysis. Choosing a location where an actual active shooter situation took place provided extensive data points that could be applied to the model to duplicate shooter, first responder and victim response actions. Replication of the exact event also aids in achieving model validation and led to meaningful data.

1.6 Scope

This research project focuses upon the reduction of casualties during an active shooter event within the confines of an outdoor open-air venue. An AnyLogic model was developed to test the impact of varying the number of available exits and placement of first responders throughout the venue. Due to the endless number of outdoor venue design layouts, an outdoor festival was chosen for the model since many of the features apply to other venues.

Research will stem from data produced by the open-air venue AnyLogic model. The model will be run hundreds of times for each variation to produce adequate comparative data while accounting for outliers. Data will be only be collected from a single model and compared against differing iterations to identify best practices. Design and build of multiple models for data collection and comparison is a huge undertaking and outside the scope of this research project.

1.7 Assumptions

The following assumptions will be considered true and factual for the remainder of this research project.

Assumptions for this research project are as follows:

1. Active shooter appears randomly within the model.
2. Active shooter will engage closest patron within field of view.
3. Patron bottleneck will occur at hard corners and narrow pathways.
4. Patrons are unfamiliar with all available exits.

5. Patrons will exit via closest available exit once evacuation is initiated.
6. Inadequate exit throughput present for all egress locations.

1.8 Limitations

Limitations for this research project are as follows:

1. Research does not span limitless number of outdoor venues.
2. Finite number of exits exist within confines of the venue.
3. Model simulation uses predetermined weapon discharge rate.

1.9 Delimitations

Delimitations for this research project are as follows:

1. Research only conducted using AnyLogic model of Gilroy Garlic Festival.
2. Exit number set to three during validation, amended to 17 for testing.
3. Total number of festival patrons set to 3,290.
4. Patrons move to nearest exit upon commencement of shooting.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Methodologies

Active shooter attacks occur randomly with no definitive way to predict when or where they will take place. Studying historical shootings provides insight into shooter mindset and traditional locations that have been selected by shooters to carry out an attack. Analysis of past cases has been the approach used by many locations for development and inclusion of active shooter response procedures within emergency response plans. Additionally, schools that have incorporated active shooter drills into the annual curriculum tie student responses to RUN.HIDE.FIGHT® and school-specific procedures developed through lessons learned from past shooter events.

The majority of active shooter response procedures and training are focused upon victim actions when inside a structure. Rehearsals and drills are much easier to execute when you have employees and staff available full time rather than part time or seasonal workers. Many open-air venues are not in place permanently, setting up for short periods of the year to host events and creating a unique problem set for event planners, who may not have their entire staff until the actual event day(s). Time is not available for proper planning by event management in these situations and no standard active shooter protocol exists for rapid implementation across all variations of open-air venues.

To test and evaluate varying active shooter response options, an AnyLogic agent-based model (ABM) was chosen due to its versatility and ability to produce limitless data sets through a safe, controlled environment. Assessing active shooter response actions while collecting adequate data for analysis can prove difficult, which led to the selection of AnyLogic software. ABM within AnyLogic provides very low abstraction and makes it possible to replicate real-world events. This is vital with regard to model validation and acceptance of recommendations based on the data deduced from the model.

2.2 Active Shooter Behavior

2.2.1 Shooter Motivation

Active shooters rely upon the element of surprise to impose violence and terror upon their victims. The ability to offset that element of surprise lies in training, rehearsals and preparation by those facilities concerned by the possibility of an active shooter event. Schools have been the target of numerous active shooter incidents and many school districts throughout the country are taking action against the threat. The thought process of an active shooter incident never taking place within "your" school is fading and "school administrators have begun to conduct training or drills" (NASRO, n.d.) to educate students and faculty on the proper response techniques in the event an active shooter attack takes place.

Individuals that carry out mass shootings typically show signs leading up to the event. According to Peterson and Densley (2019), "practically every mass shooter we studied had reached an identifiable crisis point in the weeks or months leading up to the shooting". Many shooters experience some sort of trauma or difficulty during their upbringings, and this becomes a shaping force in their desire to carry out a mass shooting event. Not every person that goes through a difficult childhood will turn into an active shooter, but it is a commonality among many shooters, whether in a school or workplace. Additionally, active shooters often have the access to weapons to carry out their plans, and "in 80% of school shootings, perpetrators got their weapons from family members" (Peterson & Densley, 2019). This statistic makes sense due to the limited movement made by minors who typically live at home with family or guardians. Minors generally do not have the ability to purchase weapons themselves and utilize other opportunities to acquire the firearms required to carry out their plans. Peterson and Densley (2019) also suggest the following in order to deter active shooters:

> Another step is to try to make it more difficult for potential perpetrators to find validation for their planned actions. Media campaigns like #nonotoriety are helping starve perpetrators of the oxygen of publicity, and technology companies are increasingly being held accountable for facilitating mass violence. But we all can slow the spread of mass shootings by changing how we consume, produce, and distribute violent content on media and social media. Do not like or share violent content through social media.

In one study, researchers used Lexis-Nexis to search for news stories from 2000 to 2010 involving active shooter events in the United States. Possible events were identified and then evaluated to see if they met the following definition of an active shooter event: It involves one or more persons engaged in killing or attempting to kill multiple people in an area (or areas) occupied by multiple unrelated individuals (Blair et al., 2013). The data was then cross-checked between reports from the investigating agencies, the supplemental homicide reports produced by the FBI, and news stories. The researchers identified 84 active shooter events from 2000 to 2010. The detailed data from these events were then coded for analysis. Some of the important key findings of this research include:

- Business locations were the most frequently attacked (37%), followed by schools (34%), and public venues (17%).
- The median number of people killed during active shooter events is two. The median number shot is four.
- The attacks ended before the police arrived 49% of the time.
- In the 56% of attacks that were still ongoing when the police arrived, the police had to use force to stop the killing.
- Emergency Medical Services entry to the attack site is often delayed because the police must conduct a thorough search of the scene to declare it secure.
- Some shooters attempted to deny police access to the attack site with barricades.

2.2.2 Common Shooter Personality Traits

One active shooter event that stands out from the rest involved the Virginia Tech Massacre on April 16, 2007. The shooter, Seung-Hui Cho, was a South Korean citizen that had received a green card for residency within the United States. Cho moved to the United States with his parents at the age of eight and began to display troubling personality signs as early as eighth grade (System Planning Corporation, 2009). These personality alterations included an infatuation with the Columbine High School shooting and continued throughout the rest of Cho's life. They also led to a diagnosis of major depressive disorder (System Planning Corporation, 2009). He would continue to display worrisome behavior throughout his high school career and into college. It was a progression of symptoms and behavior traits that unfortunately culminated in Cho carrying out an active shooter massacre aboard the Virginia Polytechnic Institute and State University (Virginia Tech) campus.

Prior to entering seventh grade, Seung-Hui Cho received his first counseling from the Center for Multicultural Human Services (System Planning Corporation, 2009, p. 22). During April of his eighth-grade year, an event took place that would shape and change Cho's life: the massacre at Columbine High School. Cho seemed to praise and admire the Columbine shooters and his schoolwork began to depict homicidal ideations. One of his teachers took notice of the sudden change and made the suggestion that Cho receive a psychiatric evaluation, leading to one year of treatment via anti-depressant medication (System Planning Corporation, 2009, p. 22). Despite the perception that Cho was responding well to treatment, the Columbine school shooting became a key motive for his actions; Cho even planned the killing spree aboard Virginia Tech to align with the week of the Columbine anniversary.

Cho transitioned to high school without event aside from his first official diagnosis of emotional disability. He continued to receive therapy for the duration of his high school years, but it had no impact on his academics. Cho finished high school in the Honors Program and was subsequently accepted to attend Virginia Tech. His parents were concerned by his decision and felt that he still needed specific attention for his condition, suggesting he attend a school with smaller enrollment numbers. Cho ignored the advice of his parents and began taking classes aboard Virginia Tech in August 2003. The first two years of his college career were uneventful, and Cho kept to himself, achieving good grades and exhibiting little sign of depression.

The onset of Cho's junior year at Virginia Tech triggered his behavioral issues to resurface. Violence began to appear in his writing and led to Cho's removal from an English class following a recital of a dark poem and snapping unwanted pictures of classmates. Virginia Tech professors contacted the Virginia Tech Police Department (VTPD), Dean of Student Affairs, and the Virginia Tech Cook Counseling Center for advice on how to properly handle the situation (System Planning Corporation, 2009, p. 24). A decision was made to tutor Cho one-on-one and professors advised him to seek out counseling. Cho refused to attend counseling and a Virginia Tech Care Team met to discuss the events surrounding Cho. It was determined that no further action was needed and considered the response adequate.

Cho's abnormal behavior was not limited to the classroom. Shortly after the incident with the Virginia Tech professors, complaints began to surface accusing Cho of harassment. Cho singled out female students beginning in November 2005 and this signaled a change in his behavioral pattern. Contact with the female students came through various means, from email to instant messaging, to written messages outside their dorm rooms. Complaints against Cho were registered with both the VTPD and resident advisors within the Virginia Tech dormitories. His stalking spanned more than a month and finally led to a restraining order placed against him following one of the complaints logged with VTPD. Cho did not handle the restraining order well, taking it as a personal attack. The Virginia Tech Review Panel (2007) cited the following response on December 13th by Cho:

> Cho sends an IM to his suitemate stating, "I might as well kill myself now." The suitemate alerts VTPD. The police take Cho to the VTPD where a prescreener from the New River Valley Community Services Board (CSB) evaluates him as "an imminent danger to self or others." A magistrate issues a temporary detaining order, and Cho is transported to Carilion St. Albans Psychiatric Hospital for an overnight stay and mental evaluation. (p. 24)

The start of Cho's spring 2007 semester marked the beginning of his firearm purchases. Cho purchased two handguns, a .22 caliber and 9mm, in just over a one-month span, indicating that he was knowledgeable on the minimum wait time between gun purchases. During the purchase procedures for both pistols, each gun store processed the mandatory background check associated with gun purchases. No record of Cho's mental instability was present that would have precluded Cho from purchasing the pair of weapons with which he carried out his deadly agenda. Following the purchase of his murder weapons, Cho began to stock up on ammunition. He proceeded to make seven more ammunition stockpile trips between the purchases of his handguns and April 16th (System Planning Corporation, 2009, p. 26). Additionally, Cho began preparations for his actions, essentially conducting a walkthrough at Norris Hall two days prior to the shooting. He was seen by a faculty member and there were reports that chains were seen on the doors during the time Cho was within Norris Hall. The reports of Cho's presence were disseminated post-shooting and discovered while authorities conducted their investigation. It can be argued that even had the eyewitnesses reported Cho's actions to Virginia Tech police, nothing would have come from it, nor prevented the shooting from taking place.

Studies have shown that active shooters typically express their actions ahead of time and this was certainly the case with Cho. He chose to reveal his unstable mental state via writing, which was recognized by a few of his professors. While Cho was not deemed to be a hazard to himself or others during one of his evaluations, perhaps the evaluator of his mental health did not have all the problem signs compiled at his or her review. Had all the students and professors reported the strange and disturbing behavior displayed by Cho, perhaps his mental evaluation would have turned out differently. Failure to take action accomplishes nothing, and just a year following the shooting, Franzosa's (2009) study found the following:

Senator Jim Webb, D-Va., introduced legislation that would amend FERPA, which determines how much of a student's mental health records can be disclosed by a university. Webb argued that the Virginia Tech massacre may have been prevented had the policy been clearer on when information about a mentally ill student can be shared by a university. (p. 13)

2.2.3 Shooter Research and Rehearsals

Active shooters tend to rely on research when developing plans to execute a mass shooting. Glamorization of past shootings can be perceived through excessive media attention or publicity. If a past shooting received "a high amount of media attention, it attracts potential future shooters seeking to gain the same type of following" (Silva & Capellan, 2019). These individuals are often suicidal and are seeking to inflict death upon as many people as possible prior to taking their own lives ("Mind of a Rampage Killer," 2013). Due to their motive to kill and mental instability, nobody can positively predict their exact behavior. All active shooter events are slightly different, but "most end with the shooter taking their own life prior to engagement with law enforcement" ("Mind of a Rampage Killer," 2013). With the increased number of school shootings throughout the country and the numerous commonalities shared by many of the perpetrators, students must be educated on reaction and response actions should an active shooter event take place.

In school shooting situations, logic and planning of the shooter are difficult to interpret, and the mindset unbalanced and perilous. The actions of the shooter are unpredictable and most often bent on causing the greatest amount of devastation possible. Individuals who orchestrate these crimes are struggling with mental health issues and have often dealt with trauma in their personal lives. These factors contribute to irrational thinking and exacerbate the threat level to those around them. Reid Meloy, a forensic psychologist and FBI consultant regarding school shootings said, "We know that mental health issues are very much in the mix; the child might be... very depressed." (Reid Meloy et al., 2012). According to Lee (2013), "There are two leading causes of school shootings: bullying (87%), as well as non-compliance and side effects from psychiatric drugs (12%)." The external trauma in the form of bullying and the internal traumas of mental health issues in combination with medical side effects establish a dangerous foundation that culminates in irrational behaviors and intentions. By attempting to understand the motivation, purpose, and plan behind school shooting incidents and their perpetrators, law enforcement personnel are better able to build systematic threat resolution plans meant to contain and quickly suppress danger.

In the past, many school shootings included an extensive amount of fire power brought to bear at the site with the intent of injuring or killing as many people as possible. The school shooting in Parkland, Florida was committed using an AR-15 style assault rifle with over two hundred rounds of available ammunition. The shooter also carried a knife. The Columbine High School shooting was committed with four guns and over 30 homemade bombs. The wide array of weapons increased the likelihood of damage and effectiveness of the assaults. Understandably, arsenals are a key concern of law enforcement personnel. Along with the ability to personally inflict damage, a school shooter might set traps such as self-detonating bombs, lock doors to funnel potential victims, or use other harmful equipment to hurt others. This ultimately affects the way that law enforcement should proceed when looking to resolve these situations.

2.2.4 Shooter Intentions for Victims

Research conducted by the United States Department of Justice looked at the big picture surrounding these events to identify the best ways for law enforcement to prevent, prepare for, respond to, and recover from active shooter events. According to this study, 70% of incidents took place within commerce and educational environments. It also revealed that the "shooter would victimize people regardless of race, creed, or sex" (Department of Justice, 2017). This indicates that the intentions are primarily motivated to cause as much damage as possible; compared to targeting a specific ethnic group or minority population. From 2000 to 2018, the Federal Bureau of Investigation (FBI) reported a total of 277 active shooter incidents with educational environments being the second most targeted location behind commerce areas (Federal Bureau of Investigation, 2019). The FBI (2019) reported 57 active shooter incidents in education environments accounting for 171 deaths and 220 wounded. Through 2019, there have been 45 total school shootings recorded (Wolfe & Walker, 2019) and current data on active shooter incidents shows that schools are especially vulnerable. Compared to commerce areas, educational environments provide a means to replicate a potential active school shooter incident and practice various scenarios. These types of rehearsals are slowly transferring over to open-air scenarios as well, with law enforcement officials recognizing the need to train officers on proper response techniques.

The United States Department of Justice (Department of Justice, 2017) also references the FBI's observation of active shooter incidents having a steady rise over the years. This study brings attention to combatting the increase in active shooter threats by not only furthering training for law enforcement officials, but also "preparing citizens as well" (Department of Justice, 2017). Citizen preparation is key to minimization of casualties during an active shooter event and that preparation should extend to all demographics since studies have shown that shooters typically do not single out individuals during a mass shooting (Department of Justice, 2017). One way to better prepare citizens to defend themselves during an active shooter event is through training and rehearsals. While the inclusion of patrons may not be attainable for most open-air locations, staff training, and response actions are critical to bolster the safety of patrons in attendance. Businesses should establish an emergency action plan for every venue site and staff roles depicted to minimize chaos during an active shooter situation (Department of Homeland Security, n.d.). The planning cycle depicted in *Figure 2.1* outlines basic steps to take to establish and refine an emergency action plan.

Figure 2.1 - Active Shooter Emergency Planning Cycle

2.2.5 Law Enforcement Engagement

Another source of uncertainty is how the shooter has planned for the attack to end. In many situations, such as Columbine in 1999, the two shooters planned to commit suicide. However, in the Parkland shooting in 2018, the shooter intended to blend in with other students and sneak out of the school undetected. This flexible dynamic adds another level of complexity to response. Getting students to safety is the ultimate goal but attempting to do this as quickly as possible increases the risk of the shooter potentially blending in as a student or teacher. Law enforcement must take dilemmas like this into account when operating as a unit attempting room clearance, for example. The level of uncertainty amongst police officers could be in a constant state of flux during response, however police awareness of these varied risks allows for comprehensive plan development. Understanding shooter logic is critical in determining the best way to proceed in a school shooter situation.

Over the past few years, there has been an unprecedented increase in the number of active shooter events. Law enforcement is struggling to address the concerns of the citizens and adequately respond to these attacks. Research studies abound in this subject matter, ranging from topics of prevention to mental health of instigators and first responders alike. In the end, the purpose of the studies is to provide administrators with accurate information to make informed policy decisions (Blair et al., 2013). The policy decisions drive potential response resolution plans.

Active shooters are driven by intentions that do not align with most other criminals. “Active shooters’ intentions are usually an expression of hatred or rage, rather than financial gain or motives associated with other types of crimes. Thus, police tactics of containment or negotiation may be an inadequate response to an active shooter” (Knox, 2018). These individuals are not looking to negotiate some sort of deal with law enforcement and choose their target location carefully. As previously suggested in this paper, active shooters select locations not by chance, but due to familiarity. If an active shooter is a student at a particular school, then they are familiar with the layout of the building. This gives them a decisive advantage over law enforcement and better enables them to carry out their intentions in a rapid manner. “Active shooters often, but not always, are suicidal. Escape from the police is usually not a priority of an active shooter. Most active shooters have not attempted to hide their identity.” (Knox, 2018). While not always the case, shooters do not seek an engagement with law enforcement. The way they envision the situation ending is through suicide rather than surrender or succumbing to law enforcement fire. Law enforcement agencies are aware of this tactic and train for single-man entries during an active shooter event (A. Waibel, Personal Communication, April 1, 2020). The longer law enforcement delays entry, it gives the shooter more time to continue engaging victims. Time is of the essence once the shooter begins an assault, and the faster officers can converge upon a shooter reduces the opportunity for the active shooter to continue engaging victims. “Current police practices include moving directly to the sound of gunfire” (A. Waibel, personal communication, April 1, 2020) and no longer involve clearing every room while progressing toward the shooter. Law enforcement utilizes the most expeditious route to the shooter, with the end state being neutralization or custody.

2.2.6 Interpretation

There is no definitive method to predict the actions of an active shooter. Individuals that choose to carry out a mass shooting are mentally unstable and follow an unpredictable path. The majority of active shooters are also suicidal (Knox, 2018) which can push a person to the edge, with no regard for harm to themselves. Mental instability creates actions that are near impossible to predict, but identification of behavioral patterns can lead to better understanding of how a shooter will handle situations that lead to them using a firearm against innocent victims. Active shooters tend to share commonalities when it comes to preparation for their actions and warning signs leading up to the implementation of their plan. Knowing what to look out for ahead of time can open the door for intervention to take place prior to the shooter pulling a trigger. Warning signs are typically present well in advance, sometimes years, of the shooter shifting from thought or fantasy to reality. Recognition of these signs could prevent shootings from taking place altogether.

If an active shooter cannot be prevented, familiarity with behavioral patterns also aids law enforcement response. First responders to an active shooter event do not have time to hesitate, not during travel to the scene nor once pursuing the shooter. Any type of familiarity with shooter actions serves as an advantage for law enforcement officers and may be the difference in the reduction of casualties. Victims of active shooter events also play a large role in prevention of unnecessary casualties. Rapid response upon the onset of shooting is vital to saving lives and victims must understand that they are dealing with a mentally unstable individual.

Victims cannot hesitate to take action and adequate preparation, or rehearsals could be the difference maker for them. A deeper understanding of active shooter behavior is needed to curb and reduce the number of active shooter events within the United States, with the eventual goal of eliminating them all together.

2.3 Gunshot Triangulation Technology

Active shooter events within a large crowd can cause instantaneous chaos and hysteria amongst those within the venue. Shootings that take place at indoor structures differ from those that occur in outdoor spaces. Indoor shooters typically have a smaller, confined space to use as an area of operation for their terror spree. Most buildings are designed with dedicated corridors for people to enter and exit, offering space for traveling throughout the structure to reach various locations. Shooters can use building designs to their advantage since those dedicated spaces designed to aid or expedite foot traffic during daily events become funnels during mass evacuations. However, as shooters continue their assault throughout an indoor structure, locating the general proximity of the shooter becomes easier for first responders and victims.

Walled structures contribute to the containment of firing acoustics, which increases the ability to identify which structure contains the shooter, especially for shootings that take place with multiple structures present like Marjory Stoneman Douglas High School in Parkland, Florida. Narrowing down the structure that houses the shooter is only the beginning, as first responders need to access the structure to neutralize the shooter. General shooter proximity also assists victims with location avoidance, sheltering in place, or evacuation. Indoor structures typically offer more areas of cover and concealment from the shooter when compared to an open space outdoor venue.

Outdoor venues present challenges when it comes to shooter detection. Unlike indoor structures that suppress the gunfire acoustics, making it easier to narrow down the general proximity of the shooter(s), outdoor venues do not suppress gunfire. Outdoor event venues can sprawl across several acres, especially large state fairs or amusement parks. A shot may be heard by patrons within the venue, but the open outdoor space enables shot acoustics to dissipate much easier than indoors. To improve shooter location, the use of gunshot triangulation technology can be applied for accurate information regarding the general area of a shooter.

The rise in gun violence throughout the United States created a need to better inform responding officers. The use of firearms during violent crimes peaked in the 1990s, which saw an increase from "67.9% of murders in 1974 involved a firearm, while 69.5% of murders in 1993 involved a firearm" (Choi et al., 2014). The increased usage of firearms meant more officers were responding to emergency calls involving gunshots, often with little to no background information regarding the scene. Officers are tasked with piecing together a crime scene that often involves uncooperative witnesses, no witnesses at all or the lack of evidence surrounding the location of the gunfire (Choi et al., 2014). These factors erode officer productivity and may have a negative impact on public relations within the community if there is a perception that law enforcement is incompetent. The addition of gunshot triangulation technology may offer an enhanced approach to "identify, investigate, and prosecute gun-related crimes with greater accuracy" (Choi et al., 2014).

2.3.1 ShotSpotter

Gunshot triangulation is not a new technology, but price point was out of reach for many agencies when it first became available. As more companies began to market gunshot triangulation capabilities, accessibility and cost reduction sparked usage increases by law enforcement. A study by K. Strom et al. (2016) found that 16.2% of law enforcement agencies with over 250 sworn officers had implemented gunshot detection technology by 2014. One type of gunshot detection technology available is ShotSpotter, which utilizes multiple acoustic sensors to triangulate the gunfire location. The sensors are "installed in high locations with unobstructed paths to other nearby sensors to improve triangulations of identified gunshots" (Lawrence et al., 2018). Sensors are also discrete to avoid unwanted attention or tampering, but also enables them to blend into surroundings or structure themes that are popular within amusement parks. The sensor network can decipher between single or multi-shot weapon systems based upon the acoustic profiles, which is important information to share with first responders. For ShotSpotter to provide an accurate assessment of the acoustic sound wave, at least three sensors must simultaneously detect and register the wave emission. Once the sensors have detected a wave emission, an alert is sent for analysis and provides a location latitude/longitude point (Williams, 2017). The latitude/longitude point is then converted over a mapping system, which provides a precise location for responding officers. This puts officers closer to the scene of the suspected gunshot, enabling them to "quickly recover forensic evidence in the form of shell casings, which is critically important with respect to investigating and following up on that shooting" (Williams, 2017).

The data collected by the ShotSpotter sensors can be analyzed via two methods. The first involves transfer of the data to ShotSpotter headquarters "within a few seconds after the shot(s)" (Lawrence et al., 2018) for analysis by human operators. These operators are highly trained on the ShotSpotter equipment and can provide real-time analysis of the gunfire validity, ensuring that only information pertaining to actual gunfire incidents "is sent to a law enforcement agency's computer aided dispatch system" (Lawrence et al., 2018). This option is referred to as the "Flex" system offered by ShotSpotter and is subscription style, with pricing based on coverage area size, necessary maintenance or repairs of sensors and routine updates to software (Lawrence et al., 2018). ShotSpotter provides all the means necessary to implement gunshot detection capabilities and runs it like a service, which can be canceled at any time.

The second option offered by ShotSpotter is where law enforcement agencies purchase all necessary equipment from ShotSpotter to equip respective areas of operation. This option is enticing because the equipment will be owned, not rented, and does not come with a subscription fee. However, ShotSpotter will not analyze data collected by the emplaced sensors, so law enforcement agencies or companies must provide their own dispatchers on equipment usage and subsequent communication with first responders. The appeal of this option extends to areas where the risk of gunfire is relatively low, such as outdoor venues, concert venues, amusement parks or fairgrounds.

The costs associated with a subscribed ShotSpotter service to provide 24/7 support may not appeal to all clients. The average cost of a supported subscription varies between $65,000-$90,000 per square mile annually, with an additional $10,000 one-time setup fee for emplacement of sensors (*ShotSpotter FAQ*, 2018). Until pricing is reduced for subscription services, it is not financially affordable for small venues to pursue the installation of ShotSpotter. However, a cost analysis should be conducted to determine how many dispatchers are required to support a particular venue, the amount of training new dispatchers require and where training can be procured. There may be savings involved through the pursuit of purchasing ShotSpotter equipment without the full subscription service. Since dispatchers do not need to be physically located on the venue site, there is flexibility for establishment of a command center to process sensor data, which is beneficial for venues that are not constructed strictly to host outdoor events.

2.3.1.1 St. Louis Metropolitan Case Study

St. Louis, Missouri adopted an acoustic gunshot detection system (AGDS) to curb the number of gun-related crimes throughout the St. Louis metropolitan area. During the early 2000s, automated gunshot detection systems were referred to as acoustic gunshot location systems (AGLS) prior to transitioning to the term AGDS. St. Louis served as an early city to implement this technology during August 2008, initially covering an area of approximately one square mile (Mares & Blackburn, 2012). The area was selected due to the amount of historical violent crime that had taken place within the neighborhoods covered by the AGLS. The initial coverage area served as an experiment to determine the effectiveness of the AGLS, which would drive the decision-making process on expanding the service. During the 14 months of data collection, there were nearly 900 reports of gunfire, with just 17 leading to the actual identification of a violent crime and just a single arrest (Mares & Blackburn, 2012). To make matters worse, five percent (Mares & Blackburn, 2012) of the reports stemmed from fireworks, which led some associated with the study to question the AGLS effectiveness. However, the neighborhoods selected for the experimental data collection did show fewer reports of gunshots were received once the AGLS was in place. Officer response time and effectiveness were indeterminate at the time, but the city of St. Louis expanded the use of AGLS.

A follow-up study was conducted to evaluate the use and effectiveness of AGDS once again in St. Louis from 2013-2018. The same authors, Mares and Blackburn, directed the study, with a focus upon police officer work hours and associated costs. By 2013, St. Louis had expanded its AGDS coverage to just over 3.5 square miles, more than triple the initial roll out. The expansion was justified by the city due to coverage encompassing neighborhoods that accounted for nearly 40% of the city’s violent crime (Blackburn & Mares, 2019). During the three year study, St. Louis police officers responded to 17,000 AGDS triggers and 14,000 citizen phone calls stating shots were fired in the area (Blackburn & Mares, 2019). Average officer response time was virtually identical regardless of the trigger, whether AGDS or phone call, with officers spending slightly less time on scene when responding to an AGDS trigger. Blackburn and Mares (2019) concluded that roughly 1,200 hours were spent by officers responding to

AGDS triggers each year, raising the annual cost to support ShotSpotter, the AGDS used by St. Louis, from $65,000-$90,000 to $90,000-$115,000. The cost increase was calculated using $75 per hour per officer and added it to the cost that ShotSpotter charges for its services (Blackburn & Mares, 2019). The study shows that an AGDS cannot provide the same level of details generated by a human element, leading to a significantly smaller proportion of arrests when compared to a citizen phone call. Blackburn and Mares conclude that further development of AGDS is necessary, perhaps finding unique ways to integrate it into current police protocol. The high cost of AGDS, especially for police departments with budgeting concerns, has come under scrutiny and provides varying results dependent upon location.

2.3.1.2 Las Vegas Implementation

Like St. Louis, Las Vegas chose to install AGDS in hopes of reducing gun violence throughout the city. The Las Vegas Metropolitan Police Department introduced ShotSpotter gunshot detection technology to problematic, high crime areas of the city. The initial rollout took place in "2017 with gunfire sensors in 6 square miles" (*ShotSpotter FAQ*, 2018). The city intended to focus upon the areas with highest amounts of gun violence to determine if ShotSpotter was helpful in assisting with crimes involving firearms. After one year of analysis, it was determined that ShotSpotter successfully located nearly 1,500 gunshots throughout Las Vegas (Nelson, 2018). "Police in several Las Vegas neighborhoods shared with the community members how ShotSpotter technology has helped locate crime scenes and even find victims" (Schultz, 2020). The department has deemed the technology successful and has since expanded the usage to over four times the size of the initial coverage area from 2017. Officers are not the only ones seeing the benefit of the advanced technology, as Las Vegas residents have reported a significant decrease in gunfire through 2020 (Schultz, 2020). Increasing the safety of residents and visitors alike is the goal of police departments like Las Vegas, with ShotSpotter paying dividends since its introduction in Las Vegas' problematic neighborhoods.

2.4 Unmanned Aerial Systems

Development of unmanned aerial systems (UAS) over recent years has drastically increased their capability and affordability. Unmanned aerial vehicles (UAV), also referred to as drones, have made their way to the hands of average citizens for recreational use. Commercial UAVs also possess much improved battery life to increase flight time between charges. Recent development trends have produced UAVs that are “cheap, lightweight, miniaturized and readily available” (Alam et al., 2019). UAS have seen an uptick in usage by news agencies and law enforcement for surveillance purposes, especially in scenarios that require mobile coverage. UAVs can reduce standoff distance in dangerous situations and provide real-time footage to improve situational awareness.

A study by Alam et al. (2019) tested the ability and latency of a low-cost UAV conducting surveillance, with video sizes kept to a minimum and inclusion of cloud computing to increase efficiency. Testing showed that low-cost UAV options are available to provide real-time surveillance. Incorporation of these types of systems into open-air spaces would offer benefits beyond the scope of active shooter events. UAVs could capture potential crimes, medical emergencies, lost children location, or identify additional safety hazards outside of active shooters. The UAS does not need to be sophisticated, as proven by Alam et. al, but does require operators for the UAVs and monitoring of the real-time video feed. Open-air venue management would be responsible for ensuring UAS were in place and could dictate flight paths based upon coverage areas or highly trafficked sections of the venue. Much like helicopters used by law enforcement to track suspects, UAVs could be incorporated into emergency action plans as the standard response to varying emergency situations.

Use of UAVs to combat active shooters is a relatively new concept, partly due to the technological advancements of drone capabilities over recent years. UAVs offer distinct advantages that could be applied to interdict an active shooter and can provide first responders with key details while converging on the shooter’s location. UAVs can bypass crowds and other obstacles en route to a shooter’s location, making them much faster than first responders on foot. Also, UAVs take out the human elements like “fear, confusion and limited situational awareness” (Wingo, 2018) that come into play when pursuing an armed assailant. Drones do not possess emotion, and therefore some agencies use them in deadly situations like firefighting, bomb detection or apprehending armed suspects. The risks involved with a drone moving directly toward a source of danger are not nearly as severe compared to serious injury or death when humans are carrying out the same duties.

UAVs can be armed with non-lethal response options, also known as less than lethal technology, that include electro-shock, tear gas and dazzlers (Wingo, 2018). Dazzler technology has been around for over a decade and first came into use by the military, using lasers to cause temporary blindness to disable a target. Adding the ability to disable an active shooter on top of the benefits of distracting a shooter and capturing real-time imagery, points to some strengths that UAVs bring to combating armed threats.

Drone developers have been working to establish effective response actions to counteract active shooters. Small business owner John Mendonca from Las Vegas began developing a non-lethal drone for use against potential active shooters in response to the Route 91 Harvest Music Festival shooting (Walker, 2017). The goals of Mendonca's actions were aimed at distracting or disabling a potential shooter to afford victims increased escape time. Mendonca self-tested his drone inventions, which include a high-powered laser and rocket-propelled powder irritant (Walker, 2017). Both responses are designed to subdue a shooter's vision or cause discomfort, interrupting the ability to engage victims. Drone advancements are the result of work ranging from small inventors to large corporations, but weaponized drones, whether lethal or non-lethal, have been met with controversy.

Weaponizing UAVs, even with non-lethal means, raises the question of legality and privacy concerns. There have been situations where personally-owned drones have been shot down by citizens and protests occurred in 2014 due to UAV use by the Seattle Police Department (Wingo, 2018). There would inevitably be work involved to shift public perspective toward UAVs as emergency response and protection tools, rather than threats upon individual privacy. Also, verbiage could be included on tickets sold to open-air events indicating entry onto private property that utilizes surveillance drones for public protection purposes.

Autonomous UAS also exist and incorporating them into AGDS, deploying to seek out an active shooter upon the onset of gunfire, could be an instantaneous response option. Coupling two emerging active shooter response options would greatly reduce response time and eliminate first responders from fighting chaotic crowds making their way to exits. According to research by Wingo (2018), recent neuromorphic chip advancements have enabled autonomous UAVs to learn from current environments while operating upon a cyber-resilient control system that can overcome GPS-denied environments. This is important in the event of an active shooter that employs a GPS jammer at their location. GPS jammers are inexpensive, readily available, and quick to setup, making them an appealing commodity to potential shooters. As AGDS continue to evolve and equipment costs fall, the possibility of pairing the system with a UAS may produce an active shooter response suite and arm first responders with the ability to neutralize active shooters within seconds rather than minutes.

2.4.1 Unmanned Aerial System Usage

The world's largest producer of drones is DJI, headquartered in China (Wilson & Swider, Matt, 2021). The company offers a wide variety of drones that meet various needs of the consumer. DJI directs focus to the important aspects and characteristics of a drone: size, weight, camera quality, flight time and ease of flight. One of the biggest drawbacks of drones in the past has been lack of flight time, specifically tied to battery power required to keep them airborne. However, there are plenty of modern drones with flight times that exceed one hour.

Drone commercialization and drastic reduction in prices have extended use across a wide variety of domains. There is an estimated 3.5 million UAVs and drones in the United States, with 347 law enforcement agencies across 43 states utilizing them to bolster capabilities (Fleming, 2019). For the sake of this research project, the focus will be upon drone incorporation into police and first responder tactics. "Police agencies are using UAVs for search and rescue, traffic collision reconstruction, investigations of active shooter incidents, crime scene analysis, surveillance and crowd monitoring" (Margaritoff, 2017). All these uses take place after the initial response by first responders, rather than simultaneously. Situations such as an active shooter event could benefit from a drone feed, assisting officers with details on a shooter's description, armament, location, movement, and current actions.

During an active shooter event, civilians are often fleeing the area around the shooter, restricting freedom of movement for responding officers. This is especially true if there is a large crowd on hand or pathways that funnel foot traffic in and out of the location. Taking to the air, drones can effectively bypass the congestion on the ground to quickly locate the suspect. Drones can also serve as a distraction to shooters, prompting assailants to divert attention from victims. While this has yet to be proven, past active shooter events have shown shooters focus upon law enforcement once they are engaged and take fire from first responders. During the 2019 Gilroy Garlic Festival shooting, the shooter engaged 20 casualties, three fatally, prior to being neutralized by police officers and succumbing to a self-inflicted gunshot wound (CBS News, 2019). However, no casualties were inflicted, outside of the shooter, once responding officers returned fire (Rosen, 2020). While the entire shooting event lasted but 60 seconds, police presence caused the shooter to direct his gunfire toward officers, enabling victims to gain stand-off distance. The same could hold true for overhead drones, buying time for fleeing patrons to evacuate or find cover.

Companies have begun to develop drones specifically in support of first responders and military. BRINC Drones in Las Vegas, Nevada has developed the LEMUR, a ruggedized tactical drone tailored to the needs of professionals, not just hobbyists. The LEMUR possesses AES 128-bit encryption, zero-latency high resolution video, window breach attachment, night vision, and carbon fiber reinforced nylon construction weighing just 2.4 pounds (*BRINC Series Protecting Lives in Dangerous Situations*, 2021). An added feature of the LEMUR that most other drones do not share is an integrated speaker, powerful enough to be heard up to 500 feet away (*BRINC Series Protecting Lives in Dangerous Situations*, 2021). The speaker also has a microphone, so two-way communication could be established with an active shooter. An ability to speak with a potential shooter offers the possibility of negotiation or distraction while officers close upon the suspect. The LEMUR's small size makes it difficult to detect, creating a hard target to engage if an active shooter turned his/her weapon upon it. Advancements in drone technology like the LEMUR are tailored to the specialized needs of military and police, which combine specialized mission sets with modern technology.

2.4.2 Unmanned Aerial System Considerations

The market for UAS is diverse depending on client requirements. Law enforcement has different needs than drone hobbyists, thus the focus upon equipment characteristics must be directed toward mission support, and specifically for this research topic, assist with active shooter mitigation. Drone flight time is a top consideration and to achieve lengthy flight or loiter times, a powerful battery system must be in place. Most affordable commercial drones, $1,500 or less, have lithium polymer (LiPo) batteries capable of achieving nearly 30 minutes of usage between charges (Wilson & Swider, Matt, 2021). Even though active shooter events typically last less than seven minutes (J. Y. Lee, 2019), flight time longer than 30 minutes is desired to provide the controlling entity time to locate the shooter and provide details to responding officers. Drones are available with flight times near 60 minutes but come at a substantially higher cost than those used by hobbyists. DJI produces drones, like the Matrice 300 RTK, that can achieve 55 minutes or more of flight time depending upon payload, but also exceed $13,000 each (*DJI Store*, 2021). The cost of these drones pushes them beyond the reach of the general public but appeals to businesses and agencies that require higher performance. A significant portion of the increased cost is a LiPo battery that possesses double the output power of cheaper drones. However, there are many other advanced features that set these drones apart and push the cost to over 10 times more than those used by hobbyists.

Weather considerations are necessary when purchasing drones that integrate into an emergency action plan. All-weather drones are a necessity since shooter attacks are unpredictable, like precipitation. Incorporation of a drone incapable of operating within precipitation is a limiting factor that should be avoided, if possible. Additionally, many higher priced drones have a wide variety of operating temperatures, permitting them to function during both winter and summer outdoor events. The previously mentioned Matrice 300 RTK carries the capability to operate in temperatures between -20° to 50° Celsius and is an all-weather platform (*DJI Store*, 2021).

Protection from interference, whether intentional or unintentional, is an aspect that cannot be overlooked. Drones require connectivity to be controlled and any type of disruption could be catastrophic. Electromagnetic interference from high output devices, especially those required for concert performances or even power lines, can interrupt a drone signal. The ability to operate on multiple channels and frequencies afford drones flexibility to operate in disruptive environments (Wingo, 2018). Encryption and security are other aspects of connectivity that factor into drone integrity. Secure transmission to and from the drone is important, especially when dealing with an active shooter situation. First responders that utilize a drone feed to combat shooters need reliable feeds and instantaneous control. Incorporation of AES-256 bit encryption protects a drone connection from being compromised and is often a feature only found in the upper tier of drones (*DJI Store*, 2021).

Camera quality is another important factor when selecting a drone. While many of the modern drones are equipped with high megapixel cameras, not all are outfitted with ability to zoom from extreme distances. This provides first responders with a visual of the shooter sooner by utilizing camera zoom while applying standoff distance between the drone and perpetrator. Zoom is only beneficial if picture clarity accompanies the feed. Video quality of 1080p provides an excellent picture and even lower priced drones are marketed with 1080p cameras. The incorporation of a gimbal also improves video quality, offering stability to the feed. Gimbals stabilize cameras during movement and are excellent additions to mobile filming vehicles. Drones that can handle higher payloads to accommodate a camera with gimbals are often higher priced, but a necessity to be effective assets for officers responding to an active shooter situation.

2.5 Armed Security Considerations

There may be a perception that adding armed security guards to the work force is a simple way to stymie active shooter attempts. While this approach is highly effective and places first responders on site, security guards, specifically armed security guards, come at a cost. A cost-benefit analysis should take place by event organizers or ownership to determine the need for armed security. Number of patrons, patron to guard ratio, length of event, budget and qualified security guard availability should all be taken into consideration during the planning process.

The monetary cost of adding armed security can add up quickly. On average, armed security guards are paid between $20 and $100 per hour, with cost variance associated with skillset and experience (*How Much Does It Cost to Hire a Security Guard?*, 2018). Basic armed guards start out at $20 an hour, with higher starting rates when going through a licensed security agency rather than independent guards. "Most security companies provide quotes for event security services based on the type of event, size of venue, number of hours and how many guards are needed, as well as what they'll be doing at the event" (*How Much Does It Cost to Hire a Security Guard?*, 2018). This provides flexibility for event management and the ability to compare quotes from multiple security guard agencies. However, the average hourly rate remains high for armed security guards, even when quoted for a larger event, and these costs add up quickly, especially for smaller venues.

The use of volunteers to augment paid guards is a cost-friendly option to boost the security footprint. Volunteers give the appearance of a much larger security team and their presence could deter all threats, not just active shooters. The Rose Bowl parade is an example of an annual event that utilizes a large number of volunteers. The Tournament of Roses Association is a non-profit organization that oversees planning for the Tournament of Roses Parade and Rose Bowl game, comprised of 35 staff members and approximately 1,200 volunteers (Connors, 2007). Due to the parade length and coverage area, volunteer staff is necessary to safeguard the route and aid police or armed security guards. Another example of expanded use of volunteer security is during the Olympic games. Events are spread out amongst multiple venues, with athletes and spectators constantly moving throughout the venues. Volunteers at the Olympics are used primarily for access control on the outer perimeter (Connors, 2007), which requires less credentialing than working inside a venue. Those working inside a venue or as security guards, whether under arms or not, typically require background checks, which are normally handled by licensed security agencies.

It is recommended that venues source armed security staff through licensed security agencies. Various reasons exist for going through a vetted security agency, and these agencies are approved through the respective state in which they operate. For example the state of Indiana requires agencies to complete an application for licensure that includes experience verification, criminal background checks, fingerprint checks through the Indiana State Police, proof of limited liability insurance, academic transcripts showing proof of a four year degree in Criminal Justice, copy of Indiana corporate filing paperwork, and finally a $300 application fee (*Indiana Professional Licensing Agency*, 2020). Potential employees seeking unarmed or armed security guard positions in Indiana must be approved through a licensed agency. The agency is responsible for ensuring that employees meet the other requirements to serve as a security guard, not the business or venue that is being supported. The liability insurance requirements carried by security guard agencies offer protections against litigation should legal action be taken stemming from the actions of a security guard. This type of insurance does not completely protect venues from being held liable for wrongdoing on their properties, and a liability insurance policy should be in place regardless of whether armed security guards are on staff.

The state of Tennessee has a licensing process in place similar to Indiana. The steps to acquire a license are more relaxed, however, requirements placed upon employees serving as armed security guards are quite detailed. Again, the licensed security agency is tasked with oversight on Tennessee training requirements for its employees, which include no past drug/alcohol addiction, fingerprints for FBI background check, four-hour armed security guard course, four hours of marksmanship training and training on the use of less than lethal devices such as a club, stun gun, chemical spray or night stick (*Tennessee Private Protective Services*, 2020).

2.6 Shooter Weaponry

Active shooters use a variety of weapons to carry out their plans, with firearms broken down into two primary categories: handguns and rifles. Shotguns have also been used during active shooter events, but are typically seen as a supplemental weapon, not the primary firearm to carry out the assault. Compared to handguns and rifles, shotguns are not viewed as deadly due to reduced round lethality, accuracy, and capacity. As depicted in *Figure 2.2*, shotguns were only used in 14% of active shooter events between 2000-2019, with handguns and rifles used in 85% of active shooter events spanning the same period (*ALERRT*, 2019). One percent of the active shooter events between 2000-2019 did not indicate the type of firearm used during the attack, which is not listed in *Figure 2.2*.

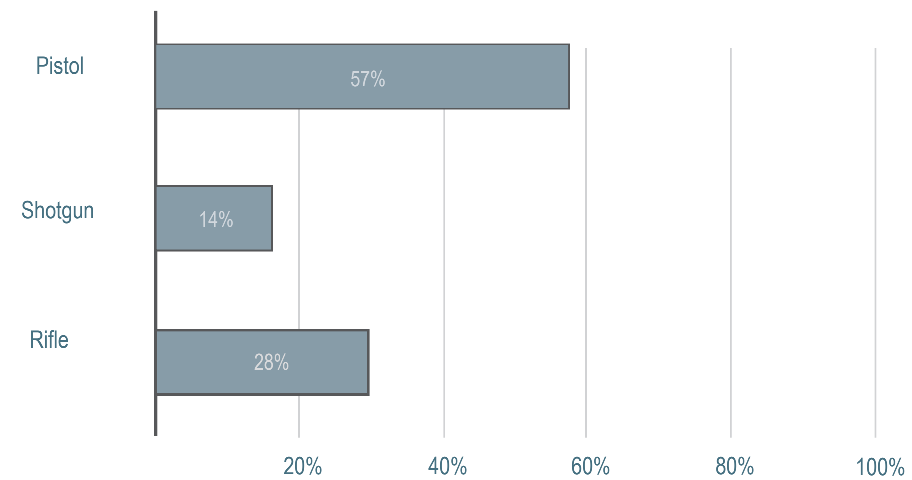

Figure 2.2 - Shooter Weapon Use

2.6.1 Weapon Type Comparison

The differences between a rifle and handgun factor into a shooter's decision, and it is important to analyze the effects of each. Rifles used during active shooter events are categorized as semiautomatic or non-semiautomatic. It should be noted that when the FBI compiles an active shooter report, there is no distinction between semiautomatic and non-semiautomatic rifles, with both being categorized as simply rifles. The broad categorization makes it difficult to extrapolate data based upon semiautomatic rifles, non-semiautomatic rifles and handguns. However, a study conducted by de Jager et al. (2018) investigated all active shooter events from 2000 through May 2018 listed on the FBI database. To gain perspective on the usage of semiautomatic rifles, de Jager et al. applied a research triangulation method to find alternative sources that clarified the exact weapon type used during attacks. The additional research methodology produced 248 active shooter incidents where the weapon used for the attack was identified beyond rifle or handgun. Of the 248 shootings analyzed between 2000 and 2018, 24.6% involved a semiautomatic rifle, with the remaining 75.4% carried out with a non-semiautomatic rifle, shotgun or handgun (de Jager et al., 2018). While there was a substantially higher percentage of shootings that did not involve a semiautomatic rifle, those that were carried out using a semiautomatic rifle resulted in a higher proportion of casualties, 9.71 vs. 5.51 per incident (de Jager et al., 2018).

While the study by de Jager et al. showed a correlation between the use of semiautomatic rifles and higher casualties, the study possessed multiple limitations that included no total number of rounds fired, shooter intent and total time shooter fired prior to neutralization by first responders. The de Jager et al. (2018) research claims that semiautomatic rifles create more casualties due to the ease of use, higher velocity rounds and large capacity magazines (LCM). However, there was no research conducted on LCMs and their impact on total casualties during an active shooter event.

There has been research conducted on previous active shooter events to compare the use of LCMs to magazines limited to 10 rounds or less. In a study by Knolhoff et al. (N.D.), there was a negligible difference in total casualties regardless of magazine size, which included shootings at Virginia Tech, Marjory Stoneman Douglas High School and Aurora. Two of the three active shooter events were carried out by shooters using 10 round magazines. Knolhoff et al. examined magazine reload times and cited reload times based upon total rounds expended over time at Marjory Stoneman Douglas High School in Parkland, Florida, where the shooter fired 150 rounds over the course of seven minutes. Using an average magazine reload time of three seconds, the shooter would have averaged firing one round every 2.5 seconds using a 10 round magazine compared to 2.3 seconds with a 30 round magazine (Knolhoff et al., N.D.). The researchers concluded that magazine capacity would not make a meaningful impact on the shooter's ability to fire additional rounds.

While some handguns have magazines that hold over 10 rounds, LCM delineation usually applies to semiautomatic rifles. LCMs are not limited to 30 rounds, with the Gilroy Garlic Festival shooter possessing a 75-round drum and the Aurora, Colorado shooter using a 100-round drum. In both of these shootings, victims reported the perpetrators experienced firearm jams, which limited the overall firing time before first responders intervened. With just one quarter of active shooters using semiautomatic rifles and an even smaller percentage using high-capacity drum magazines, it is difficult to arrive at a conclusion on the impact of these style LCMs on total casualties. Larosiere (2017) claims that "drum" style magazines may be less lethal on the victim pool due to the high malfunction rate. Short of testing malfunction percentage per rounds fired, a clear answer does not exist aside from a few documented historical occasions.

2.7 Summary

Active shooter events are an ongoing issue within the United States. This chapter provided insight on shooter mindset, outlined historical examples and challenges associated with combating active shooters once an assault commences. The purpose of this research project is to analyze and assess an open-air active shooter event to identify mitigation techniques that aid in reduction of casualties. As outlined within the chapter, there are relatively modern advances in technology that can aid in the detection of gunfire or locating the position of a shooter. However, technology carries a financial burden that the majority of venues cannot afford. Large cities and police departments have budgets to incorporate new technology, which aids in identification of shortfalls and refinement for future use. Advancements in defense measures are key to properly preparing against an active shooter attack, regardless of the site. Studying lessons learned from past shootings and incorporating revised response efforts may lead to advancements for all involved that fight the battle against active shooters. This chapter emphasizes the inherent problem faced by open-air venues, many of which operate with limited resources and lack adequate time to refine emergency action plans.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Overview

The research methodology and procedures applied in this study directly support answering the associated research questions. Agent-based modeling (ABM) was chosen for this research project due to the advantages it offers toward the study of active shooter incidents (ASI). ABM provides realistic output data through the ability to assign humanistic traits to the agents without risking the safety of human subjects. Reality is important when using ABM, prompting the researcher to select an AnyLogic agent-based model for data analysis. The AnyLogic model was designed to recreate a historical ASI that applies mitigation techniques to the problem set in hopes of identifying best practices to minimize casualties during future active shooter events within open-air venues. This chapter will examine the application of AnyLogic modeling software to active shooter research and touch upon some of the strengths that this software provides toward data collection involving dangerous situations. Next, background information and details of an active shooter event at the 2019 Gilroy Garlic Festival in Gilroy, California will be outlined, with explanation of why it was chosen to serve as the basis of the model build. The following chapter will discuss model variations, initial data collection, and statistical analyses to achieve validation and compare results to the historical event.

3.2 AnyLogic Software

AnyLogic simulation software was used for research due to its flexibility in producing agent-based models focused upon discrete events with parameters that can be easily manipulated to show changes in results or data. Parameter changes can be made quickly and only come at the cost of time involved for the developer to make the adjustments within AnyLogic. The software can create models in 2D or 3D space that offer excellent visual depictions of animations that replicate real-world events. These animations do not include human participants for data collection, which greatly reduces risk associated with studies involving firearms. The agent-based method employed by AnyLogic permits inclusion of human movement, traits and interaction to best reproduce events that took place in a historical scenario. However, removal of actual human subjects eliminates the concern over rights or welfare violations during data collection.

Replication is key within modeling and simulation to reach validation, where the AnyLogic model produces results that match the historical event which the model is intended to mirror. Validation compliments additional data points extracted from the model since it has been established that it can produce a level of realism associated with an actual event. Research acceptance within academia is important for findings and conclusions to have an impact, which starts with achieving validation. AnyLogic serves as an excellent platform to validate items not traditionally collected via simulation while easing safety concerns associated with weapon studies.

3.3 Gilroy Garlic Festival

The Gilroy Garlic Festival first began in 1979 and did not receive its name by chance. Gilroy, California grows and processes a high volume of garlic each year, which led the festival organizer, Dr. Rudy Melone, to formulate a plan to highlight the city's love of garlic. The inaugural Gilroy Garlic Festival took place aboard the Bloomfield Ranch in August 1979, attracting over 15,000 guests that raised $19,000 (*Gilroy Garlic Festival*, 2020). The festival concept was to share the lore of garlic by passionate locals with people around the country, which eventually gave Gilroy the title of "Garlic Capital of the World". All proceeds benefit the local community and modern-day beneficiaries include schools, charities and non-profit groups within the city of Gilroy. A garlic festival has been held every year since 1979 with the exception of 2020 due to COVID-19, attracting approximately 80,000 to 100,000 patrons annually (*Gilroy Garlic Festival*, 2020). Due to growing popularity, the festival has expanded to a three-day event spanning the last weekend in July and has transitioned to Christmas Hill Park, also located within Gilroy (*Gilroy Garlic Festival*, 2020).

On July 28, 2019, tragedy struck the Gilroy Garlic Festival. At 5:41 p.m. Santino William Legan opened fire upon the crowd with a Wassenaar Arrangement Semi-Automatic Rifle (WASR-10) Romanian AK-47, killing three people and injuring another 17 (Rosen, 2020). While the shooting event was horrific, the outcome could have been much worse given the amount of ammunition in Legan's possession. Fortunately, the festival was within an hour of closing on its final day, decreasing patron attendance below its peak. Additionally, due to such high attendance numbers at the festival, Gilroy police officers patrol the grounds during the operational hours between 10:00 a.m. to 7:00 p.m. daily. Three patrolling officers interdicted Legan within a minute of firing, minimizing casualties. Upon taking fire from the responding officers, Legan turned his weapon from civilians to the officers and eventually himself. The quick actions of the officers saved lives by diverting Legan's attention and they were positioned to respond immediately to the active shooter situation. The use and placement of first responders at the Gilroy Garlic Festival serves as an excellent example of proper planning and execution of an emergency action plan.

3.3.1 AnyLogic Model Implementation

The model design was based upon a diagram of the Gilroy Garlic Festival at Christmas Hill Park in Gilroy, California. The diagram and imagery in *Figure 3.1* were produced when the festival was active, approximately four hours prior to the shooting, to depict accurate locations of vendor tents, shade areas, performance stages and other attractions. Utilizing the Pedestrian Library within AnyLogic, these items were reproduced in the model through the Rectangular Wall, Rectangular Area, Target Line and Wall. These features within AnyLogic shape pedestrian movement, whether preventing pedestrians from entering a space (vendor tents or stages) or creating a destination for pedestrians moving throughout the model. The addition of these elements integrates realism into the model by better capturing actual human movement. Pedestrian movement speed was also calculated using average walking pace of an adult, then assigned to all patrons within the festival. Shooter and officer speeds were calculated based upon distance traveled and total time of the shooting. These parameters will be discussed in detail in later sections.

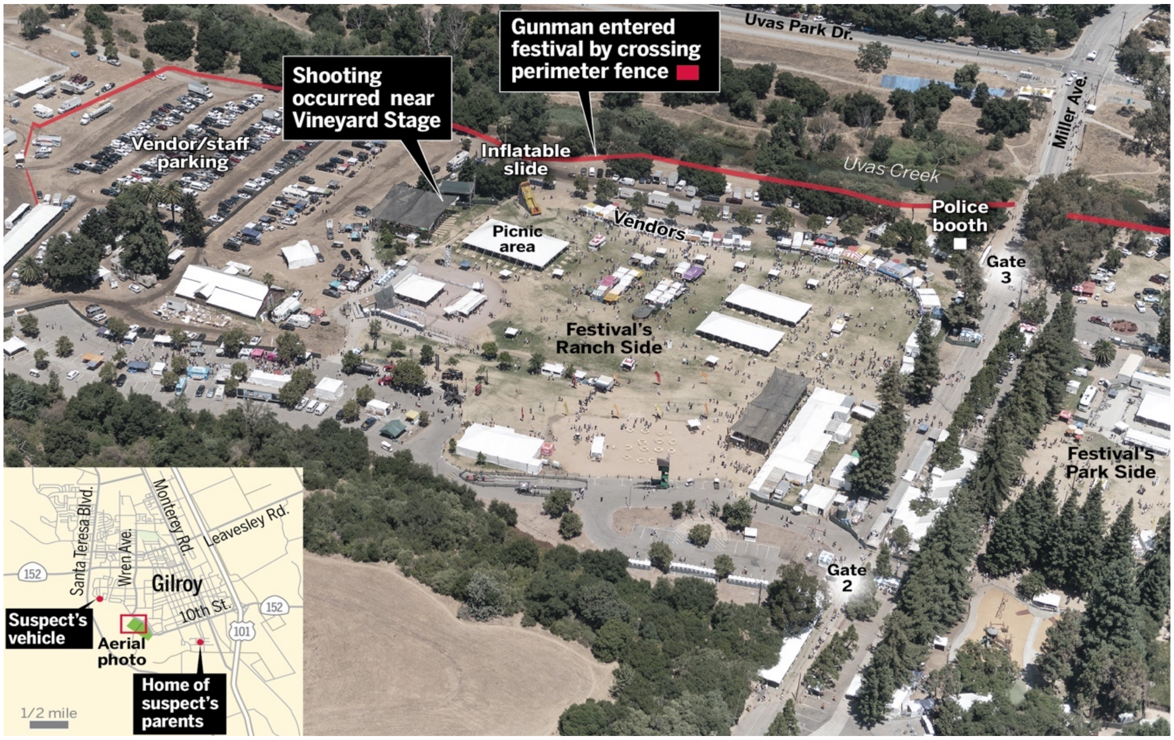

Figure 3.1 - Gilroy Garlic Festival at Christmas Hill Park
(Wei, 2019)

After importing the image, *Figure 3.1*, into AnyLogic, adjustments were made to ensure that all important items transferred over to the model. This required using the previously mentioned features in AnyLogic to refine the model, which basically adds dimensional objects from the festival photo to the modeling space. For instance, the image of a tent imported into AnyLogic is meaningless to an agent or pedestrian within the model. The tent needs to be built into the model using AnyLogic features, but the imported image is important because the researcher can duplicate exact dimensions and layout without the issue of scale. *Figure 3.2* is the AnyLogic model produced to serve as the test platform following the creation of all structures contained upon the festival grounds.

Figure 3.2 - AnyLogic Gilroy Garlic Festival Footprint

3.4 Variables and Parameter Description

Parameters for the model were set to achieve data collection. Data was focused upon specific outputs to aid in identification of consistencies during analysis. The output name and data type described in Table 3.1 outline the data associated with the model. These names are the actual entries within the AnyLogic model and built into the underlying logic. Each data type has a short description to identify the origin and composition.

Table 3.1

Model Parameter Description

Output Name	Data Type	Descriptor
model_runtime	integer	Model duration in seconds
shooter_discharge_radius	double	Shooter weapon discharge radius in degrees to engage civilians and police
shooter_discharge_angle	double	Shooter field of fire in degrees
shooter_discharge_accuracy	double	Percentage of shooter rounds fired that strike target
shooter_discharge_rate	double	Discharge interval of shooter
shooter_target_ct	integer	Total number of civilians and police
shooter_casualty_ct	integer	Total casualties caused by shooter
shooter_speed	double	Shooter movement in ft/second
civilian_ct	integer	Total number of civilian agents within the model
police_discharge_radius	double	Police weapon discharge radius in degrees to engage shooter
police_discharge_angle	double	Police field of fire in degrees
police_discharge_rate	double	Discharge interval of police
police_discharge_accuarcy	double	Percentage of police rounds fired that strike the shooter
shooter_rounds_ct	integer	Total rounds fired by shooter
shooter_duration_end	long	Model ends when shooter is neutralized by police

3.5 AnyLogic Agents

Multiple agents were used throughout the model, with various origin, movement throughout the model, capabilities, response to certain conditions and actions upon engagement by the shooter agent.

3.5.1 Agent Pool

Utilizing the Pedestrian Library within AnyLogic, Pedestrian Type was selected to create the agent population contained within the model. Pedestrian Types each contain differing characteristics that dictate actions within the model. The Pedestrian Type selection was applied to create one shooter, three responding police officers and 3,290 festival patrons.

3.5.2 Agent Location and Origin

Rectangular Areas were used to create Attractors for agents within the model, depicted in *Figure 3.2* by blue and yellow rectangles. Attractors draw agents to the location and serve as areas where patrons gather within the actual festival. Using the Pedestrian Library, Ped Source was chosen and applied to the five large yellow Rectangular Areas to serve as origin points for patrons. These areas then become a waiting area using the Ped Wait feature until the model is prepared to begin. At the start of the model run, all 3,290 patrons originate or spawn within the five yellow Rectangular Areas. The patrons then populate the model at the Attractors, *Figure 3.3*, and begin moving throughout the model. The shooter will begin inflicting casualties once the first three patrons engaged during the real-world event reach their position within the model. The shooter will continue to randomly engage 17 more patrons. Three police agents spawn within the model and will begin movement once the shooter agent commences firing upon the patrons, moving to the real-world location where they engaged the shooter.

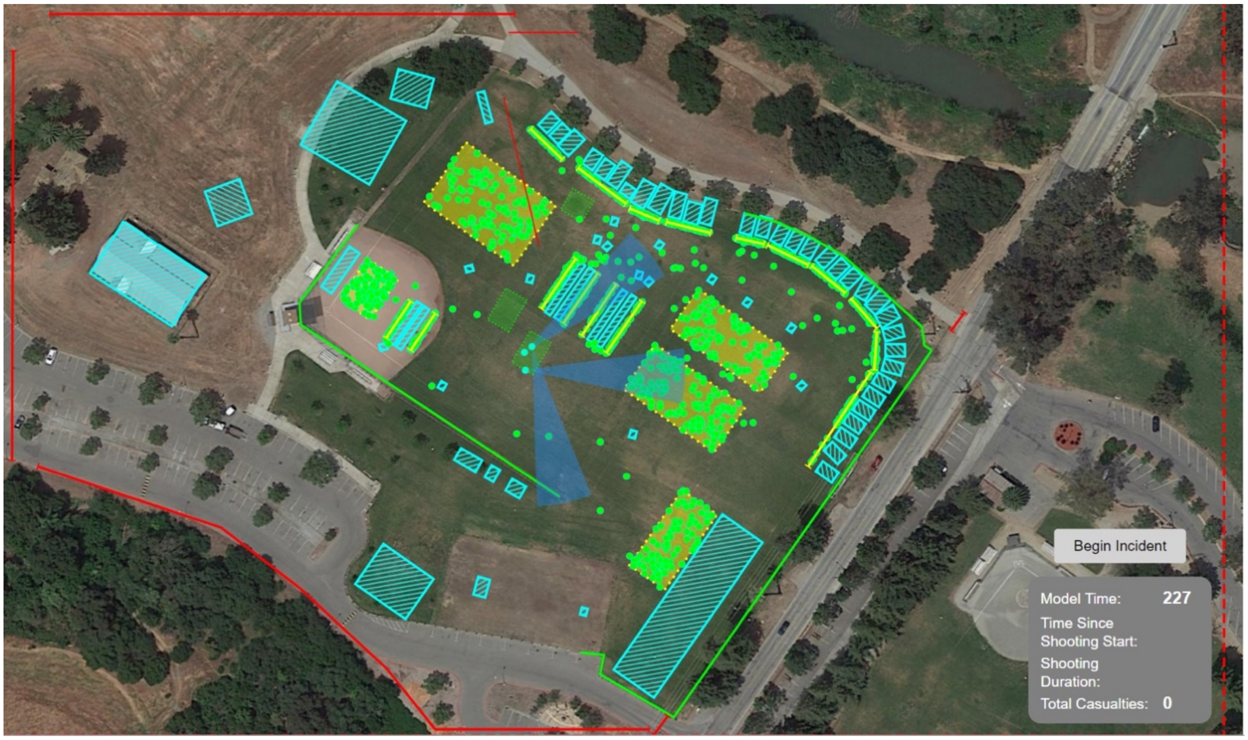

Figure 3.3 - Model Loaded with Patrons and Police Agents

3.5.3 Patron and Police

Once all 3,290 patrons spawn and load the model, movement commences. Patrons move randomly throughout the model between Attractors prior to the onset of shooting. The shooter agent will engage three historical "deceased" casualties once they reach the respective locations that marry up to the actual event. This initial shooter engagement will trigger all remaining patron agents to run toward the nearest exit, which is determined using a Java function that calculates the shortest distance from the patron agent to an exit. This function updates once every second to constantly ensure patron agents take the most expeditious route out of the festival.

3.5.4 Shooter Movement

The shooter agent enters the model via the same route followed during the actual event. The path leads the shooter agent to an inflatable slide in the upper center of the model, depicted by a blue rectangle in *Figure 3.2*. There is limited movement by the shooter agent upon arrival at the inflatable slide during validation runs that replicate the actual event. During this event, the shooter pushed south just past the slide to initially engage victims, then retreated abreast the slide to utilize concealment afforded by the attraction while remaining stationary to discharge all remaining rounds. Once the shooter agent achieves 20 casualties during the model validation run, suicide will take place that corresponds with the actual event and the model will end. Follow-on experimental model iterations permit shooter movement throughout the model to random locations for target engagement.

The shooter agent will engage potential targets through calculation using a Java function that determines proximity of the nearest patron or police agent. Only "alive" targets will be engaged by the shooter agent, which means that the shooter agent will bypass "deceased" targets. The shooter agent engagement range is set to 200 feet, so a potential "alive" target must also be within range to be targeted by the shooter. Target identification and scanning is refreshed every second to provide the shooter agent with the most opportune target population for engagement.

3.6 Agent Status

Agents within the model are all depicted by a circular shape, which after accounting for map scaling becomes one foot in diameter. Agent color is dependent upon the state of the agents and outlined within Table 3.2. The shooter agent is represented by a red circle outlined by a green ring, police agents by blue circles and patron agents by green circles. Once the model begins running and an agent becomes a casualty, whether a police or patron agent, they turn red and cease movement. Casualty definition applies to both injury and death from a shooter agent discharged round. There is no logic built to depict agents that become casualties after suffering a gunshot wound but remain alive. The shooter remains the same color state throughout the model but will also cease movement once becoming a casualty. Shooter death triggers the end of the model, which negates the need for a graphical change in the shooter agent upon becoming a casualty.

Table 3.2

Agent Depiction

Agent Type	Alive	Injured	Deceased
Shooter	Red w/ green ring	N/A	Red w/ green ring
Police	Blue	N/A	Red
Patron	Green	N/A	Red

3.7 Validation Parameters

Parameters were determined through a mix of historical data obtained from the actual shooting event combined with trial and error within the model to achieve validation, which equates to a model that closely replicates the real-world 2019 Gilroy Garlic Festival shooting. Data extracted from the validation run was not analyzed until specific details of the shooting were assimilated into the model: total shooting time, casualties, deceased casualty location, shooter movement, shooter location, total patrons, total responding police officers, officer location during engagement and rounds expended by both the shooter and police officers. Table 3.3 highlights tailorable parameters and whether they were available through historical documents or determined through trial and error following model construction. During the experimentation phase, each experiment is compiled from data spanning 1,000 model iterations. The values contained in these parameters were instrumental in laying the foundation for reliable methodology that will be incorporated into all other experiments using this model to identify mitigation techniques that aid in casualty reduction. These parameters will be manipulated in the following chapter to identify best practices available for active shooter response.

Table 3.3

Model Validation Parameters

Parameter Name	Type	Value	Source
Shooter_speed	Fixed	3.02 ft/sec	Model
Police_speed	Fixed	3.1 ft/sec	Model
Civilian_speed	Fixed	3.28 ft/sec	Research
Shooter_discharge_radius_ft	Fixed	200 ft	Model
Shooter_discharge_angle	Fixed	15.1°	Model
Police_discharge_radius_ft	Fixed	200 ft	Model
Police_discharge_angle	Fixed	2°	Model
Police_historical_ct	Fixed	3	Historical
Civilian_ct	Fixed	3,290	Historical
Shooter_ct	Fixed	1	Historical
Shooter_discharge_rate	Fixed	1.36 sec/round	Historical
Police_discharge_rate	Fixed	3.33 sec/round	Historical
Shooter_accuracy	Fixed	0.6 (60%)	Model
Police_accuracy	Fixed	0.15 (15%)	Model
Shooter_discharge_ct	Fixed	36	Historical
Police_discharge_ct	Fixed	18	Historical

3.7.1 Shooter Speed

Prior to establishing the movement speed of the shooter agent within the model, historical human movement speeds were researched for incorporation into the model baseline. The baseline speed was set at 1.11 meters per second (m/s), which was converted to 3.64 feet per second (ft/s), to align with findings during human movement research by Li et. al (1999). Li et.

al (1999) also concluded that the average human running speed is 2.22 m/s, which converts to 7.21 ft/s. Using these statistics helped narrow the possibilities of shooter movement speed. Multiple experiments were conducted to match the shooter movement speed to the 60 second duration of the actual firing time of the historical event. *Figure 3.4* outlines the initial experiment, indicating the shooter speed falls between two and four ft/s. A second experiment was conducted to narrow the shooter movement speed, focusing between two and four ft/s. This experiment pointed toward a shooter movement speed near three ft/s. Finally, a third experiment was conducted using increments of 0.02 ft/s between 2.9 and 3.1 ft/s. The final experiment, *Figure 3.5*, concluded that a shooter movement speed of 3.02 ft/s was most applicable to achieve the shooter's movement over the 60 second shooting timeline, as he paused multiple times to engage patrons along the route.

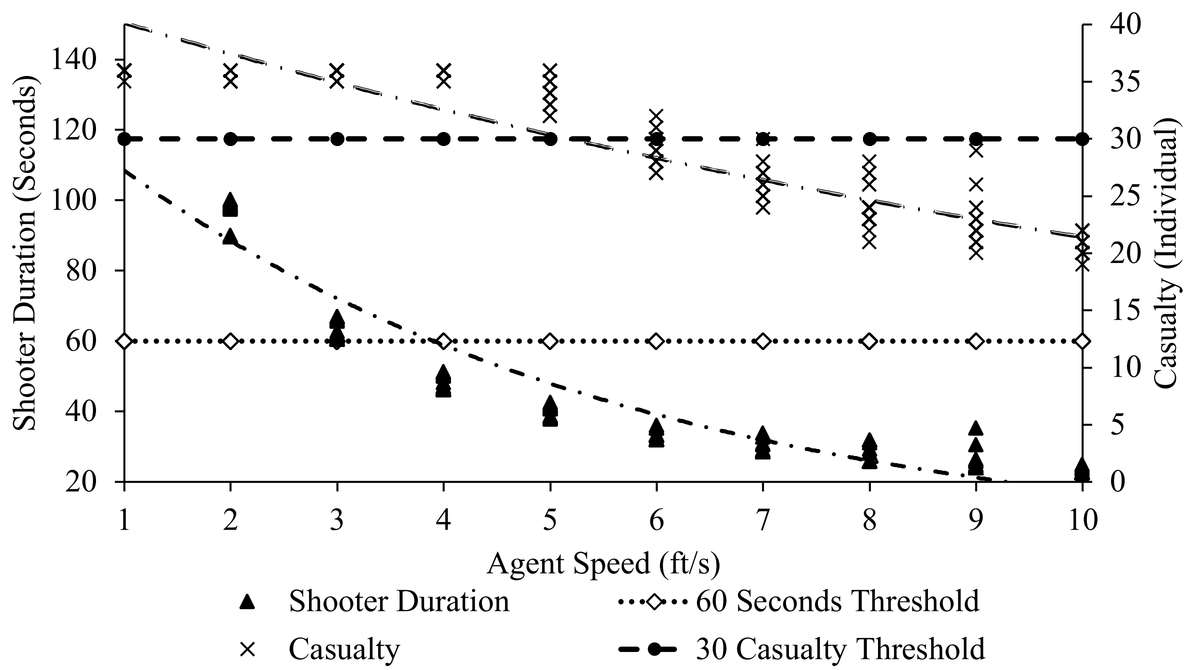

Figure 3.4 - Experiment 1: Initial Shooter Agent Speed

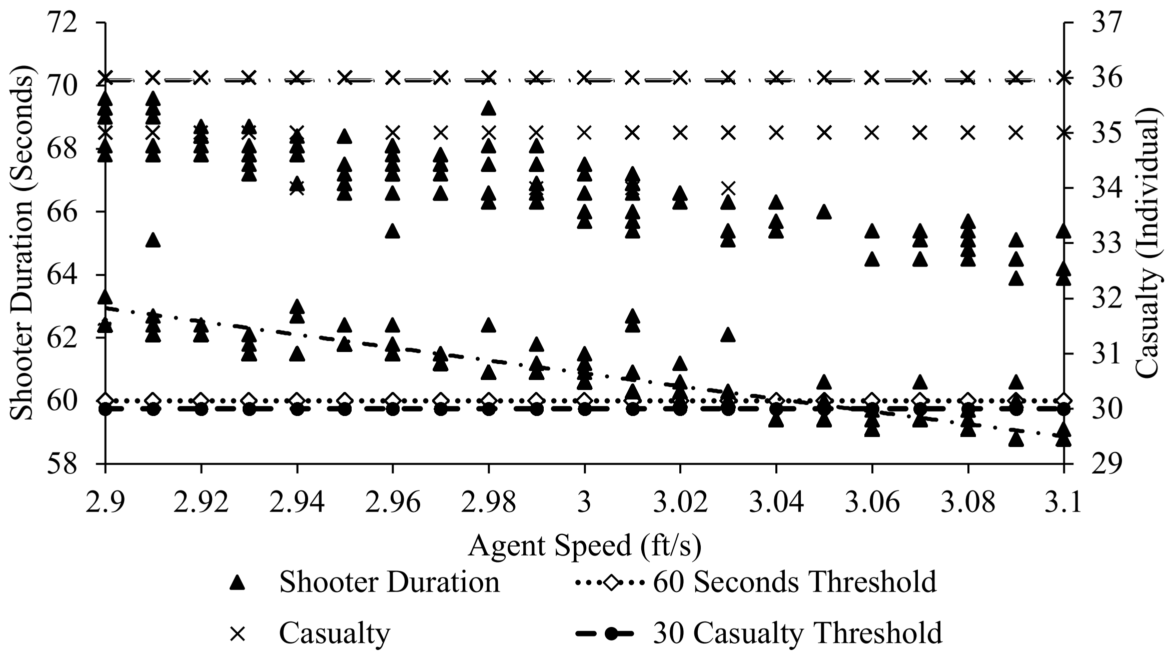

Figure 3.5 - Experiment 3: Final Shooter Agent Speed

3.7.2 Shooter Discharge Interval

The baseline discharge interval, or time between shots being fired, was determined from historical information on the shooter's total discharged rounds over the 60 second shooting timeframe. The shooter discharged 36 rounds over 60 seconds, which equates to firing one round every 1.67 seconds. This baseline was incorporated into the model for experimentation over 1,000 iterations. *Figure 3.6* highlights the data produced on the initial shooter discharge interval experiment, indicating the correct discharge rate was near 1.4 seconds. Using this information, a subsequent experiment was conducted, *Figure 3.7*, that narrowed the scope of the interval to align total casualties to the shooter duration of 60 seconds. The experiment was conducted between 1.3 and 1.5 seconds with intervals of 0.02 seconds between each. This experiment also set shooter accuracy to 100% initially, equating to 36 rounds fired producing 36 casualties. Shooter accuracy would be adjusted in later experiments to align with historical casualties at the 2019 festival. Applying this methodology, it was determined that final shooter accuracy set at one round every 1.36 seconds would best support alignment to real-world outcomes.

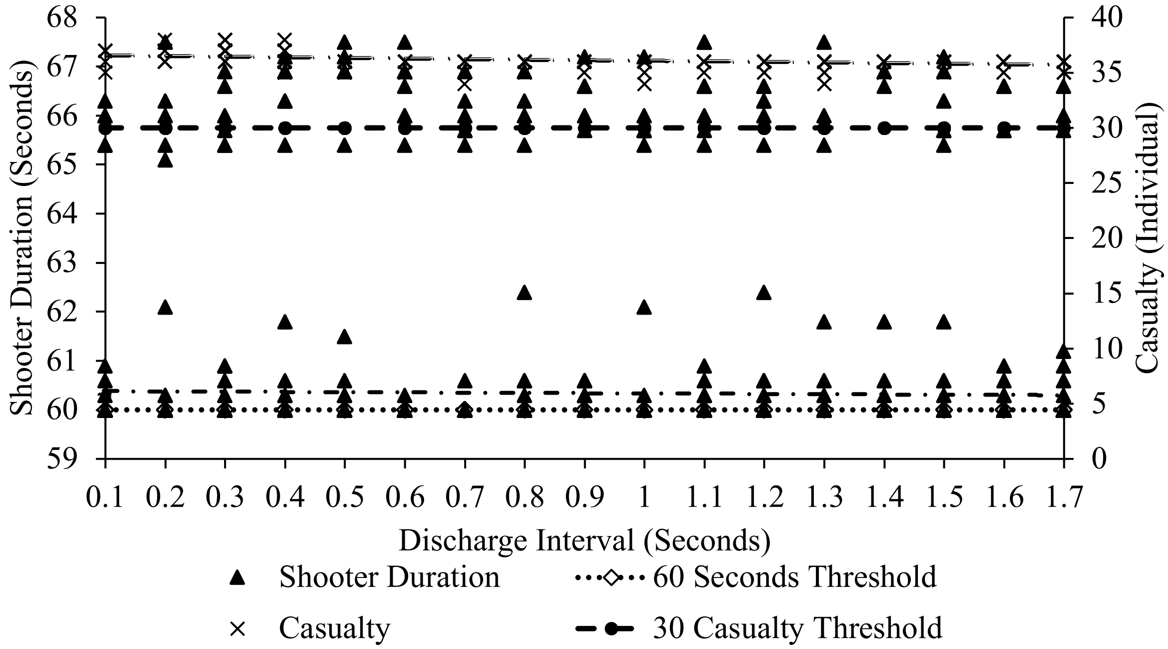

Figure 3.6 - Experiment 4: Initial Shooter Discharge Interval

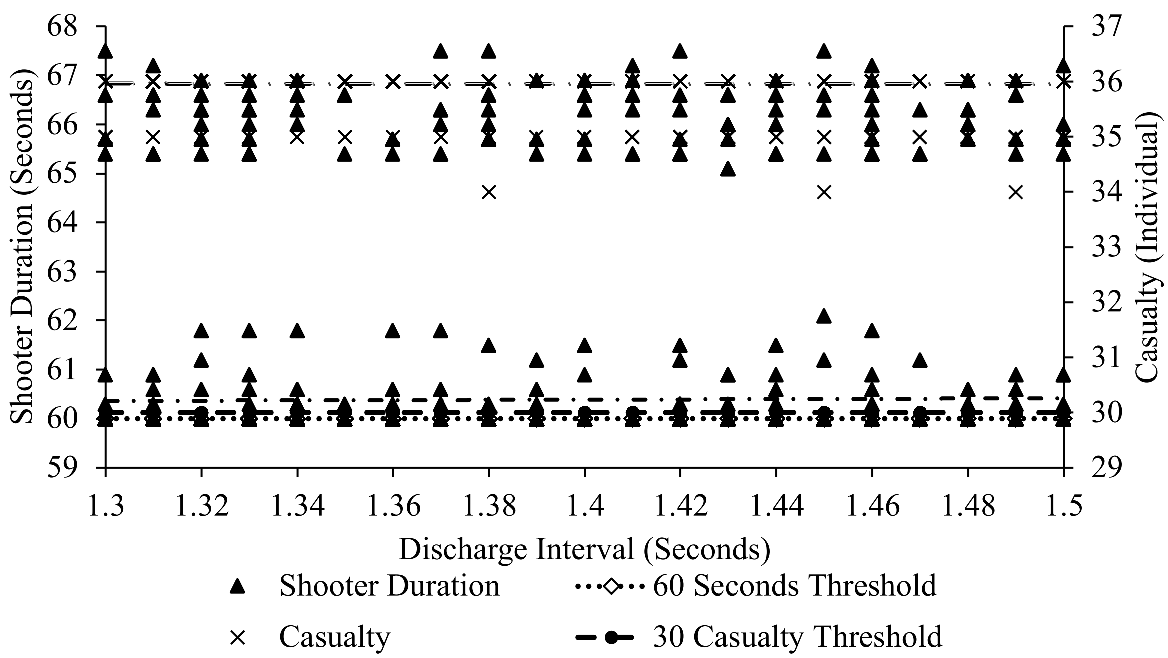

Figure 3.7 - Experiment 5: Final Shooter Discharge Interval

3.7.3 Shooter Discharge Angle

The initial shooter discharge angle applied to the model was 90° to assess the impact on shooter engagement. *Figure 3.8* depicts the 90° angle impact when applied to 36 casualties and 60 second duration time. The numbers were close to aligning with real-world events, but both categories were short of the actual statistics from the festival. Due to the lack of a real-world baseline, two more experiments were conducted, reducing the discharge angle each time to evaluate the impact on the model. The third experiment examining shooter discharge angle produced data very close to utilizing a 15° angle. This led to a final experiment, *Figure 3.9*, that focused upon discharge angles from 14.9° to 15.2° using .05° intervals. A shooter discharge angle of 15.1° produced data most in line with the historical shooting event.

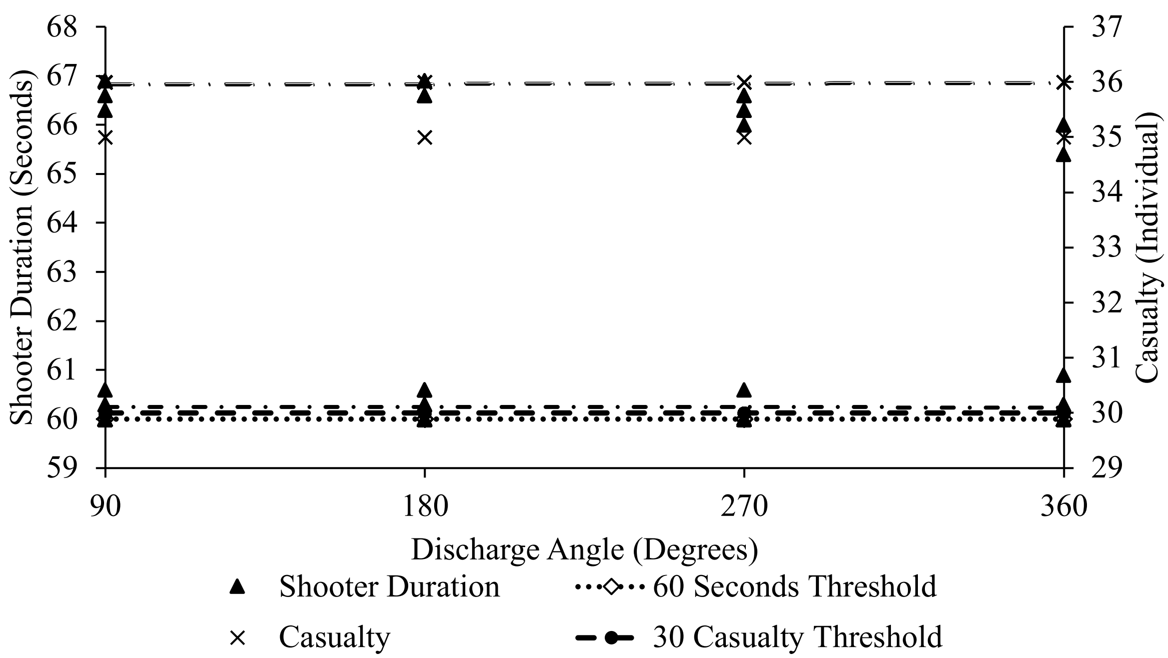

Figure 3.8 - Experiment 6: Initial Shooter Discharge Angle

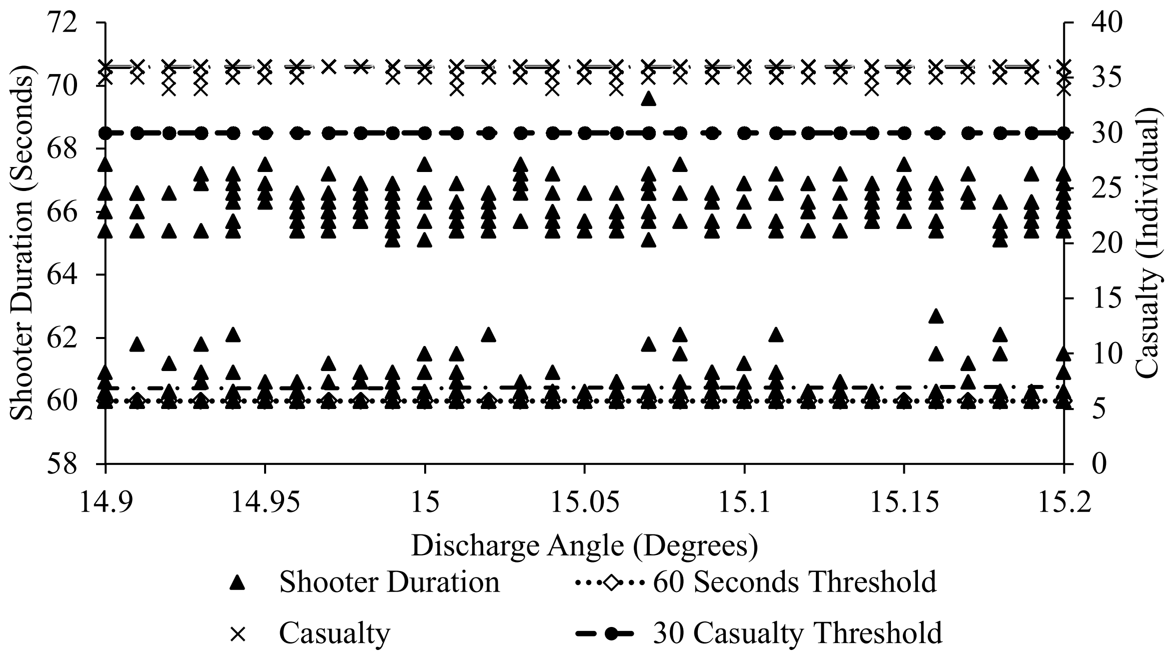

Figure 3.9 - Experiment 10: Final Shooter Discharge Angle

3.7.4 Shooter Discharge Accuracy

The shooter's discharge accuracy was determined through the application of a baseline comparing the number of rounds discharged to total casualties. The shooter fired 36 total rounds, striking 20 casualties during the 60 seconds of engaging patrons. This is a 56% accuracy rate and was applied as the initial shooter discharge accuracy parameter. *Figure 3.10* confirms that the shooter accuracy rate indeed falls out near 56%, with the initial experiment examining accuracy rates from 10-100%. Further refinement was necessary to achieve 20 total casualties over 60 seconds of firing.

A second experiment, *Figure 3.11*, was conducted that narrowed the scope of accuracy to 50-70%. After 1,000 iterations, analysis of the compiled data revealed that shooter accuracy was slightly higher to satisfy the complimentary parameters of total casualties and shooter duration, setting final shooter accuracy at 60%.

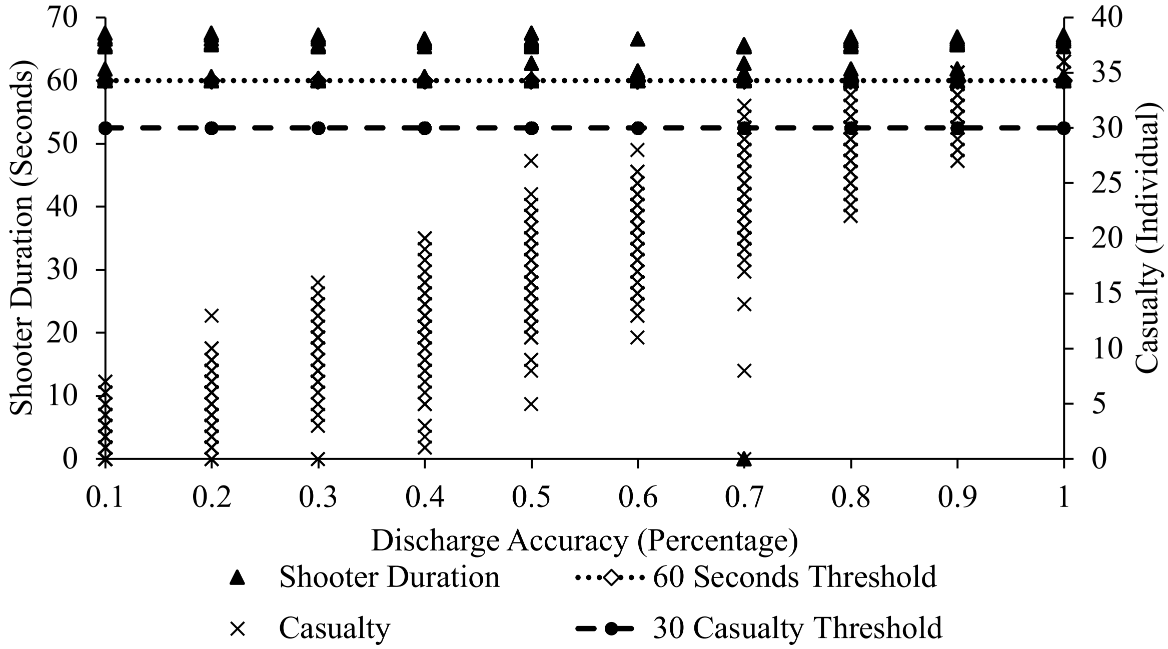

Figure 3.10 - Experiment 11: Initial Shooter Discharge Accuracy

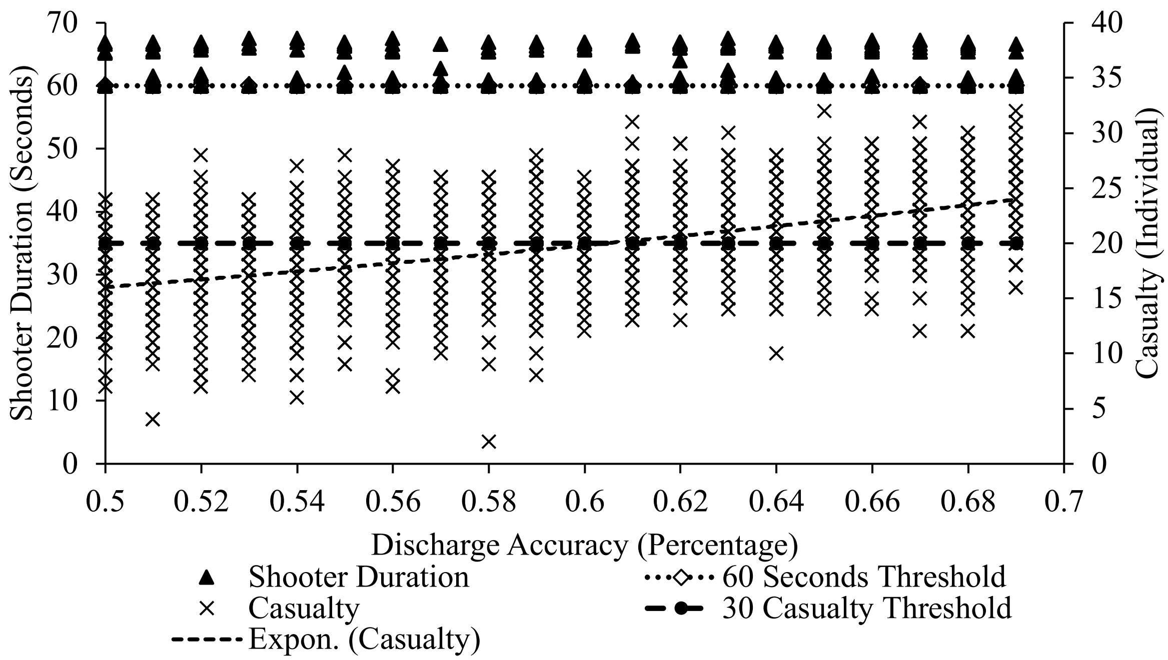

Figure 3.11 - Experiment 12: Final Shooter Discharge Accuracy

3.7.5 Officer Speed

Exercising the previously established human movement speed, focus upon officer movement was calculated via similar means. However, the assumption was made that the responding officers were running rather than casually walking to interdict the shooter. This assumption would only apply for a short period of time while officers physically positioned themselves on the shooter's location, not while roaming the festival grounds. The shooter's movement speed of 3.02 ft/s was used to establish a foundational movement speed to use for the initial officer movement speed experiment. Three total experiments were conducted to align the officer movement speed to the 60 second duration of the actual firing time during the historical event. *Figure 3.12* outlines the initial experiment, indicating the officers' speed is indeed near 3.0 ft/s. Two more experiments were conducted, with the third experiment narrowing officer movement speed to 3.1 ft/s. This experiment, *Figure 3.13*, concluded that officer movement speed of 3.1 ft/s was most applicable to permit officers reaching their respective engagement locations from the historical event while conforming to the 60 second shooting timeline.

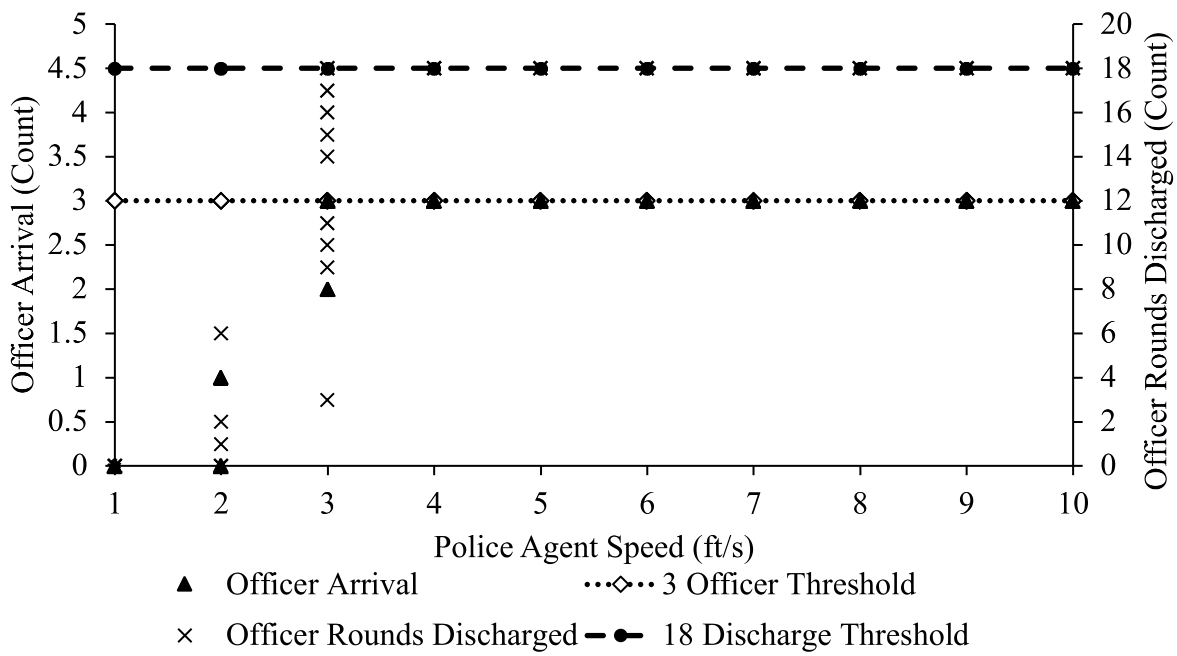

Figure 3.12 - Experiment 15B: Initial Arrival and Rounds Discharged by Officer Speed

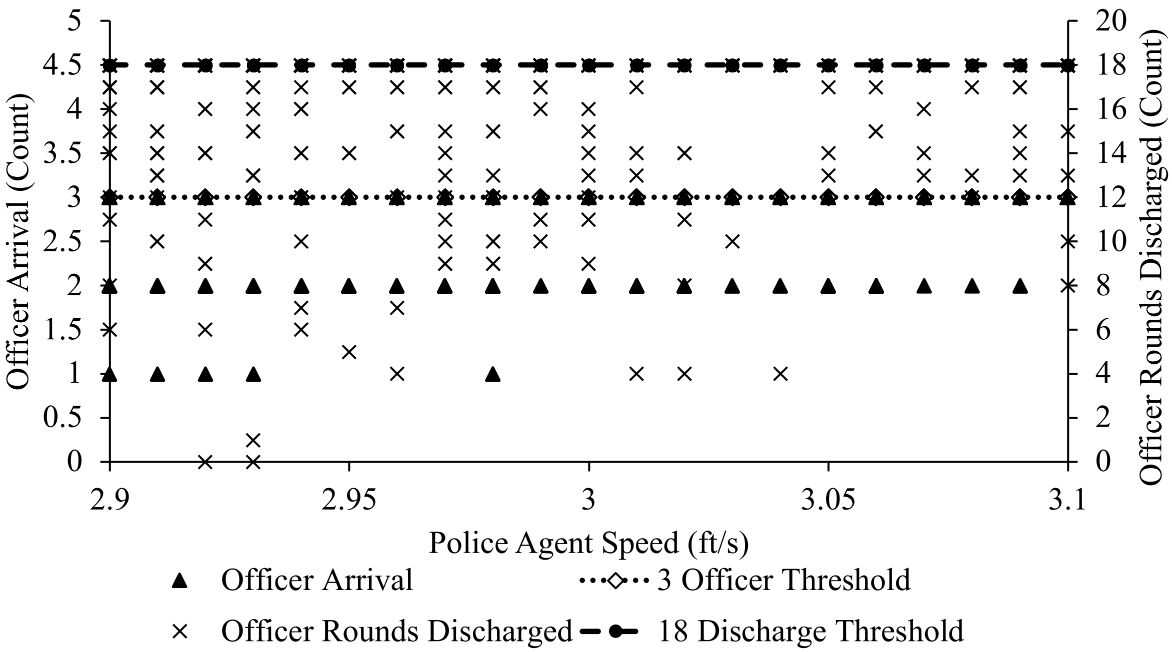

Figure 3.13 - Experiment 17B: Final Arrival and Rounds Discharged by Officer Speed

3.7.6 Number of Officers and Discharged Rounds

While collecting data to support officer movement speed, other parameters were considered simultaneously to meet the 60 second event timeline. Historical documents collected by the Santa Clara County District Attorney show that there were three total responding officers that discharged weapons, totaling 18 rounds fired upon the shooter (Rosen, 2020). The location of the officers was also outlined in the district attorney's report, which was integral while determining officer movement speed. The speed had to permit the three officers enough time to reach their respective engagement areas while granting enough time to discharge 18 rounds prior to the perpetrator taking his life. *Figure 3.12* shows officer movement speed while setting total officers at three. However, rounds discharged came out to 17.7 with movement speed at 3.1 ft/s and three officers. Total rounds fired were adjusted to 18 for satisfaction and alignment to historical data.

3.7.7 Officer Discharge Interval

The initial discharge interval utilized for experimentation was determined from historical information on the total number of rounds fired by the three officers. The officers discharged 18 rounds upon reaching their respective engagement areas, which equates to firing one round every 0.86 seconds. This baseline was also incorporated into the model for analysis over 1,000 iterations. *Figure 3.14* highlights the data produced during the initial officer discharge interval experiment, highlighting the correct discharge rate was one round per every 0.86 seconds. This parameter was compared against both the total duration that the perpetrator engaged victims and historical casualties inflicted upon the crowd. Using this information, a second experiment was conducted, *Figure 3.15*, that verified the officer discharge rate did not adversely affect the total number of officers or rounds fired by the three responding officers. The second experiment reinforced the discharge rate accuracy by proving it did not negatively impact or adjust the officer count while producing 18 total rounds expended that mirrors the actual event.

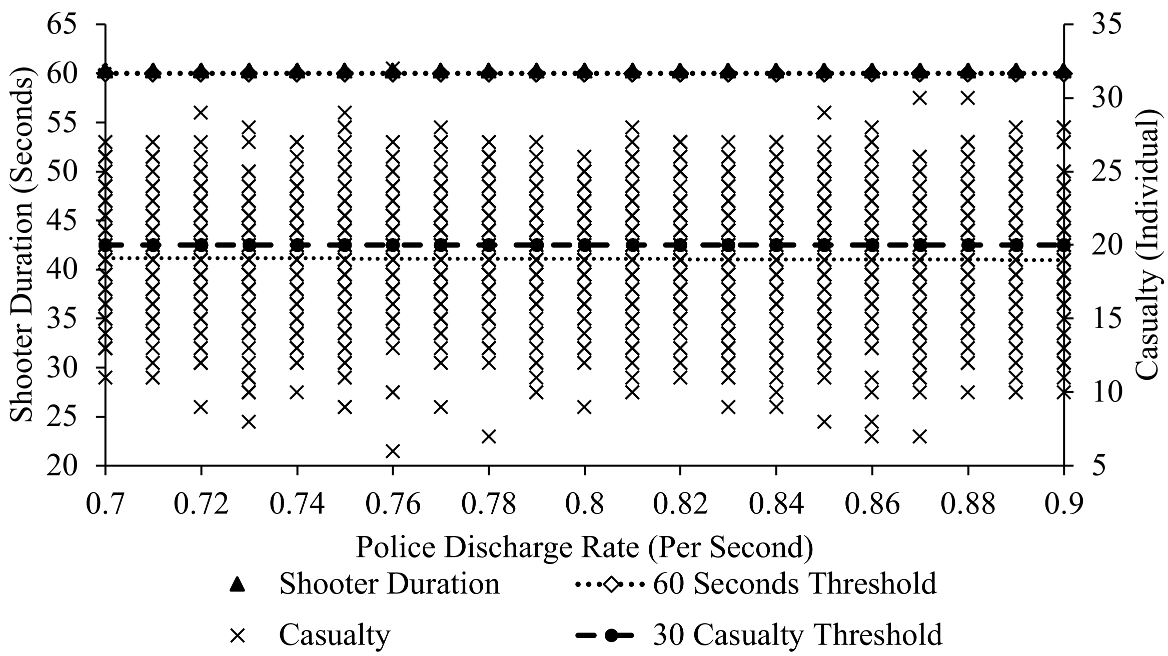

Figure 3.14 - Experiment 19A: Officer Discharge Interval

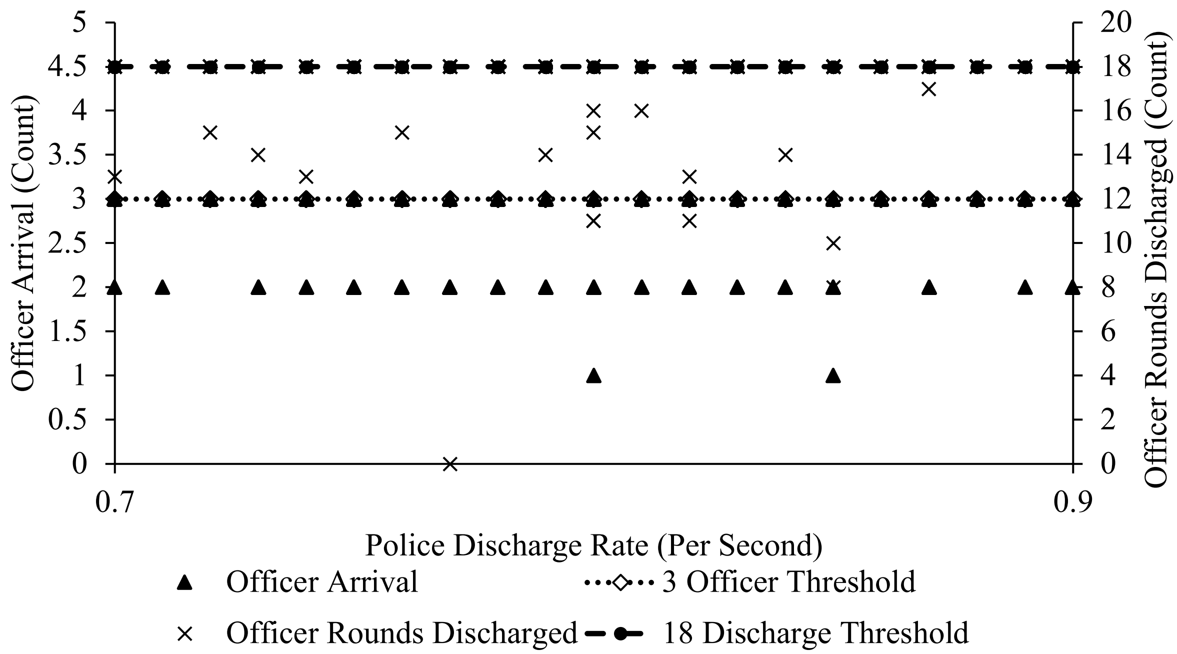

Figure 3.15 - Experiment 19B: Officer Arrival and Rounds Discharged

3.7.8 Officer Discharge Angle

The initial police discharge angle applied to the model was 90° to assess the effectiveness upon police officer engagement of the shooter. *Figure 3.16* depicts the 90° angle impact when applied to all three responding officers over a 60 second duration time. It was evident that further testing of smaller weapon discharge angles was necessary for application to trained professional police officers. Police officers are thoroughly trained on weapon employment and are not seeking to inflict a high number of casualties upon the victims, unlike active shooters. Thus, a smaller discharge angle for police officers would be much more appropriate.

In the absence of a true baseline, three additional experiments were conducted to hone the police officers' weapon discharge angle. While running each iteration of experiments, focus was directed toward the impact upon the model and other affected results. The final discharge angle experiment, *Figure 3.17*, drastically reduced the officer engagement area from 90° to 2°. The fourth experiment examining officer discharge angle produced data that focused between 2° to 2.1°. This experiment showed that a police discharge angle of 2° best supported validation while satisfying all other parameters within the model. Such a small discharge angle also reinforces the assumption that police officers are well trained in weapon employment and not firing randomly within the crowd, but rather focused solely upon the active shooter.

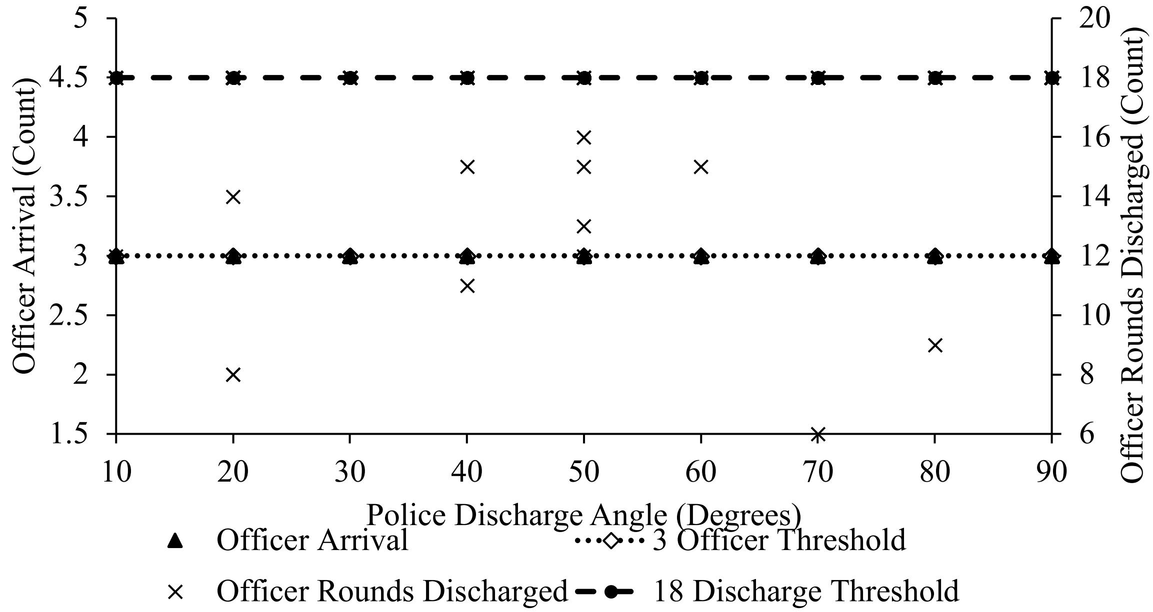

Figure 3.16 - Experiment 21B: Initial Officer Discharge Angle

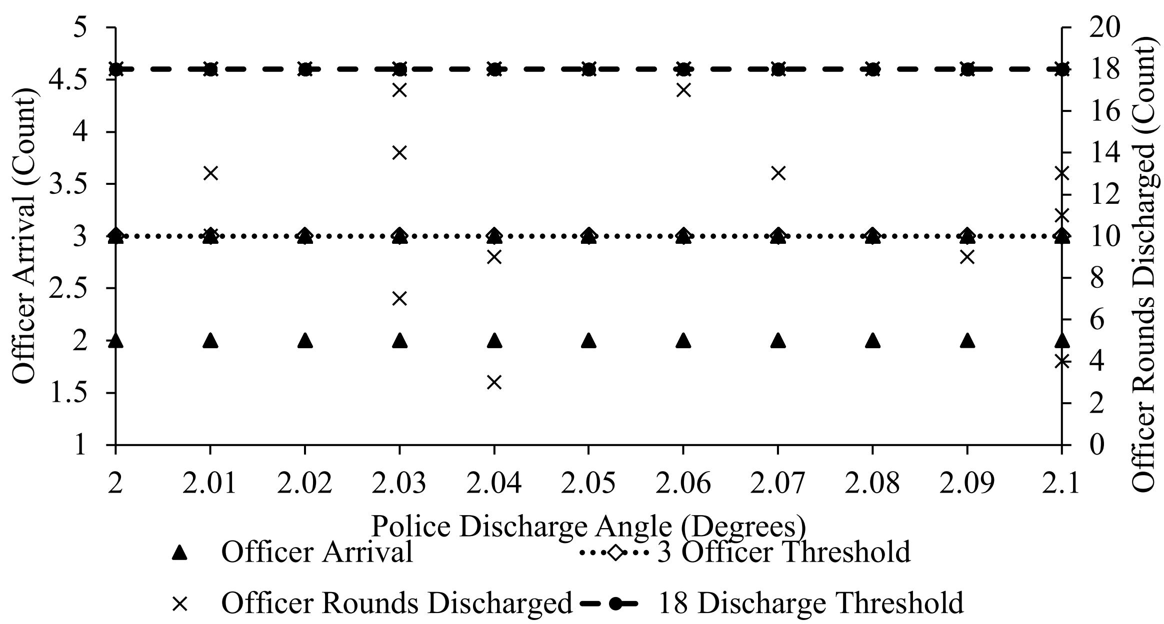

Figure 3.17 - Experiment 24B: Final Officer Discharge Angle

3.7.9 Officer Discharge Accuracy

The officers' discharge accuracy was determined through the application of a baseline comparing the number of rounds discharged to the total number of rounds that struck the gunman. Combined, upon reaching their respective engagement locations, the three officers fired 18 total rounds, striking the shooter seven times. This is a 39% accuracy rate and served as the area of focus during the initial accuracy experiment. *Figure 3.18* shows that during the initial experiment examining accuracy from 0-100%, police firing accuracy appeared closer aligned to 10% rather than 39%. Total rounds discharged by the officers using a 39% accuracy rate over 1,000 iteration averaged 13 rounds. Further experimentation was needed to push discharged officer rounds to 18 while not altering the other parameters necessary to achieve validation.

A second experiment, *Figure 3.19*, was conducted that narrowed the scope of accuracy analysis to 10-20%. After 1,000 iterations, the compiled data revealed that police accuracy was much lower to satisfy the complimentary parameters of total officers and discharged rounds, setting final officer accuracy at 15%. Officers only engaged the active shooter and had to be selective with shots. The gunman was firing at officers during the brief exchange, forcing officers to take rapid shots while avoiding fleeing victims. This was indicative during testing of the model and highlighted the perception of a low accuracy rate for the officers that neutralized the shooter.

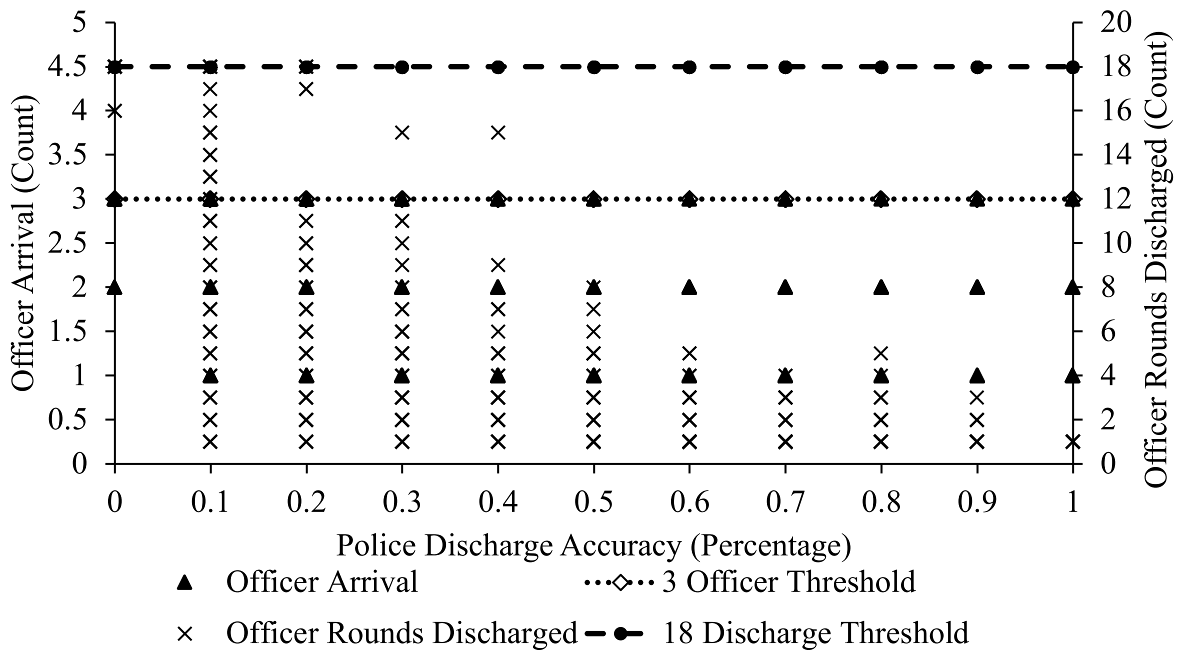

Figure 3.18 - Experiment 25B: Initial Officer Discharge Accuracy

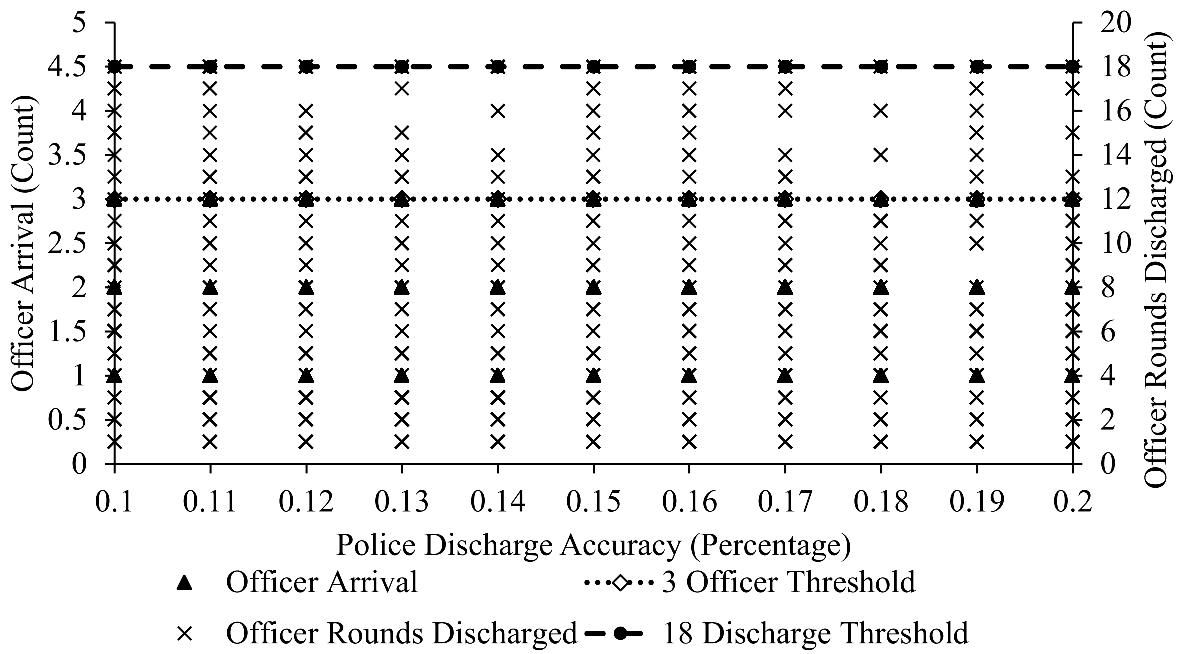

Figure 3.19 - Experiment 26B: Final Officer Discharge Accuracy

3.8 Conclusion

Application of the methodology outlined for this research project will produce results that answer all the research questions. Data collected from this study shall determine best practices to implement throughout outdoor venues in the event of an active shooter situation. Recommendations for minimizing casualties while expediting shooter neutralization will stem from the results of the data produced by the AnyLogic model that identify gaps or weaknesses. Once these vulnerabilities are identified, procedures for incorporation into standing emergency action plans will be delineated to bolster the defensive posture of open-air venues.

CHAPTER 4. ANALYSIS AND RESULTS

4.1 Overview

The analyses and results contained in this section incorporate parameters established through collection of data outlined in the previous chapter. These parameters were used to achieve validation, yielding model results that mimic real-world events. Keeping those settings in place, experiments were conducted spanning three scenarios with police officers at the following locations: Substation situated within venue confines, patrolling throughout venue grounds, and staged outside venue gates two and three.

A vital aspect of data collection during this research project was model validation. The details outlined in the previous chapter highlight the number of experiments and amount of data that was collected to shape the model. Thousands of iterations of the model were completed to finetune parameters and account for data outliers. The data was refined prior to subsequent model iterations to observe the effect on output. Assurance of meaningful, valid data during model construction was a key component prior to testing variations that drive policy refinement.

Unlike the validation experiments, the active shooter randomly navigates the venue for all experiments within this chapter. The variation of movement increases realism by randomly placing the shooter in a different location each iteration. Police must locate and neutralize the shooter regardless of starting location. The goal of modifying total exits, police location and shooter location is to examine the impact upon total casualties with hopes of identifying procedures that minimize damage inflicted during active shooter events at open-air venues.

4.2 Determination of Police Location and Number

The first assessment was determination of where to stage police officers during open-air events. The historical event had armed officers roaming the Garlic Festival grounds and this police location was used during the validation process. However, testing was necessary to determine if roaming officers offered an advantage over other positions. Also, the shooter will appear in various areas within the venue, which may alter police response time dependent upon the starting location.

4.2.1 Substation within Venue

The first experiment focused upon positioning police within the venue at a substation for rapid deployment in case of emergency. The advantage of this location is it reduces response time for officers by placing them closer to the patrons, and in the event of an active shooter, automatic response to gunfire. Table 4.1 was constructed running 1,000 total iterations, 100 for each change in police officer count. The shooter has unlimited ammunition, and the scenario ends when a police officer neutralizes the active shooter.

Table 4.1

Police Substation Data Summary

Officer Count	Mean Runtime (Seconds)	Mean Shooter Casualty Count
1	214.3	28.2
2	174.9	12.6
3	172.8	11.9
4	173.2	11.9
5	172	11.7
6	169.1	11.4
7	170.3	10.8
8	169.5	11.4
9	168.5	11
10	169.3	10.9
Average	**175.4**	**13.2**

The number of total casualties decreases when 1-7 officers are present, with a slight uptick with eight officers before slowly decreasing with 9-10 officers. The model run time, or time the shooter engages victims, coincides with the decrease in casualties. *Figure 4.1* highlights the decrease in casualties as officers are added to the model, with a sharp casualty drop-off when adding a second officer and seven officers being the most effective. The average shooter engagement time varying officers between 1-10 was 175.4 seconds, creating 13.2 total casualties.

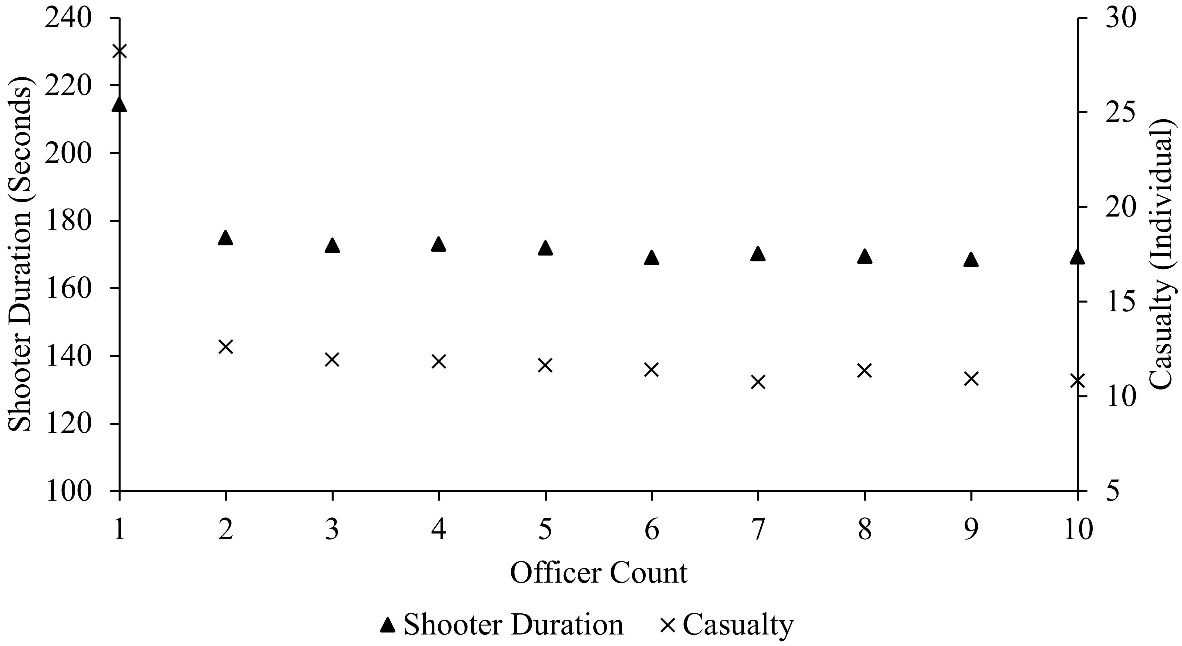

Figure 4.1 - Experiment 27: Police Deployment from Substation

4.2.2 Patrolling Venue Grounds

The second experiment applied patrolling police officers to the model. Depending on the total number of officers on patrol, this application offers the best coverage of an outdoor venue by placing armed first responders throughout the venue. Officers are best situated to avoid fleeing victims to engage the shooter shortly after firing initiates. The historical shooting at the Gilroy Garlic Festival also applied patrolling officers, which limited the shooter to just 60 seconds of firing time. Table 4.2 was constructed running 1,100 total iterations, 100 for each change in police officer count. The initial iteration was run with no police present to highlight a worst-case scenario. The shooter has unlimited ammunition, and the scenario ends when a police officer neutralizes the active shooter. The scenario with zero officers ends after 10 minutes, with the assumption that the shooter will be neutralized by officers responding from off-site locations.

Table 4.2

Patrolling Police Data Summary

Officer Count	Mean Model Runtime (Seconds)	Mean Shooter Casualty Count	Mean Shooter Rounds
0	600	184.6	309.1
1	212.2	29.7	50.2
2	176.3	12.3	20.5
3	169.9	10.4	17.9
4	161.4	7.1	12.1
5	160.4	6.2	10.4
6	160.1	5	8.7
7	162.8	4.9	8.8
8	157.7	3.2	5
9	155.1	3.7	5.3
10	154.2	2.9	4.5
Total Average	**206.4**	**24.5**	**41.1**
Average 1-10	**167**	**8.5**	**14.3**

The number of total casualties during the iteration with zero police officers on site lasted 10 minutes with the shooter causing an average of 184.6 casualties. This indeed stresses the need to incorporate police presence at open-air venues no matter the location. There was a steady decrease in casualties with 1-6 officers present, showing a decrease of over 23 casualties in total. The casualty rate drop slows with 7-10 officers present, only dropping two total casualties with the addition of three more officers. Total rounds expended by the shooter aligns to casualties, steadily falling as casualties become fewer. *Figure 4.2* highlights the reduction in casualties as officers are added to the model, with a drastic casualty drop-off when adding the first officer and six officers being the most efficient. Efficiency in this situation is defined by officer to casualty ratio while considering cost effectiveness and viability. Each venue must conduct a cost benefit analysis to determine the appropriate number of officers. The average shooter engagement time varying officers between 1-10 was 167 seconds, causing 8.5 total casualties (the zero-officer iteration was removed during calculation).

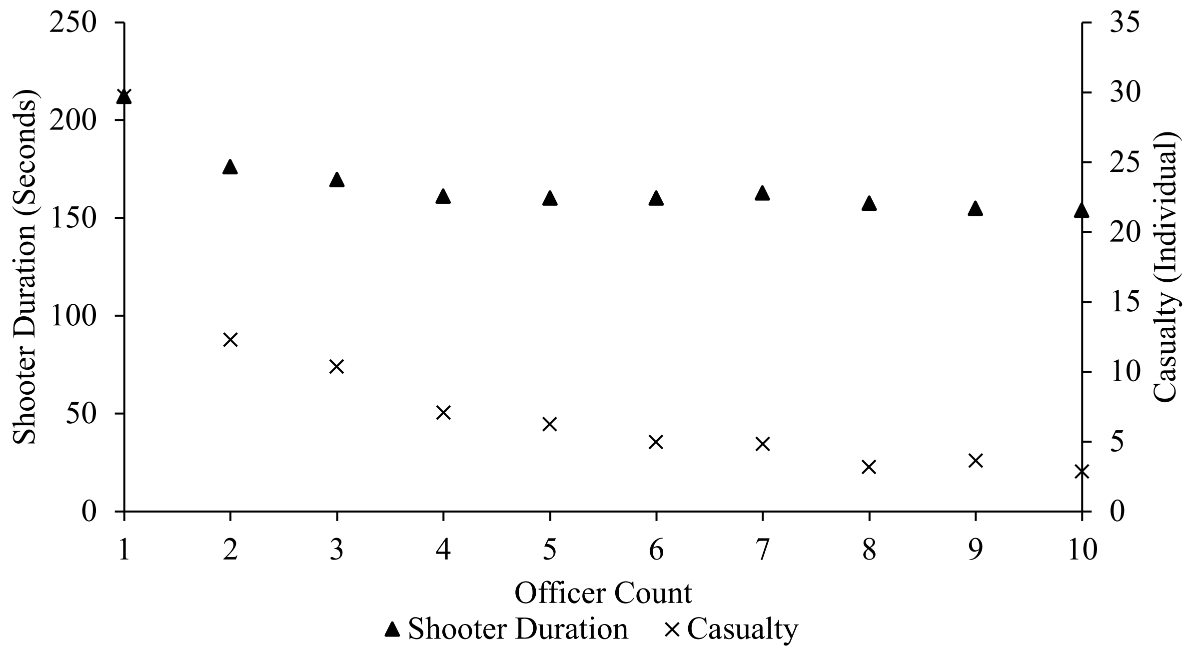

Figure 4.2 - Experiment 28: Police Patrolling Venue

4.2.3 Staged at Gates Two and Three

The third experiment examining police location placed officers at venue gates two and three, depicted in *Figure 4.3*. Officers positioned at these main entry/exit points offer the advantage of bolstering perceived defensive posture but must move against the direction of fleeing victims when pursuing an active shooter. Table 4.3 was constructed running 12,100 total iterations, 100 for each change in police officer count. The averages for each gate combination are listed, which was calculated to apply 0-10 officers at gate two, while running 100 iterations each placing 0-10 officers at gate three. With zero officers at gate two, experiments were conducted by running 100 iterations with one officer at gate three, then 100 iterations with two officers at gate three until reaching 10 officers at gate three. For all 12,100 iterations, the shooter has unlimited ammunition, and the scenario ends when a police officer neutralizes the active shooter. Scenarios with zero officers end after 10 minutes, with the assumption that the shooter will be neutralized by officers responding from off-site locations.

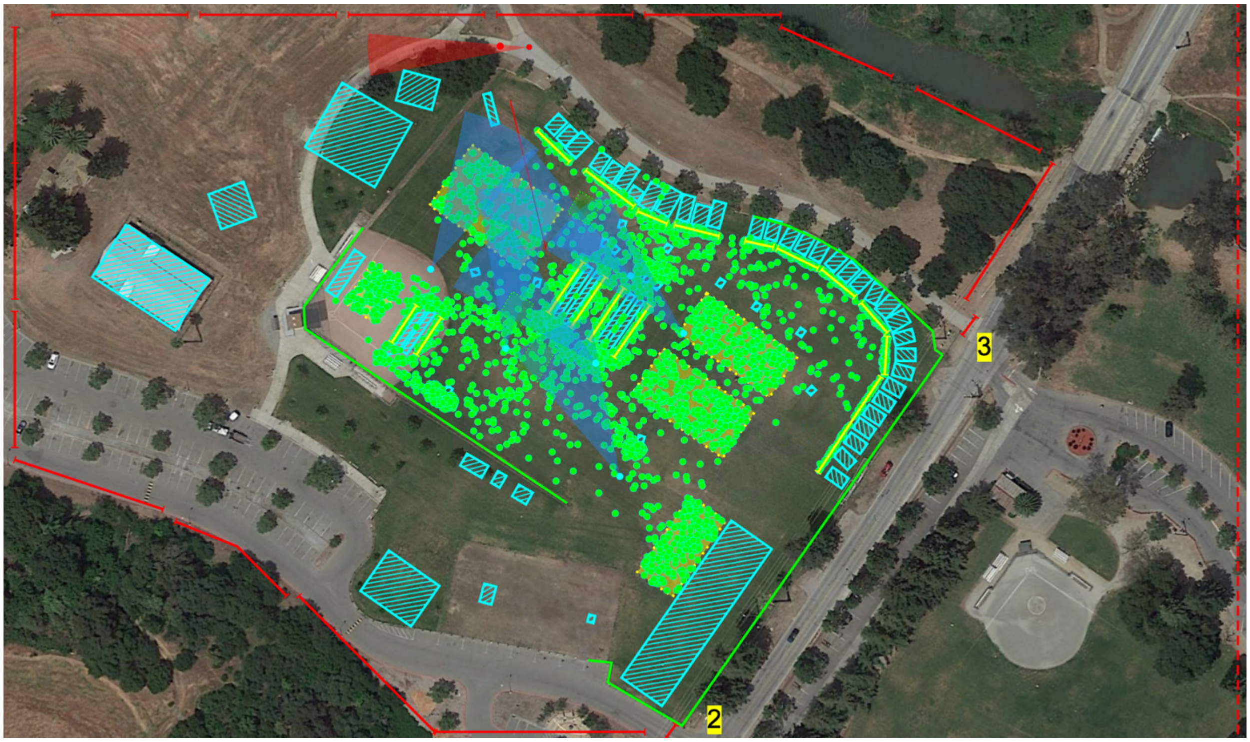

Figure 4.3 - Location of Gates Two and Three

Table 4.3

Police at Gate Two and Three Data Summary

Police Count Gate 2	Police Count Gate 3	Mean Runtime (Seconds)	Mean Casualty Count
0	0-10	293.1	64.4
1	0-10	286.5	61.6
2	0-10	285.6	61.1
3	0-10	279.4	59.5
4	0-10	278.7	59.4
5	0-10	280.5	60.4
6	0-10	276.9	58.3
7	0-10	276.1	58
8	0-10	277.4	58.6
9	0-10	275.2	57.5
10	0-10	276.3	57.8
Total Average		**280.5**	**59.7**

The number of total casualties with zero officers at gate two is slightly higher than iterations with 1-10 officers at the gate, regardless of the number of officers staged at gate three. The model run time, or time the shooter engages victims, follows the decrease in casualties. *Figure 4.4* highlights the decrease in casualties as officers are added to the model, with a small decrease occurring until reaching six officers at gate two. With 6-10 officers responding from gate two, casualties and model run time plateau. While the chart is difficult to read, it reinforces the point that data becomes nearly identical as officers are added to the model. The average shooter engagement time varying officers between 0-10 at gate two and three was 280.5 seconds, creating 59.7 total casualties.

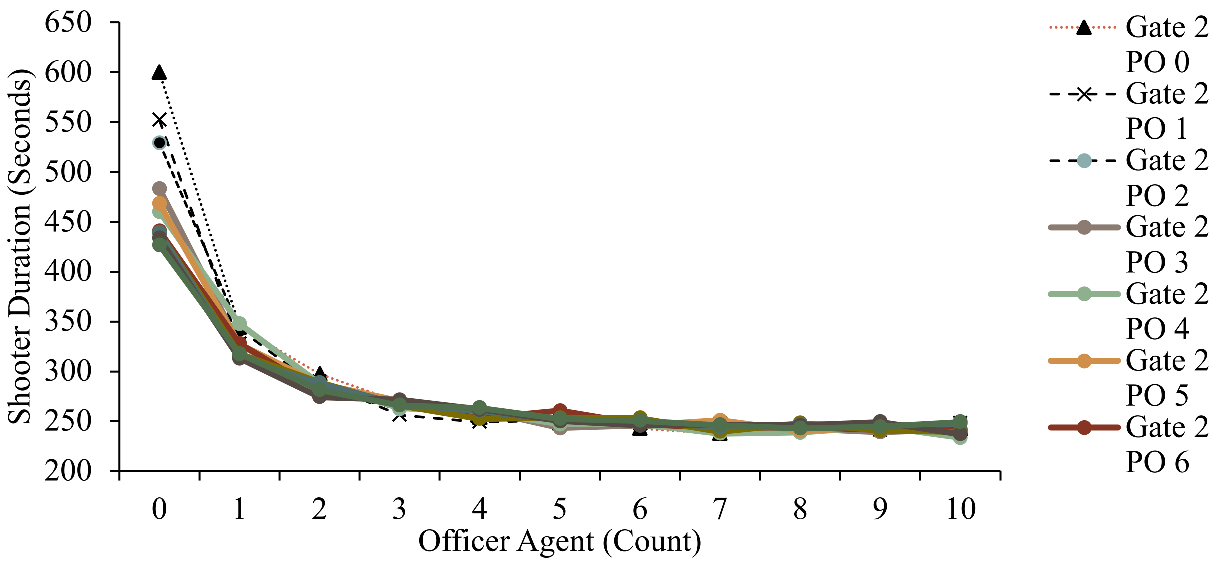

Figure 4.4 - Experiment 29: Police at Gates Two and Three

4.3 Analysis of Police Locations

Following the completion of thousands of iterations testing numerous combinations of police numbers and locations, it was determined that police patrolling the venue offer the best response to an active shooter event. Table 4.4 compares the overall casualty count and shooter engagement time of the three variants tested, with patrolling officers producing the lowest overall totals of any iteration. As highlighted in *Figure 4.2*, ten patrolling officers limited casualties to an average of 2.9 while restricting the shooter to just 154.2 seconds of firing time.

However, there was a nominal decrease from 6-10 patrolling officers in both casualties and shooter firing time.

Table 4.4

Police Location Data Summary

Location	**Mean Runtime (Seconds)**	**Mean Casualty Count**
Substation	175.4	13.2
Patrolling	167	8.5
Gates 2 & 3	280.5	59.7

Due to the accessibility of dedicated support from professionally trained police officers and the associated fiscal cost, it may prove difficult to secure up to 10 officers at every open-air event. As previously suggested, the data listed in Table 4.2 shows that the most efficient application of police officers for this specific model landed at six. *Figure 4.5* displays six patrolling officers oriented toward intercept of the shooter immediately following the onset of firing. Six police officers provided comparable protection and response to an active shooter as 10 total officers with 3,290 patrons on site. When applying six police officers supporting a venue of 3,290 patrons, this generates an average of one police officer per every 548 patrons or 1:548 ratio. This calculation can be applied to all open-air venues, regardless of footprint.

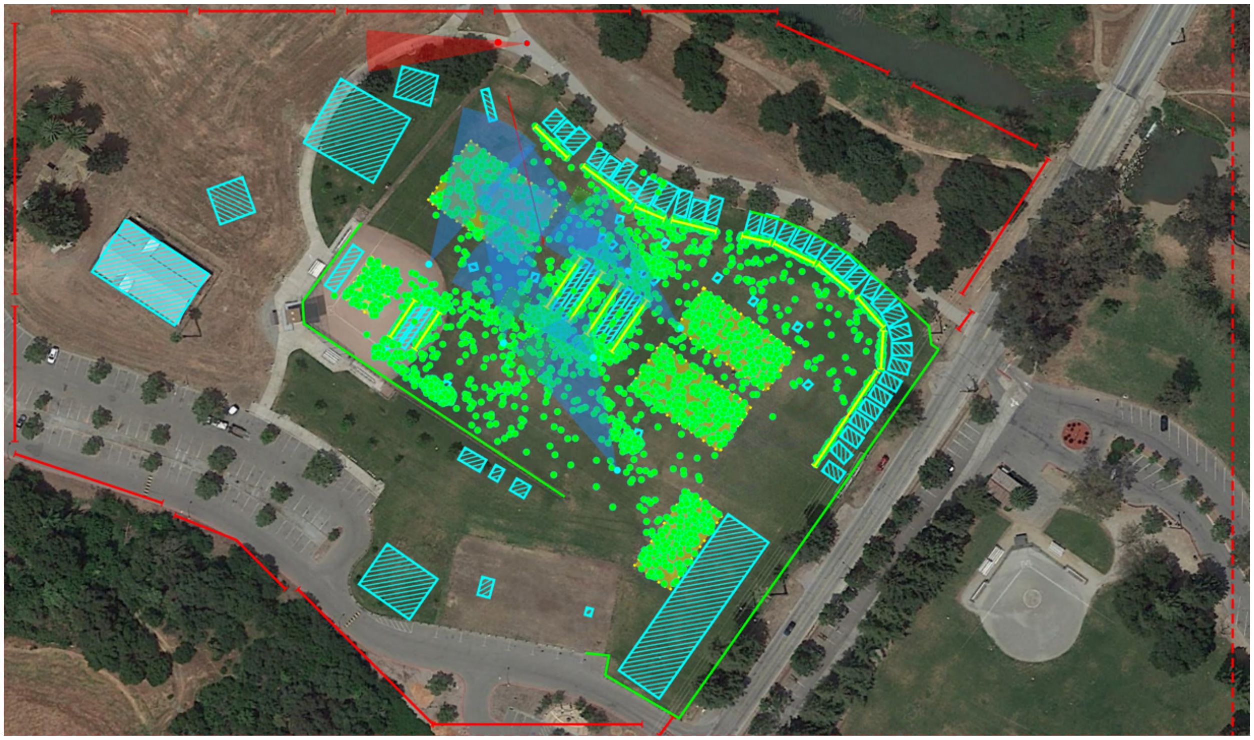

Figure 4.5 - Six Patrolling Police Officers

4.4 Determination of Exits

Upon determination of the optimum location and number of police officers, six patrolling officers were added to the model while manipulating the number of available exits. This was accomplished through the creation of 17 total exits surrounding the perimeter of the Garlic Festival venue, depicted in *Figure 4.6*. The experiments used for validation set total exits at three, limiting the number of areas that patrons could use for evacuation. Expansion of available exits was analyzed to assess the impact upon total casualties and shooter engagement time, applying a random application of available exits for patrons as the exit number was increased within the model.

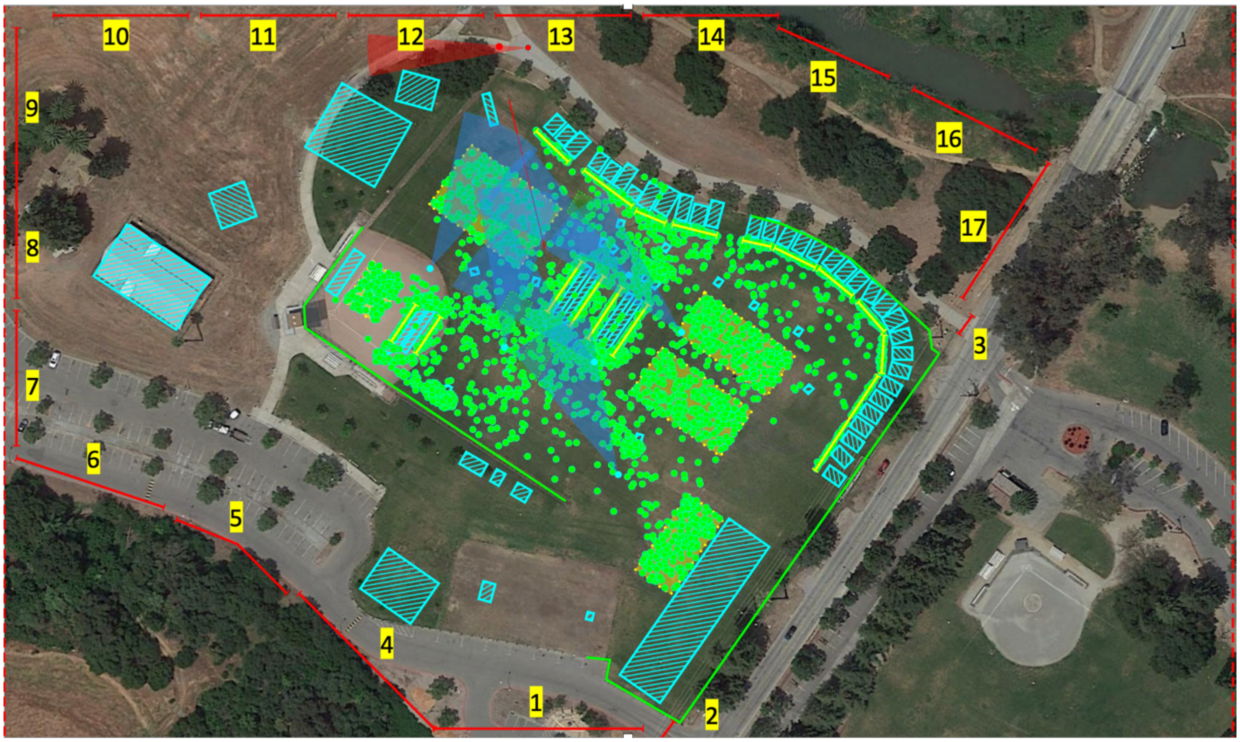

Figure 4.6 - Model with 17 Exits

4.4.1 Exit Analysis with Officers

An experiment assessing the effect of altering the number of exits was conducted, applying 2-17 total exits to the model. One exit, gate two, remained in place for all iterations. Two exits were put in place as the baseline iteration, adding gate three for the first exit locations. Table 4.5 shows that as exits were added, the number of iterations per total gates increased until reaching nine gates, with 12,870 different possible combinations. In total, 65,536 iterations were analyzed to test the impact of exits on the model. During analysis, it was discovered that casualty count increased between two and three exits, then again between three and four. As shown in Table 4.5, results between 4-16 gates produced very little change, with less than one casualty difference on average. 17 gates provided the highest casualty total, averaging 13 over all iterations. The initial setting that applied two gates to the model had the lowest average casualty count at 3.6. Through observation of the model while running on AnyLogic, the increased casualty count associated with added exits is associated with patron proximity to the shooter. Adding exits increases the chance that patron(s) will move toward the active shooter while attempting to evacuate. The reduced number of exits with just gates two and three keep patrons on the eastern portion of the venue, forcing the shooter to pursue them as they flee. The pursuit of patrons takes time for the shooter to engage victims and slows down the rate of casualties prior to responding police officers intercepting the shooter.

Assessment of total engagement time closely resembled the findings tied to casualties. The application of six patrolling police officers was evident when analyzing the model runtime for each iteration. Three total exits minimized shooter engagement time, averaging 159.3 seconds over all iterations. However, there was just a 15 second difference between the engagement times with three exits compared to 16 exits, the least efficient application of exits. The small disparity between engagement times can be credited to the presence of six patrolling officers and their broad coverage of the venue. Officers maintain similar response times to neutralize the active shooter, regardless of the shooter's position when firing commences. These findings led to the need for a subsequent experiment to test exit impact in the absence of officers.

Table 4.5

Exit Number Data Summary (Six Patrolling Officers)

Exit Count	Mean Runtime (Seconds)	Mean Casualty Count	Exit Combinations
2	163.7	3.6	16
3	159.3	5.1	120
4	161.9	6.8	560
5	162.8	6.4	1820
6	162	6.3	4368
7	162.4	6.4	8008
8	162.6	6.31	11440
9	161.8	6.2	12870
10	162.8	6.4	11440
11	162.5	6.4	8008
12	162.1	6.4	4368
13	162.3	6.3	1820
14	161.4	6.	560
15	163.3	6.7	120
16	174.3	7.6	16
17	165.5	13	1
Average	**162.34**	**6.34**	**N/A**

4.4.2 Exit Analysis without Officers

Following analysis of altering exit numbers with patrolling police officers, it was discovered that very little variation existed with regard to shooter engagement time and casualties. The patrolling officers' mean time to neutralize the shooter was 162.3 seconds, with just 15 seconds of variation between all exit combinations tested within the model. A need existed to test the impact of exit variance without the presence of police officers.

Data analysis was applied to the iterations run with patrolling police officers while varying exit numbers. The 10 highest and 10 lowest casualty counts from all iterations, regardless of total available exits, were selected for further testing without any police presence. Each were conducted 10 times to account for anomalies, as it was determined that 63,000+ iterations were not necessary for such a similar experiment. Additional iterations utilizing two exits (gates two and three) and all 17 exits were also examined to observe the effect in absence of police officers. Table 4.6 displays the findings during exit manipulation, with focus upon model runtime and casualty count. There was not a limit on model runtime, or shooter engagement, for this experiment. The iterations ended once all patrons evacuated the venue since no police were present.

Table 4.6

Exit Data Summary (No Police)

Iteration	Mean Runtime (Seconds)	Mean Casualty Count	Available Exits
1	786.6	252.9	8
2	917.5	308.3	10
3	713.5	231.4	10
4	990.8	345.2	8
5	663.9	199.8	8
6	694.1	196	11
7	897.7	312.8	9
8	877.8	296.4	6
9	890.2	242.1	8
10	1021.8	313.4	6
11	949.3	325.3	8
12	948.9	321.4	8
13	780.3	224.3	10
15	845.5	300.2	10
16	848.6	303.4	10
17	943	291.5	10
18	843	304.5	9
19	779.7	218	9
20	716.1	204	9
21	879.4	295.4	17
22	1124.8	431	2
Average	**862.5**	**281.8**	**N/A**

Evaluation of the data revealed that a combination of 11 exits produced the least number of casualties, averaging 196 across all iterations. This provided a 120% reduction in casualties when compared to iterations with two exits, which averaged 431 casualties.

Venue layout also contributed to increased casualties throughout most of the testing. A low number of exits caused backup and congestion of patrons. Adding all 17 available exits often drew patrons into the shooter's engagement zone since patrons evacuate via the nearest exit upon the onset of gunfire. Upon evacuation, the attractions force agents to go around locations to gain access to an exit. This causes a delay for fleeing patrons, which is present for all evacuations with and without police officers. Adjusting venue layout to ease exit access in case of an emergency would be beneficial for not just the Gilroy Garlic Festival, but all open-air locations.

4.5 Research Question 1

Where is the best place to position first responders at open-air venues to minimize attack time by a potential active shooter?

4.5.1 Answer to Research Question 1

The location of first responders absolutely matters and plays a significant role in active shooter engagement or attack time. The research data shows that patrolling officers reduce shooter engagement time by 7.4 seconds compared to officers deployed from a substation and 113.5 seconds compared to officers staged at gates two and three. This is a 5% and 40% reduction in engagement time, respectively. These findings are significant considering the shooter discharges one round every 1.4 seconds, and reduction of shooter engagement time directly correlates to casualty prevention.

Positioning officers on patrols throughout the venue also had a significant impact on casualty count. Patrolling officers reduced casualties by 35% compared to officers deployed from a substation, and a remarkable 86% over officers staged at gates two and three. The markedly higher casualty rate with officers responding from gates two and three correlates to response against the flow of fleeing patrons. Officers entering the venue were observed to be hindered by exiting patrons while in pursuit of the shooter. The model showed officers moving slowly as they made their way through patrons clustered at exits, which resulted in much higher shooter engagement times when compared to officers already staged within the venue.

Simply adding patrolling officers to open-air venues produced a reduction in both shooter engagement time and total casualties during all iterations. This is a change that can be applied immediately to all emergency action plans that involve armed police officers or security. The ratio of 1:548 was established using data within this research project as a baseline for determination of officers needed to support total patrons. Regardless of the number of officers present, patrolling venue grounds offers the best protection against active shooters.

4.6 Research Question 2

Does the total number of available exits at open-air venues impact casualties during an active shooter event?

4.6.1 Answer to Research Question 2

The number of exits available does impact casualty count during an open-air venue active shooter event, but not as drastically as the positioning of police officers. The simple addition of more exits does not yield a reduction in casualties or shooter engagement time. It was detected that the addition of exits combined with six patrolling police officers increased casualties. Mean casualty count was 259% higher between two exits and 17 exits with patrolling officers. It was observed that upon commencement of firing, patrons proceed to the nearest exit for evacuation, regardless of whether the exit was in the path of the shooter. Patrons often began to move toward the shooter rather than gaining standoff distance, ultimately becoming casualties. The iteration with two exits used gates two and three, both located on the eastern side of the venue. These exit locations often drew patrons away from the shooter, granting the patrolling police officers time to intercept and neutralize the active shooter. With patrolling police present, all iterations had a mean of 6.3 casualties, a 215% casualty reduction compared to the historic event tested during validation. Responding officers during the historic event were also patrolling, but the optimum number of officers determined through simulation was set at six, which is double the number during the 2019 Gilroy Garlic Festival shooting. The lowest casualty combination of exits and patrolling police officers was established at two exits with six patrolling officers, limiting casualties to a mean of 3.6 throughout all iterations.

The number of available exits with no police present suggested a higher reliance upon the speed of evacuation, which correlates to total exits. Two exits had the highest mean casualties at 431, with 11 available exits being the optimal option at 196 casualties. Throughout iterations with two exits, patrons were observed backing up at exits due to limited throughput. This enabled the shooter to bear down upon victims and engage them at will. Iterations using 11 exits achieved a mean of 196 casualties through a balance of speed and avoidance of the active shooter. Expanding exits to 11 enabled a higher number of evacuees to remain outside the shooter's engagement range, while easing exit throughput concerns. The result was a 120% reduction in casualties compared to iterations using two exits.

Exit configuration and total number of exits does impact casualties, but careful consideration must be applied to venue resources during the determination of exits. If no armed police officers are present, more exits are required to ensure rapid evacuation of patrons. However, too many exits increase the probability of directing patrons closer to the active shooter rather than further away. This issue is partially a limitation of AnyLogic and the inability for agents to recognize danger. Agents are programmed to evacuate via the nearest exit upon the onset of shooting, regardless of the active shooter's position.

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

5.1 Overview

Data was exclusively collected using an AnyLogic model based upon the 2019 Gilroy Garlic Festival active shooter incident. Historical facts surrounding the shooting were used to develop model parameters to achieve validation, equaling the real-world event in every important category. The focus of the casualty mitigation recommendations within this section are directed toward open-air outdoor event venues, which drastically vary in footprint, design and available structures. These facilities lack many of the mandatory exit guidelines that govern indoor structures, which exacerbates the chaos associated with victims seeking exits during an active shooter situation. Most victims enter open-air venues through limited entrances and are unfamiliar with all exits, regardless of the number available. Unlike public buildings, signage directing patrons to exits during emergency situations are not required at open-air venues.

The recent increase in open-air active shooter events demands investigation and testing of non-traditional methods to reduce casualties. Shooters seem to be drawn to densely populated areas to inflict high numbers of casualties in a short period of time. Rapid response efforts must be put into place to minimize engagement time by potential shooters. Depending on venue size and budget, multiple response techniques outlined within this section could be combined to maximize effectiveness by limiting a shooter's agenda.

5.2 Study Significance

As active shooter events continue to increase, new defense mechanisms must be implemented to protect the public and minimize casualties. Testing and evaluation of active shooter scenarios aids first responders with development of modified response techniques. While there are many aspects of an active shooter event that cannot be replicated due to safety concerns, analysis through realistic training and simulation can identify shortcomings or provide amended response options. This research project focused upon the manipulation of current safety measures in place for open-air events, providing recommendations for police support and exit layout. Incorporation of patrolling police using a 1:548 officer to patron ratio is an initial step that can be immediately implemented across the vast majority of open-air events. Adjustment of exits that consider police officer support is equally important to provide patrons with options when fleeing the vicinity of an active shooter. This is another low-cost alternative that venues an put into place with very little change or planning. However, when adding exits, consideration should be given to informing the crowd during an emergency. This requires the integration of modern technology to properly direct panicked patrons. Dynamic signage that can be adjusted real-time would benefit outdoor venues with limited areas for people to take cover during an active shooter event. Signage can also have other options incorporated into the design, such as speakers, strobe lights, etc. to better attract the attention of the crowd. With proper testing and development, increased signage throughout event grounds could greatly assist with the protection of patrons at open-air venues during all emergency situations, not just active shooter events.

5.3 Dynamic Signage

Signage throughout venues, especially pop-up outdoor locations, can be very limited. A misconception of detraction from the main event can exist, stirring reluctance from management to place signage that could aid patrons in the event of an emergency. Signs large enough to be seen from a distance could potentially block a stage during a concert or present a perceived "eye sore" within the venue. Management may also see signage as an unnecessary cost associated with the event itself, falling low on the budgeting priority list. Unlike buildings, open-air venues are not governed by organizations such as the National Fire Protection Association to ensure adequate emergency procedures, including exit signs, are in place, and vary so much in footprint and layout that no governing bodies exist to oversee emergency response criteria. Simple exit signs and emergency lighting are required within "stairs, aisles, corridors, and passageways leading to an exit in occupancies such as, but not limited to, assembly, educational, hotels, mercantile and business" (Mahoney, 2020). These may seem like miniscule additions to improve structure safety in the event of an emergency, but patrons may not be familiar with all available entry/exit points and may need to use an alternate location if one of familiarity becomes unusable.

Implementation of dynamic signage, or signage that can be adjusted real-time, is a defense mechanism an open-air venue can employ to protect patrons in the event of an emergency. Signs strategically placed throughout the venue could serve as an aid to patrons seeking an exit and double as displays to pass general information to the public. Signage with similar characteristics to those outlined in Appendix B possess the ability to adjust real-time through control at the venue command center. In the event of an active shooter, the control center could adjust the sign to show the exit is closed, redirecting fleeing patrons to an alternate exit. These signs would maintain a low profile until enabled by the command and control center. They are also mobile, possessing the ability to be placed within areas of the most need, and can support multiple venues through relocation at the end of an event. Dynamic signage add-ons are limitless and tailorable to the needs of a specific event, with potential to serve as video surveillance if activated for the duration of an event.

During experimentation within the Gilroy Garlic Festival model, it was identified that the addition of numerous exits for patrons was not enough to reduce casualties. Many victims were observed moving toward the shooter in an attempt to evacuate the festival, which is a real-world concern as well. During the chaos that ensues following a shooting, people may not know the location of a shooter. The incorporation of signage to direct patrons to safe exits while simultaneously providing areas to avoid would be a huge safety improvement.

5.4 Drone Surveillance

Incorporation of drones to assist officers responding to an open-air active shooter event is an effective method to bolster situational awareness of a dangerous, fluid event. Drones are readily available, and operators do not require extensive training to become proficient. Larger events that have security on-site possess the means to acquire a UAS and nest it within the standing emergency action plan. Any drone outfit with a camera is better than nothing, but not all drones are equivalent in terms of capabilities.

Drone selection will be driven by factors specific to the individual open-air venue. Budget is a limiting factor for many small events, with sophisticated UAS platforms exceeding $10,000 (*DJI Store*, 2021). While higher-end drones do provide superior qualities like extended flight time, camera quality and durability, the end state remains improving situational awareness for responding officers through all means available. An inexpensive drone equipped with a basic camera can still effectively capture footage of a suspected shooter, providing officers with a description, armament information and location. These items are key data points for responding officers and could alter response speed, shot selection and engagement tactics.

The increased popularity of UAS within the general public is equally evident within police departments throughout the country. Currently it is estimated that over 3.5 million UAVs are in the United States, with over 347 police departments incorporating them to aid officers during a variety of duties (Fleming, 2019). The rising number of police utilizing drones can benefit events that integrate officers into security plans. The Gilroy Garlic Festival is directly supported by the city police department, with officers roaming the grounds and positioned at various exits (Rosen, 2020). With this professional relationship in place, the Gilroy Garlic Festival management team would not incur additional expenses for a UAS if the Gilroy Police Department outfit its organization with drones. This logic applies to other open-air events throughout the country that receive security support from local law enforcement.

Staging the UAS at the security command center is best for command and control purposes. During an active shooter situation, shooter activity and officer response will be tracked through the command center, regardless of how rudimentary the setup. With the UAS operator co-located at the security command center, this minimizes delay getting information passed to launch the drone. Once launched, mid-level drones can exceed 50 mph for short periods of time, easily covering the full size of most outdoor venues in a matter of seconds (*DJI Store*, 2021). Even with the natural launch delay while responding to the initial shooter gunfire, drones can cover ground much faster than officers on foot. To minimize drone delays, an operator should be on standby during the venue's operating hours. The operator should also be proficient with control of the specific UAS platform used by the venue, while also familiar with police response tactics and communication methods. Rehearsals of drone-supported active shooter response must be conducted to smooth reaction times while identifying friction points.

Airborne drones, non-weaponized, could serve as a distraction to an active shooter. Distracting a shooter provides valuable time for victims to continue their escape or seek cover from the gunman's fire. As displayed during shootings at Virginia Tech (Virginia Tech Review Panel, 2007) and Gilroy (Rosen, 2020), the respective shooters ceased targeting civilians when engaged by officers. While both shooters died via self-inflicted gunshot wounds, it was only after law enforcement was bearing down upon them that they turned their weapons on themselves rather than civilians. The presence of police officers created a shift in the shooters and has been evident in numerous other active shooter situations. UAS could have the same effect on shooters, acting as a distraction to limit casualties while officers bear down upon the shooter. UAS effect on active shooters is limited, with realistic research made difficult due to the unpredictable mindset of perpetrators. Further recommendations on drone implementation are listed within the future studies section of this chapter.

5.5 Recommendations for Future Studies

This research project focused upon a specific problem set and provided insight on just a handful of methods to minimize casualties during an active shooter event. Research recognized numerous areas that could have a positive impact on casualty reduction. Below is a list of future research possibilities:

1. Expand upon the implementation of dynamic signage within the confines of outdoor venues. Initial tests were conducted utilizing the Gilroy Garlic Festival AnyLogic model with results displayed in *Figure 5.1*. The signage proved effective at directing patrons toward festival exits for an orderly evacuation. However, patrons began to bottleneck at the exit locations, shown in *Figure 5.2*, creating a vulnerability that a potential shooter could exploit. Unlike the dynamic signage detailed in Appendix B, signage within AnyLogic is not adjustable real-time. Logic must be pre-built during model development and the logic used for the signage test created Attractors at the exit sign locations upon the onset of shooting. Patrons moved to the closest exit sign, then proceeded to the nearest exit. This is the concept of the signage, but in real-time the exit signs would be controlled at the venue command center, directing patrons away from the active shooter location. *Figure 5.2* highlights how an active shooter could exploit congested exits, targeting the bunched patrons. AnyLogic possesses the ability to add Agent reinforcement learning and this could be added to the patrons, with analysis of the impact upon casualties.

Figure 5.1 - Model with Exit Sign Attractors

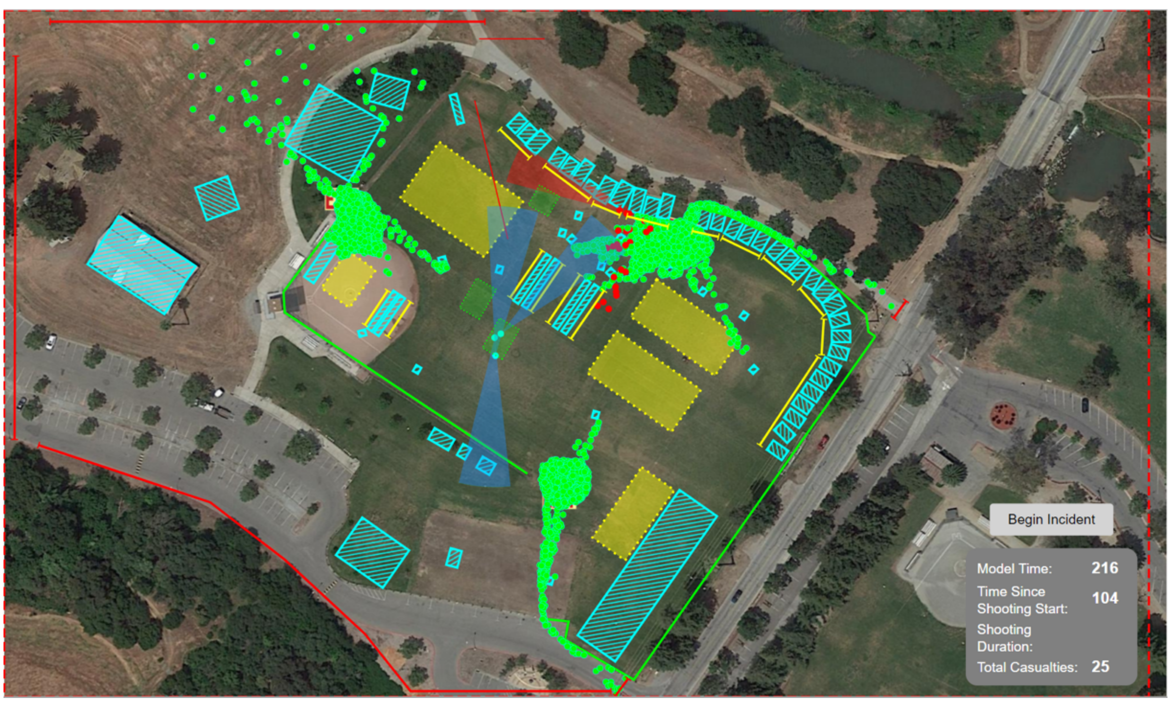

Figure 5.2 - Model with Exit Sign Attractors and Shooter Engagement

2. Incorporation of UAS into the Gilroy Garlic Festival model for data analysis. Study of UAS response times or automatic launch upon the onset of gunfire would benefit open-air venues considering the benefits of adding a drone to the existing emergency action plan. Testing the effects of a drone on casualty mitigation and shooter neutralization would prove useful for the advancement of alternate active shooter response efforts. Testing drone variants and differing capabilities would provide venue management with options that best suit respective needs.
3. Develop reinforcement learning (RL) logic for application toward Pedestrian Agents within the Gilroy Garlic Festival AnyLogic model. Through multiple trials or iterations, sufficient data will be collected to equip Pedestrian Agents with the ability to make decisions with either a positive or negative reward (Farhan et al., 2020). The negative reward in the Gilroy Garlic Festival model would be improper decisions that lead a Pedestrian Agent into the shooter's fan of fire and becoming a casualty. A positive reward would be staying alive through the application of RUN.HIDE.FIGHT® techniques. If "Fight" behavior is determined to be the best course of action and a Pedestrian Agent neutralizes the shooter, then a large reward would be given. This scenario would only be applied after many scenario observations in conjunction with logic that triggers agents to "Fight" when coming within a pre-determined proximity of the shooter. The addition of a requirement of multiple Pedestrian Agents within a pre-determined proximity of the shooter could also be a trigger to initiate a "Fight" response. RL begins to take shape following multiple scenarios and adequate observation time. Building Pedestrian Agents with the capability to avoid an active shooter within an AnyLogic model adds a level of reality to the underlying model.
4. Further analysis of Christmas Hill Park to determine the exact square footage footprint of the Gilroy Garlic Festival. The data collected during this research project showed crowd densities like the Garlic Festival are best served by a 1:548 police to patron ratio. Total square footage information could assist with manipulation of the 1:548 police to patron ratio for varying venue sizes. All events and venue locations are not the same, so patron density with respect to the venue size should be assessed when determining the appropriate number of police officers required for support.

APPENDIX A. CROWD MANAGEMENT SYSTEM PATENT

PURDUE
OFFICE OF TECHNOLOGY COMMERCIALIZATION

TRACK CODE: D2021-0032

TITLE: Crowd Management System

DISCLOSURE DATE: Aug 7, 2020

FIRST PUBLIC DISCLOSURE DATE: 2020-08-07
DESCRIPTION: The purpose of this proposal is to suggest a modular Crowd Management System (CMS) that may be in a fixed or deployable configuration and is used to direct pedestrian traffic in high-density outdoor events such as concerts, sports games, fairs, and amusement parks. The system would have several operational uses that contribute to the overall safety of the event in which it is employed.

KEYWORDS: exit, safety, crowd, crowd management

Name	Organization	Contact
Lead (Contact) Contributor: Travis L Cline		Telephone: Email: cline40@purdue.edu
Contributor 2: Braiden Frantz	Purdue University	Telephone: Email: bfrantz@purdue.edu
Contributor 3: Krassimir Tzvetanov	Purdue University	Telephone: Email: ktzvetan@purdue.edu
Contributor 4: J. Eric Dietz	Purdue University	Telephone: Email: jedietz@purdue.edu

SURVEY QUESTIONS:

Brief abstract: Previous simulations have shown that utilizing multiple exits in the event of an incident for a high-density outdoor event (HDOE) result in faster evacuation times, and reduced emergency response time. A modular Crowd Management System (CMS) is proposed to monitor for hazardous situations in real time, as well as actively direct pedestrians away from danger, and toward exits. Crowd Management Devices (CMD) are the means in which the system interacts with pedestrians and consist of networked smart signs of an unassuming nature, that inflate or extend and rotate to highlight the best route away from danger. Signs are lit and clearly marked as to be easily understood at a glance and can be rotated in real-time to match the current state of the incident. A sensor network provides a computer-generated model of the HDOE and feeds information to a processing center that communicates with the CMDs.

What problem is solved by the technology? Currently, no known outdoor signage standards or systems exist that would facilitate an efficient evacuation of high-density outdoor events (HDOE) such as amusement parks, concerts, sporting events, and fairs while being tailorable to the incident and prevents pedestrians from evacuating into the incident area.

How is the problem currently being addressed by others in the field? To the best of our knowledge it is not being addressed outside of local SOPs.

How is this technology different/better than existing solutions? There is not a system that currently exists outside of normal security procedures which may not address crowd behavior

Have you, or anyone else, made any disclosure of any part of the technology? No

If yes, please include details: what was disclosed, when was it disclosed, and where was it disclosed?

Funding/Sponsor (if blank, no external funding was used):

Is the technology related to any prior Technology Disclosures to OTC? No

If Yes, please provide details of related technology:

Are you currently engaged in any consulting work with a private company or non-profit enterprise, or any other outside activity that in any way relates to the Technology? Yes

Have you received any funding for this Technology under an Industry Focused Applied Research Agreement (Work for Hire)?No

Export Control: Does this technology require a Technology Control Plan (TCP)?

If yes, does the Purdue Export Control Office have a copy of the TCP?

What is the product? Our product is a Crowd Management System which has several components to include Crowd Management Devices that take input from a monitoring system to direct traffic towards safety at high-density outdoor events.

Who are the key players producing a competitive or complementary product? There is a company that may have a similar patent for integrated indoor EXIT signs, where more regulations exist.

https://uspto.report/TM/88791784

Will future work be conducted on this technology? Yes

If applicable, is the competitive product reimbursed?

If applicable, does the technology integrate into an existing system or platform, or will a new system need to be implemented to produce the product? It consists of a new system that may be integrated into existing security systemsIt consists of a new system that may be integrated into existing security systems

☐ FUNDING IS CORRECT.

Technology Assignment:
The undersigned hereby attest that to the best of their knowledge all of the foregoing information is true and accurate. I (we) acknowledge and agree that this disclosure is made pursuant to and controlled by the provisions of Purdue University Policy I.A.1. To the full extent of my (our) right(s) in the above-disclosed technology, by signing this document, I (we) hereby unconditionally assign ownership of the above-disclosed technology to the Purdue Research Foundation.

	Printed Name	Signature	Date
1	Name: Title:		
2	Name: Title:		
3	Name: Title:		
4	Name: Title:		

APPENDIX B. CROWD MANAGEMENT SYSTEM PATENT DISCLOSURE

Travis Cline, M.S.
Braiden Frantz, M.S.
Krassimir Tzvetanov, M.S.
J Eric Dietz, Ph.D., PE

Purdue University

Crowd Management System for High-Density Outdoor Events

Introduction

Background

In a previous study by Tzvetanov et al., (In press), agent-based modeling was used to determine the most efficient methods in which to evacuate an amusement park in the event of an incident requiring patron evacuation and emergency response. The amusement park layout used for the study is an actual project in the design phases slated to be built overseas. In one series of tests, the research team determined that pedestrian movement throughout an amusement park is minimized if pedestrians were re-directed to seven emergency exits evacuation times would decrease by an average of 24% when compared to leaving through the large main exit toward the parking lot Tzvetanov et al., (In press). Further, the study showed the importance of multi-exit evacuations regarding the impact of police response times to arrive at one of three incident locations, as well as the potential negative impact on hard corners and pedestrian flow in an evacuation Tzvetanov et al., (In press). In addition, the study established that some exits may be disproportionately loaded with pedestrians due to their proximity to major attractions. In this case there will be further timesaving if the crowd exiting that attraction can be guided to different exits to balance the load. This study serves as a starting point to assess the potential effects of an operational evacuation system or crowd management system prior to its deployment.

<u>Standards for Outdoor Signage</u>

Standards in place for outdoor events are generally vague and call for generic protocols to be in place for mass evacuations. The NFPA 1616 (2017) outlines a public communication system to be present for the passage of warnings, notifications, and general mass communication to patrons. The communication system is intended to ensure the health and well-being of patrons and staff throughout the venue. The communication system should be tested regularly, and the U.S. Department of Homeland Security recommends a video surveillance system to bolster security (Risk Management Division, 2006).

Signage is also an important factor for any emergency situation involving densely populated areas. Strategically placed signs can direct patrons toward safety and reduce the risk of injury involved with a mass evacuation. However, when it comes to standardization or mandates for outdoor spaces, direction is lacking from governmental entities. The U.S. Department of Homeland Security has issued a few general guidelines of when to use signs, such as signs to restrict access to areas off-limits to the public and instructions to ensure that signage uses standard emergency verbiage (U.S. Department of Homeland Security, 2019). However, there is no guidance for sign placement, size, color, shape, etc. Many outdoor venues are in locations that do not host large masses of people regularly or attract patrons that are not familiar with the layout. There is a need to implement on-demand emergency evacuation signage in high-density outdoor venues to keep patrons safe as they exit and guide people away from dangerous or overcrowded exits.

Problem

Currently, no known outdoor signage standards or systems exist that would facilitate an efficient evacuation of high-density outdoor events (HDOE) such as amusement parks, concerts, sporting events, and fairs while being tailorable to the incident and prevents pedestrians from evacuating into the incident area.

Solution

The purpose of this proposal is to suggest a modular Crowd Management System (CMS) that may be in a fixed or deployable configuration and is used to direct pedestrian traffic in high-density outdoor events such as concerts, sports games, fairs, and amusement parks. The system would have several operational uses that contribute to the overall safety of the event in which it is employed.

Claims:

1. Emergency signage and systems can aid in the safe evacuation of high-density outdoor events (HDOE)
2. Signage and systems controlled within a command center provide real-time directional crowd control during emergency evacuations within HDOE
3. Crowd management devices (CMDs) can re-direct traffic away from one or more hazardous event such as a shooting, terrorist attack, or inclement weather conditions
4. Traffic can be directed toward alternate emergency exits, which may not be well labeled or known to pedestrians for outdoor spaces. Foot traffic can also be directed away from an overloaded exit to prevent stacking.
5. CMDs can maximize throughput at hidden emergency exits when coupled with active pedestrian monitoring through a network of sensors and interactive signs
6. Sensors can monitor pedestrian density and re-direct traffic from high-density bottlenecks that could potentially lead to trampling or crushing events

Funding

No funding has been sourced or given for this patent proposal.

We propose a Crowd Management System (CMS) made up of several modular components to help solve this problem. The system will be comprised of three primary categories which will be explained in greater detail within this document:

- Command and Control System (C2)
- Sensors
- Crowd Management Devices (CMDs)

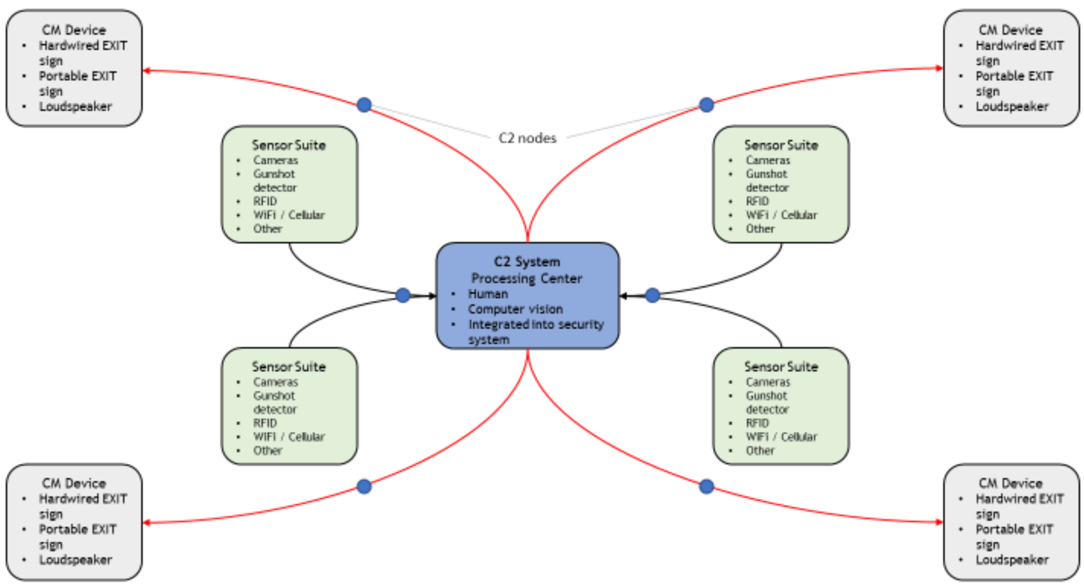

Figure 1 - Concept Sketch of Crowd Management System

Command and Control System

The command and control (C2) system will connect data from the sensors to the traffic management devices, which include interactive signs and loudspeakers.

Processing Center

The data processing center receives data from the sensors and may form a computer model of the venue in which the system is employed. This will include a geographic representation of sensor data, traffic management devices, and exits. If equipped, this computer-model will have an approximation of the number of pedestrians per area, as processed from the specific sensors. The processing center will take input from the sensors and send signals to the traffic management devices in the event of an incident. This process can be monitored and actioned manually, or through automated software.

C2 Nodes (network)

The system will be connected in a mash or hub-and-spoke network, and primarily communicate wirelessly, through a variety of possible protocols, such as but not limited to, Zigbee, Bluetooth, Wi-Fi, etc. The network will automatically configure and will connect all sensors and traffic management devices. This will allow for a flexible mesh, or hub-and-spoke, network that can be rapidly deployed and healed if a singular node fails. Nodes will be added as necessary to cover an entire venue.

Sensors

The general purpose of the sensor category of the CMS is to monitor crowds for pedestrian count, density, movement, and behavior. Sensor data will be aggregated at the processing center to display a computer-generated representation of the event in real-time to provide situational awareness. Sensor data will be used to feed the following into the processing center:

- Pedestrian density broken up by area (unique to each event)
- Pedestrian movement and behavior
- Civil disturbance
- Gunshot monitoring
- General traffic patterns
- Distressed individuals
- Exit usage and flow
- Location of safety hazards

The CMS would be able to leverage the benefits of several different types of sensor technology to add to the overall situational awareness and safety of an HDOE.

Video Technology/Cameras

Video technology would likely be the primary sensor involved due to its low cost and proven history for manual monitoring. Additionally, over the past decade video technology combined with computer vision has rapidly evolved. When paired with the right software, video technology can track specific individuals in crowds over multiple cameras. For the purposes of the CMS, software could be integrated that can approximate count of people in a particular area, or who have passed by a particular checkpoint (S. Li et al., 2012; Zaki & Sayed, 2014). Additionally, the video could be recorded and saved for law enforcement investigations if necessary.

Passive, Active Infrared and Radio Beam

Passive and active IR have similar characteristics as it pertains to the need to measure the pedestrian count in particular areas. In both cases, a checkpoint type of deployment could be used, similar to a digital turn style. This could be used to monitor entries and exits of an area or emergency exit.

Pressure Pads

Pressure pads appear to have fairly low accuracy comparable to active and passive IR (Ryus et al., 2014) but there is not a lot of data on them. Unlike other technologies, they need to be buried under the ground which makes it more challenging to deploy on temporary bases.

Cellphone Emissions

There are three types of cellphone emissions which can be useful in counting people in different areas in the park. The first one, WiFi, has become ubiquitous. Many venues even if they are temporary offer access to the Internet and in some cases, they provide information services about the venue which further incentivizes patrons to connect to the WiFi.

The second, and even more reliable method, is to track the presence of cell phones by passively monitoring their control channel communication with the cell phone towers. Note that this monitoring only covers the address of the phone and does not determine the phone number or the individual behind it.

Last, Bluetooth emissions can be passively monitored. Cellphones routinely emit Bluetooth signals even if they are not connected to other Bluetooth devices. These signals can be monitored for unique devices and produce a relative count of devices in an area.

In all cases it is possible to collect signals passively without the need to acquire a permit. Furthermore, the MAC addresses of WiFi, Bluetooth and cellphone radio do not directly identify users and there is not a privacy concern if they are not retained and mapped to users.

Environmental/Other Sensors

The scope of this system allows for specific sensors to be deployed that address the unique hazards that may be encountered at a specific venue. These may include but are not limited to; ambient temperature, humidity, flood/water sensors, inclement weather, light, gunshot detectors, smoke, carbon-monoxide and other gases, etc. Additionally, pedestrian interactive sensors may be added that can alert attention to a specific area for monitoring. This would be similar to the emergency ‘panic’ buttons prevalent on campus walkways in the United States or fire alarm triggers.

Crowd Management Devices

Crowd management devices (CMDs) are those that are intended to change the behavior of a crowd in an incident to promote safety and good order. Crowd management devices can help direct pedestrians away from an active shooter, terrorist attack, or other hazardous event and efficiently direct them toward the nearest emergency exit, which may not otherwise be well known or labeled for outdoor events. Crowd management devices can also be used in conjunction with the CMS to redirect evacuating pedestrians to less congested exits or pathways, thus minimizing the risk of trampling or crushing by actively monitoring pedestrian density and managing pedestrian traffic.

Design

Crowd management devices are physical signs of a novel design that may be rapidly deployable or tailored to more fixed venues. The signs may or may not have an auditory component based on their intended venue and employment, which may be integrated into the venue public address system. The signs should be unassuming during normal operations, and very obvious and directive in the event of an incident. There are two primary designs that serve the same function. An inflatable sign in the shape of a column and arrow (see figure 1) and a collapsible mast and placard style sign for events in which the inflatable signs are impracticable.

Style 1: Inflatable Crowd Management Device

The approximate dimensions for this style will be a two-foot diameter cylinder with an opening for the actual inflatable sign connection. The base will also encompass a blower apparatus or compressed air to rapidly inflate the sign. The base will house a turntable style electric or hydraulic motor for the purpose of changing the sign's orientation to direct pedestrians away from an incident and toward an exit. The base will have a GPS receiver powered by a solar panel or shore power to communicate precise location and orientation to the processing center. See *Figure 2* for a concept drawing of the inflatable CMD.

Shape

The sign will have a large inflatable arrow oriented in the intended direction of crowd movement. Intended height at full deployment will be between 10-15 feet. The arrow will require material on both sides of the main inflation tube to offset the weight and add balance to the system.

Marking

Standard marking with "Evacuate" or another directive term will be on the arrow portion of the inflatable. The marking will not possess the ability to be changed real-time, so if the exit is untenable, the arrow will orient toward a safe exit location. The marking will be made of reflective material for easier sight during low light conditions.

Lighting

LED lighting will line the inner chamber of the turning motor to illuminate the inflatable column in white, making it obvious in an incident, especially during nighttime conditions. A strobe light will be added to the end of the arrow to help draw attention during daylight hours.

Power

The rapidly deployable CMD will power the GPS receiver and networking components via mounted solar panels on top of the device. Excess power will trickle charge a battery. The battery will be designed to operate the blower motor, the turn-table motor, the lighting, and auxiliary systems, such as a loudspeaker for a short duration commensurate with evacuation or approximately 15-30 minutes. The system will have an external plug that is capable of powering the entire system, as well as a battery charger component to convert the AC power to DC power for charging the battery.

<u>Auxiliary systems</u>

Auxiliary systems may be added to match the needs of the venue or security team. They will include a loudspeaker with pre-recorded messages upon deployment and may include additional sensors or capabilities.

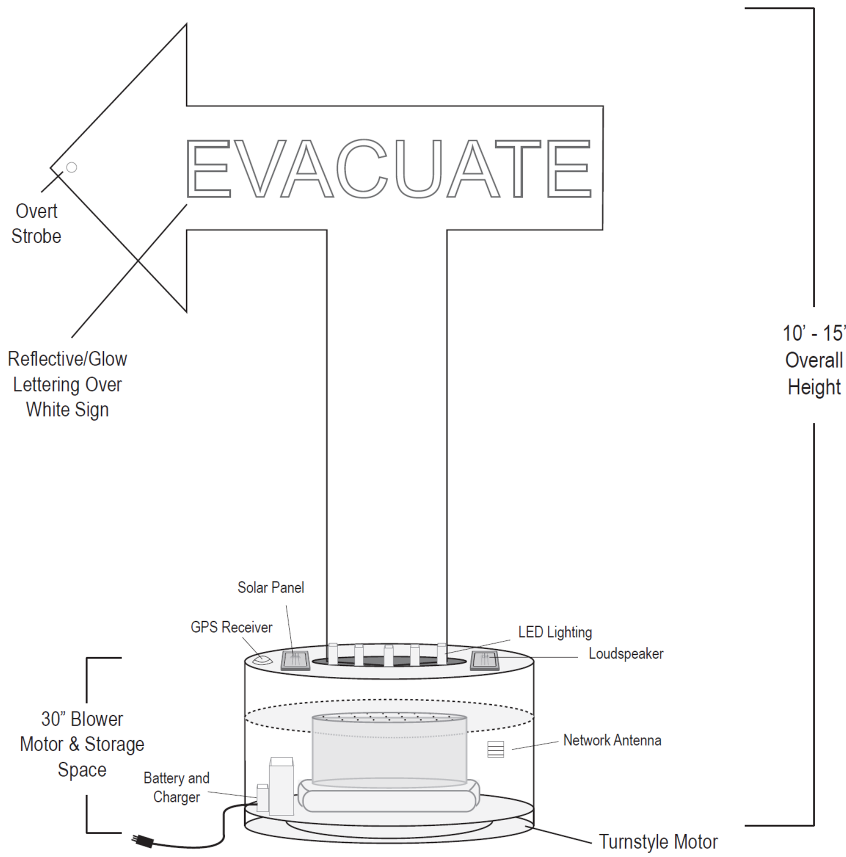

Figure 2 - Inflatable Crowd Management Device

<u>Style 2: Mast and Placard Crowd Management Device</u>

The approximate dimensions for this style will be 96 inches at full extension. The base will house a turntable style electric or hydraulic motor to change the sign's orientation to direct pedestrians away from an incident and toward an exit. The base will have a GPS receiver and magnetic direction sensor powered by a solar panel or shore power to communicate precise location and orientation to the processing center. See *Figure 3* for a concept drawing of the mast type CMD.

<u>Shape</u>

The mast will have a base that is approximately 12 inches in diameter and 48 inches in height. It will be extendable to approximately 96 inches of total height, with two incremental extensions of 24 inches. The end of the mast will have a rectangular arrow sign attached, which extends perpendicular when the mast reaches its fully extended position.

Marking

Standard marking with "Evacuate" or another directive term will be on the rectangular arrow sign. The marking will not possess the ability to be changed real-time, so if the exit is untenable, the mast base will orient the arrow toward a safe exit location.

Lighting

Only the rectangular arrow will be lit; the mast will be unlit. The sign will be illuminated green if the exit is permissible/safe or red if the exit is dangerous, with the light color controlled by the processing center. The ability will exist to adjust illumination color via the CMS. A small strobe light will also be affixed to the end of the arrow to draw attention during daylight hours.

Power

The fixed CMD will not require solar panels or batteries to operate and will be integrated into the facility power grid.

Auxiliary systems

Auxiliary systems may be added to match the needs of the venue or security team. They will include a loudspeaker with pre-recorded messages upon deployment and may include additional sensors or capabilities.

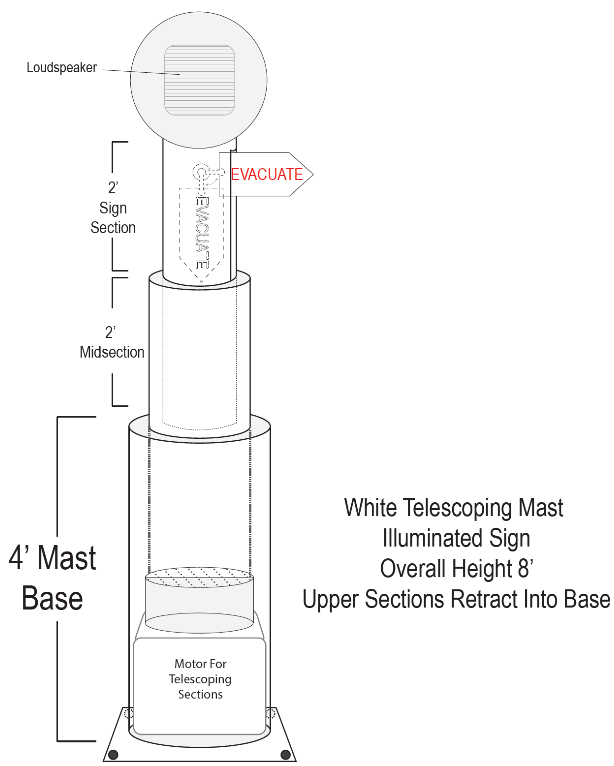

Figure 3 - Telescoping Crowd Management Device for Permanent Outdoor Venues

Conclusion

Previous simulations have shown that utilizing multiple exits in the event of an incident for a HDOE result in faster evacuation times, and reduced emergency response time. A modular Crowd Management System (CMS) is proposed to monitor for hazardous situations in real time, as well as actively direct pedestrians away from danger, and toward exits. Crowd Management Devices (CMD) are the means in which the system interacts with pedestrians and consist of networked smart signs of an unassuming nature, that inflate or extend and rotate to highlight the best route away from danger. Signs are lit and clearly marked as to be easily understood at a glance and can be rotated in real-time to match the current state of the incident. A sensor network provides a computer-generated model of the HDOE and feeds information to a processing center that communicates with the CMDs.

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Points of Contact

For any points of clarification, please feel free to contact the individuals below:

Travis Cline, M.S.
Graduate Student, Technology
Cell: 512-577-7733
Email: cline40@purdue.edu

Braiden Frantz, M.S.
Graduate Student, Technology
Cell: 928-580-7784
Email: bfrantz@purdue.edu

Krassimir Tzvetanov, M.S.
Graduate Student, Technology
Cell: 650-733-6555
Email: ktzvetan@purdue.edu

J. Eric Dietz, PhD, PE
Professor, Computer & Information Technology
Cell: 765-337-7770
Email: jedietz@purdue.edu

APPENDIX C. POLICE DEPLOYMENT FROM SUBSTATION DATA

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
1	188.92	12	1	158.51	17	1	156.29	12
1	198.33	20	1	197.03	13	1	172.77	21
1	167.89	12	1	600.00	170	1	174.33	16
1	143.83	11	1	149.83	11	1	172.58	15
1	217.45	13	1	152.50	15	1	600.00	180
1	157.53	20	1	222.19	12	1	187.79	14
1	175.55	5	1	141.58	16	1	166.60	13
1	191.47	12	1	186.05	17	1	205.30	14
1	166.33	14	1	239.73	19	1	152.30	14
1	600.00	184	1	183.21	12	1	151.98	11

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
1	152.70	14	1	141.89	10	1	201.50	13
1	600.00	151	1	162.89	11	1	159.66	19
1	180.82	14	1	161.23	14	1	178.45	18
1	164.90	13	1	192.33	18	1	600.00	165
1	184.90	13	1	156.89	14	1	227.78	15
1	214.55	11	1	182.08	8	1	190.37	15
1	600.00	185	1	160.60	13	1	165.32	18
1	215.09	15	1	149.08	11	1	160.03	15
1	170.97	14	1	142.99	22	1	184.66	16
1	237.91	14	1	600.00	179	1	160.46	13

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
1	156.62	10	1	140.56	10	1	173.30	11
1	164.05	14	1	200.62	12	1	190.90	14
1	160.47	15	1	159.48	15	1	159.81	16
1	223.34	15	1	152.52	13	1	147.39	14
1	155.61	15	1	174.81	14	1	215.53	13
1	168.36	11	1	164.13	11	1	227.76	14
1	173.34	20	1	220.45	11	1	192.68	14
1	200.66	12	1	166.44	9	1	181.60	17
1	154.16	13	1	193.68	14	1	161.16	10
1	143.08	12	1	169.67	18	1	162.64	14

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
1	137.86	11	2	138.66	16	2	156.29	8
1	185.51	16	2	187.29	14	2	174.62	16
1	175.05	19	2	184.41	16	2	205.55	18
1	169.24	13	2	168.04	8	2	195.77	15
1	600.00	181	2	171.13	13	2	143.09	7
1	170.32	9	2	173.44	10	2	139.94	11
1	600.00	168	2	180.55	11	2	183.15	12
1	194.63	11	2	153.97	12	2	171.51	11

1	207.93	13	2	152.10	13	2	171.51	11
1	155.65	15	2	150.56	12	2	183.62	9
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
2	248.06	14	2	193.17	11	2	141.63	12
2	225.88	12	2	160.33	20	2	181.92	13
2	142.75	12	2	221.40	8	2	139.41	11
2	162.99	11	2	186.40	10	2	157.69	8
2	143.58	14	2	155.88	11	2	175.37	16
2	181.34	17	2	187.92	12	2	139.89	14
2	166.13	12	2	160.05	13	2	174.34	11
2	190.14	10	2	175.43	14	2	163.03	14
2	180.92	14	2	210.78	13	2	137.19	11
2	133.71	14	2	159.29	10	2	149.48	12
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
2	163.33	11	2	138.54	13	2	183.27	11
2	139.96	17	2	182.62	5	2	152.24	16
2	176.22	19	2	157.40	12	2	157.81	12
2	196.25	17	2	203.59	20	2	163.37	10
2	166.20	6	2	178.93	12	2	174.69	10
2	174.99	13	2	182.81	13	2	187.59	12
2	190.12	13	2	166.83	13	2	191.12	11
2	177.55	15	2	141.67	14	2	170.89	15
2	223.75	13	2	210.52	7	2	252.74	15
2	164.28	12	2	139.25	15	2	165.23	14
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
2	215.93	17	2	175.06	8	3	163.75	12
2	159.45	18	2	163.13	18	3	168.13	13
2	186.00	13	2	237.75	8	3	198.16	12
2	195.47	14	2	158.83	16	3	179.44	9
2	166.26	8	2	169.56	10	3	256.09	14
2	152.24	5	2	260.26	17	3	162.36	12
2	153.14	11	2	170.87	15	3	143.77	13
2	180.29	16	2	141.03	16	3	132.78	9
2	140.85	14	2	216.41	11	3	183.19	11
2	225.05	13	2	221.26	12	3	169.67	13
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
3	175.61	5	3	146.80	12	3	143.11	8
3	154.91	9	3	133.29	14	3	192.85	14
3	212.16	10	3	223.49	11	3	195.01	17
3	190.83	11	3	180.60	16	3	192.01	11
3	156.95	13	3	176.64	15	3	151.73	10
3	146.41	11	3	169.04	13	3	205.64	10
3	175.82	14	3	141.49	8	3	216.06	16
3	176.47	9	3	163.05	8	3	149.36	9
3	207.17	12	3	220.33	12	3	171.57	13
3	204.79	8	3	171.64	13	3	172.03	10

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
3	162.23	8	3	181.08	10	3	163.43	14
3	134.80	8	3	138.82	8	3	202.21	13
3	164.38	16	3	178.52	16	3	141.86	10
3	140.00	12	3	147.97	14	3	149.31	14
3	139.51	12	3	194.30	9	3	192.28	14
3	171.16	9	3	203.87	12	3	151.37	13
3	195.55	9	3	179.72	16	3	129.64	15
3	148.69	11	3	213.04	16	3	145.66	14
3	237.32	17	3	143.07	14	3	160.79	11
3	210.46	13	3	211.86	8	3	155.34	18
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
3	141.87	13	3	195.27	12	3	172.14	8
3	161.79	14	3	170.72	10	3	160.37	15
3	190.02	12	3	165.34	9	3	161.59	11
3	158.54	11	3	185.32	13	3	158.97	12
3	163.24	9	3	138.57	14	3	175.38	8
3	228.72	13	3	149.80	13	3	219.07	8
3	157.12	16	3	155.07	7	3	179.08	10
3	214.00	14	3	136.52	12	3	154.77	14
3	196.29	12	3	153.97	12	3	162.70	14
3	182.75	14	3	166.24	11	3	161.10	19
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
4	204.64	15	4	133.31	13	4	201.22	13
4	188.64	13	4	135.11	11	4	152.00	13
4	198.65	13	4	184.78	9	4	154.73	10
4	181.62	13	4	157.26	13	4	241.90	13
4	135.67	11	4	158.25	9	4	204.32	11
4	167.48	11	4	177.72	13	4	158.13	14
4	169.19	9	4	172.97	12	4	210.18	12
4	219.06	16	4	137.47	10	4	168.50	15
4	146.47	15	4	231.39	11	4	177.22	10
4	174.51	10	4	171.99	16	4	134.80	11
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
4	206.30	14	4	164.31	14	4	164.33	14
4	150.02	12	4	159.10	12	4	148.96	9
4	162.72	11	4	199.94	10	4	189.40	10
4	148.60	11	4	214.67	13	4	151.20	9
4	187.98	9	4	160.80	7	4	158.65	12
4	157.45	9	4	166.49	16	4	149.21	8
4	199.18	10	4	148.60	14	4	186.96	9
4	155.59	14	4	181.76	11	4	159.44	10
4	145.31	13	4	144.83	16	4	186.32	12
4	196.86	13	4	165.66	13	4	226.53	10

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
4	171.32	9	4	175.44	12	4	154.52	10
4	140.68	11	4	217.82	13	4	144.53	15
4	197.71	8	4	221.03	10	4	187.52	8
4	173.30	12	4	182.60	15	4	161.86	9
4	141.55	11	4	158.02	12	4	161.80	8
4	221.54	14	4	177.08	10	4	207.26	17
4	134.37	5	4	237.85	13	4	199.65	9
4	153.96	14	4	153.27	16	4	159.95	13
4	191.22	13	4	146.90	15	4	170.29	11
4	175.27	16	4	148.15	11	4	161.80	15
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
4	200.82	14	5	170.33	12	5	174.73	13
4	179.63	11	5	170.71	13	5	170.05	15
4	171.99	17	5	165.20	15	5	142.62	11
4	158.49	14	5	208.39	14	5	147.62	9
4	155.44	13	5	168.43	13	5	171.03	9
4	171.55	11	5	178.96	17	5	251.43	9
4	168.33	11	5	182.57	8	5	221.58	11
4	176.63	11	5	153.00	11	5	212.00	10
4	157.54	6	5	156.97	15	5	204.80	9
4	160.08	12	5	210.30	11	5	154.02	10
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
5	182.88	12	5	153.84	9	5	162.94	9
5	176.22	10	5	173.67	15	5	187.55	9
5	154.21	14	5	204.58	12	5	223.74	10
5	157.48	9	5	179.61	14	5	197.08	10
5	207.61	14	5	166.77	8	5	182.90	14
5	193.11	11	5	187.24	18	5	154.67	14
5	176.77	15	5	206.02	11	5	148.68	14
5	217.36	9	5	144.13	9	5	169.13	15
5	168.83	11	5	168.45	15	5	161.46	14
5	156.95	10	5	193.69	12	5	174.31	11
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
5	143.98	9	5	155.87	13	5	156.81	15
5	160.58	15	5	173.76	11	5	158.10	10
5	176.71	7	5	213.47	10	5	231.42	12
5	186.47	10	5	156.80	12	5	138.05	11
5	172.33	12	5	154.56	14	5	172.73	12
5	159.96	8	5	168.67	6	5	168.79	13
5	151.06	11	5	127.87	14	5	148.24	11
5	146.39	10	5	136.99	12	5	165.65	8
5	173.72	8	5	208.09	7	5	184.10	10
5	164.05	10	5	185.16	10	5	196.98	13

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
5	147.71	11	5	149.61	11	6	182.68	14
5	139.88	14	5	175.32	16	6	166.02	13
5	163.91	13	5	175.78	9	6	158.43	10
5	170.22	13	5	147.62	10	6	133.53	11
5	182.29	15	5	160.23	14	6	188.83	15
5	194.92	12	5	153.98	10	6	156.84	12
5	131.75	16	5	150.15	14	6	170.65	5
5	150.89	11	5	132.61	11	6	200.55	11
5	154.03	12	5	192.73	12	6	147.65	13
5	184.89	13	5	160.80	11	6	139.41	12

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
6	137.27	5	6	162.09	9	6	156.71	10
6	243.38	13	6	139.04	11	6	156.25	14
6	144.76	12	6	146.88	13	6	193.55	9
6	135.46	12	6	157.30	9	6	173.13	11
6	175.24	8	6	166.51	13	6	149.13	14
6	130.34	12	6	197.86	9	6	197.99	13
6	166.94	7	6	145.17	12	6	194.76	12
6	139.32	13	6	158.17	10	6	143.46	11
6	176.02	9	6	186.67	10	6	152.92	12
6	144.23	12	6	162.09	9	6	153.78	10

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
6	159.67	12	6	150.31	17	6	188.69	15
6	181.19	8	6	225.27	10	6	213.99	12
6	159.67	10	6	194.43	13	6	172.76	13
6	173.17	13	6	146.70	10	6	164.13	9
6	185.87	11	6	163.89	13	6	156.51	15
6	202.58	13	6	166.17	13	6	148.76	12
6	197.36	11	6	159.63	12	6	151.40	9
6	198.37	14	6	140.78	12	6	142.10	14
6	185.25	10	6	141.15	12	6	150.61	6
6	183.02	11	6	160.57	9	6	182.16	12

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
6	206.38	12	6	148.71	10	6	142.97	15
6	193.36	10	6	141.25	13	6	183.70	14
6	162.28	16	6	161.91	13	6	187.43	11
6	255.32	10	6	183.99	13	6	172.42	12
6	203.69	8	6	153.36	13	6	143.47	15
6	173.81	12	6	167.55	9	6	166.25	11
6	158.33	12	6	193.38	12	6	155.87	13
6	158.96	13	6	165.50	11	6	159.15	11
6	219.06	9	6	168.03	11	6	139.80	11
6	194.83	5	6	196.43	13	6	157.93	13

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
7	161.73	15	7	168.72	11	7	175.78	6
7	206.45	13	7	171.16	9	7	193.66	10
7	148.66	10	7	167.55	9	7	140.60	15
7	167.07	13	7	212.13	9	7	154.78	11
7	157.50	13	7	197.23	10	7	155.78	13
7	158.62	11	7	196.39	8	7	215.43	13
7	189.14	11	7	192.70	9	7	151.64	7
7	222.57	9	7	175.92	9	7	146.24	9
7	202.72	13	7	181.59	13	7	162.67	13
7	159.81	16	7	170.96	8	7	156.32	16
7	161.73	15	7	168.72	11	7	175.78	6

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
7	156.91	9	7	180.86	10	7	175.67	8
7	176.88	13	7	183.63	12	7	178.44	11
7	132.93	11	7	199.18	15	7	167.01	12
7	180.97	16	7	173.02	10	7	166.73	13
7	162.47	12	7	151.04	10	7	140.19	9
7	180.50	8	7	149.77	6	7	132.85	10
7	193.26	11	7	207.12	8	7	179.99	11
7	200.20	13	7	159.52	13	7	177.87	12
7	150.91	11	7	154.27	12	7	163.92	12
7	157.83	15	7	160.77	11	7	145.15	7

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
7	187.23	9	7	174.03	3	7	157.92	14
7	167.77	9	7	140.20	11	7	138.54	11
7	148.11	10	7	163.68	9	7	144.66	15
7	192.13	3	7	165.71	9	7	182.56	12
7	136.88	11	7	196.08	7	7	246.16	11
7	145.75	14	7	140.54	15	7	152.58	14
7	170.53	14	7	177.53	8	7	199.27	11
7	166.71	11	7	155.22	9	7	130.68	9
7	173.79	14	7	176.69	11	7	158.10	11
7	188.38	9	7	157.81	9	7	145.02	8

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
7	165.94	8	8	131.97	11	8	207.60	10
7	149.22	14	8	189.94	6	8	152.47	9
7	160.75	13	8	152.76	15	8	173.73	15
7	240.95	5	8	193.75	8	8	202.95	11
7	167.34	11	8	184.39	8	8	180.51	6
7	182.90	8	8	150.55	17	8	167.92	13
7	215.04	5	8	165.28	11	8	219.39	7
7	163.50	16	8	171.61	16	8	185.58	14
7	160.51	11	8	157.28	9	8	199.83	15
7	142.62	11	8	162.47	14	8	159.80	12

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
8	194.14	14	8	154.36	10	8	175.87	13
8	182.00	13	8	151.38	13	8	180.43	11
8	164.15	9	8	162.76	14	8	152.00	11
8	162.92	13	8	169.92	11	8	142.59	10
8	160.30	12	8	187.09	7	8	169.88	16
8	140.41	10	8	158.37	14	8	143.36	13
8	196.26	12	8	149.92	14	8	145.44	14
8	169.04	10	8	175.45	9	8	163.64	7
8	169.73	11	8	178.86	11	8	142.83	13
8	180.13	15	8	167.90	11	8	162.64	12

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
8	149.11	12	8	179.68	14	8	138.60	9
8	178.97	9	8	157.12	15	8	155.49	11
8	204.24	14	8	134.58	12	8	177.85	12
8	223.90	11	8	165.41	10	8	165.63	13
8	183.04	12	8	139.56	11	8	208.79	6
8	228.21	11	8	191.83	12	8	168.09	12
8	171.67	11	8	178.21	8	8	159.86	14
8	176.16	11	8	192.77	9	8	146.09	13
8	121.55	6	8	151.21	13	8	142.13	10
8	162.50	6	8	170.68	11	8	162.58	10

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
8	147.87	10	8	242.38	10	9	141.06	11
8	139.81	12	8	180.18	11	9	143.45	15
8	148.47	15	8	193.25	9	9	188.46	5
8	166.07	12	8	156.69	11	9	169.47	11
8	147.69	14	8	163.65	10	9	171.09	7
8	176.87	12	8	162.62	14	9	166.75	14
8	151.44	14	8	190.06	12	9	162.73	13
8	164.39	13	8	230.94	8	9	213.98	13
8	133.61	10	8	149.67	11	9	172.70	12
8	197.15	12	8	152.81	11	9	183.81	10

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
9	211.99	10	9	153.09	9	9	174.22	10
9	159.21	13	9	154.84	12	9	154.85	15
9	147.83	15	9	188.58	9	9	153.41	4
9	155.09	14	9	149.90	14	9	176.04	7
9	150.66	10	9	159.46	14	9	182.60	11
9	136.94	12	9	184.18	8	9	165.40	10
9	155.76	16	9	165.47	12	9	177.59	13
9	164.25	13	9	173.41	17	9	200.02	12
9	192.87	7	9	137.65	9	9	166.54	8
9	183.39	10	9	165.98	9	9	158.37	10

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
9	153.65	9	9	178.44	9	9	140.87	14
9	235.64	6	9	165.49	11	9	162.89	12
9	165.54	10	9	153.57	14	9	140.94	10
9	164.55	7	9	164.35	7	9	130.14	9
9	180.18	7	9	188.37	14	9	172.03	13
9	194.56	10	9	179.19	11	9	171.41	13
9	164.08	9	9	168.83	16	9	147.62	12
9	179.29	9	9	172.07	15	9	209.62	8
9	165.20	12	9	195.62	9	9	195.14	9
9	187.12	7	9	133.07	11	9	169.06	9
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
9	148.13	11	9	214.60	10	9	197.60	9
9	170.35	11	9	160.77	13	9	200.55	11
9	195.63	12	9	156.73	12	9	176.58	11
9	143.07	10	9	137.77	15	9	168.32	9
9	206.45	9	9	218.05	11	9	143.26	11
9	171.99	13	9	148.35	12	9	144.17	12
9	171.74	9	9	133.56	12	9	151.38	13
9	159.12	13	9	187.12	8	9	159.33	11
9	168.66	11	9	144.29	7	9	129.10	14
9	165.87	10	9	158.25	14	9	176.80	15
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
10	208.30	8	10	144.88	12	10	160.97	13
10	162.36	11	10	180.91	8	10	206.71	9
10	168.70	12	10	146.82	8	10	170.71	15
10	170.57	9	10	179.66	7	10	170.01	9
10	136.70	15	10	191.99	13	10	177.53	11
10	223.40	10	10	137.51	7	10	149.95	16
10	213.98	8	10	166.83	13	10	158.65	12
10	146.10	15	10	154.94	10	10	150.88	12
10	204.61	13	10	140.11	11	10	153.20	10
10	137.85	7	10	169.29	13	10	130.10	9
Police Count	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**	**Police Count**	**Model Time**	**Average Casualties**
10	142.20	8	10	147.11	11	10	179.60	10
10	167.77	13	10	188.53	10	10	175.26	10
10	180.60	13	10	193.42	9	10	162.92	10
10	161.62	13	10	187.52	10	10	162.42	13
10	167.87	11	10	161.98	13	10	154.50	14
10	177.81	9	10	166.46	12	10	184.36	10
10	149.38	9	10	169.73	12	10	127.37	14
10	204.90	10	10	193.09	9	10	148.61	10
10	177.41	9	10	149.25	12	10	153.86	10
10	159.86	13	10	158.02	9	10	159.48	13

Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties	Police Count	Model Time	Average Casualties
10	174.07	10	10	176.42	6	10	179.84	7
10	338.11	14	10	162.71	11	10	175.12	13
10	160.41	10	10	147.24	12	10	179.49	10
10	138.99	11	10	162.21	10	10	229.99	12
10	163.82	14	10	177.70	10	10	143.57	16
10	162.38	12	10	171.30	7	10	142.67	11
10	167.24	12	10	195.75	10	10	183.67	11
10	207.45	9	10	156.86	9	10	170.71	12
10	144.59	11	10	147.21	10	10	213.27	10
10	176.82	9	10	154.79	9	10	158.48	8

Police Count	Model Time	Average Casualties	Police Count
10	165.86	14	10
10	167.18	13	10
10	140.22	13	10
10	183.20	13	10
10	189.82	7	10
10	150.07	10	10
10	144.28	13	10
10	162.24	13	10
10	165.39	6	10
10	168.26	12	10

APPENDIX D. POLICE PATROLLING DATA

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
0	600.00	174	307	0	600.00	186	302
0	600.00	165	299	0	600.00	201	314
0	600.00	185	313	0	600.00	187	311
0	600.00	196	320	0	600.00	181	307
0	600.00	202	332	0	600.00	223	348
0	600.00	180	306	0	600.00	177	309
0	600.00	188	320	0	600.00	178	313
0	600.00	198	318	0	600.00	180	312
0	600.00	178	305	0	600.00	185	303
0	600.00	183	316	0	600.00	177	314

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
0	600.00	195	324	0	600.00	168	307
0	600.00	176	296	0	600.00	174	298
0	600.00	195	318	0	600.00	180	289
0	600.00	158	297	0	600.00	167	289
0	600.00	157	286	0	600.00	216	352
0	600.00	202	348	0	600.00	174	302
0	600.00	195	319	0	600.00	195	347
0	600.00	176	317	0	600.00	199	300
0	600.00	183	300	0	600.00	184	313
0	600.00	226	366	0	600.00	174	311

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
0	600.00	181	306	0	600.00	186	301
0	600.00	171	298	0	600.00	176	305
0	600.00	177	304	0	600.00	173	290
0	600.00	184	311	0	600.00	186	303
0	600.00	181	310	0	600.00	169	278
0	600.00	171	298	0	600.00	177	323
0	600.00	191	308	0	600.00	187	303
0	600.00	185	317	0	600.00	190	298
0	600.00	184	312	0	600.00	166	296
0	600.00	185	308	0	600.00	194	313

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
0	600.00	179	301	0	600.00	191	300
0	600.00	181	301	0	600.00	177	305
0	600.00	196	306	0	600.00	194	323
0	600.00	213	318	0	600.00	176	315
0	600.00	180	304	0	600.00	154	277
0	600.00	197	311	0	600.00	179	314
0	600.00	214	343	0	600.00	216	346
0	600.00	189	314	0	600.00	188	309

0	600.00	185	297	0	600.00	185	293
0	600.00	190	299	0	600.00	181	293

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
0	600.00	164	317	0	600.00	181	311
0	600.00	183	296	0	600.00	183	300
0	600.00	195	317	0	600.00	194	293
0	600.00	187	326	0	600.00	169	286
0	600.00	182	315	0	600.00	196	294
0	600.00	189	306	0	600.00	183	295
0	600.00	181	302	0	600.00	179	317
0	600.00	176	284	0	600.00	181	331
0	600.00	189	310	0	600.00	197	318
0	600.00	188	305	0	600.00	167	289

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
1	158.47	0	0	1	190.09	13	27
1	168.32	29	46	1	600.00	194	301
1	187.83	12	29	1	152.93	17	29
1	187.68	19	30	1	184.20	28	44
1	233.62	19	29	1	187.91	17	34
1	205.09	21	36	1	159.67	16	48
1	182.42	32	55	1	192.53	24	47
1	163.50	10	25	1	189.81	31	45
1	157.63	14	30	1	205.65	14	23
1	196.61	18	30	1	149.73	13	27

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
1	186.43	4	4	1	186.02	20	35
1	204.52	27	45	1	125.47	0	0
1	206.38	28	38	1	171.88	19	29
1	600.00	196	318	1	198.82	27	55
1	194.01	34	54	1	175.74	24	38
1	600.00	193	298	1	230.58	33	61
1	169.26	21	40	1	148.07	0	0
1	138.90	19	26	1	153.37	6	14
1	211.72	25	46	1	232.74	23	42
1	219.78	19	30	1	206.16	33	51

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
1	250.46	33	51	1	223.15	33	51
1	196.75	23	36	1	211.56	26	38
1	221.42	33	59	1	213.85	15	39
1	221.58	16	36	1	139.66	2	1
1	154.47	2	13	1	182.91	15	21
1	129.53	8	8	1	187.16	23	36
1	133.35	10	12	1	163.04	1	0
1	228.42	21	47	1	184.27	23	44
1	166.90	21	38	1	188.84	11	18
1	181.24	22	35	1	160.90	13	17

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
1	218.91	28	47	1	600.00	185	311
1	224.10	26	41	1	125.34	1	0
1	125.72	1	1	1	153.54	12	21
1	167.16	10	11	1	600.00	185	328
1	166.15	18	31	1	125.08	0	-3
1	197.95	26	39	1	162.49	17	27
1	600.00	169	302	1	154.07	5	11
1	270.47	30	43	1	193.62	22	32
1	132.06	0	-3	1	133.47	0	3
1	600.00	225	363	1	195.69	25	45

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
1	199.51	17	28	1	155.06	13	15
1	254.30	29	58	1	153.61	13	25
1	203.49	27	42	1	147.53	16	39
1	248.25	23	54	1	145.69	4	7
1	173.11	28	42	1	135.63	0	0
1	158.45	2	1	1	229.26	26	48
1	186.68	23	40	1	202.47	31	46
1	163.10	12	26	1	196.98	26	50
1	183.27	4	5	1	204.85	5	4
1	201.09	26	42	1	178.97	20	36

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
2	160.28	14	20	2	201.23	14	21
2	141.02	1	0	2	160.24	7	6
2	152.60	11	14	2	170.34	14	37
2	164.31	15	26	2	233.49	19	31
2	130.28	7	13	2	265.69	30	49
2	160.63	13	24	2	139.38	14	24
2	195.78	27	38	2	188.73	19	38
2	253.96	14	20	2	193.30	0	0
2	163.48	15	21	2	137.59	4	5
2	173.68	18	40	2	188.54	20	41

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
2	190.26	0	-3	2	147.08	12	19
2	150.48	4	5	2	180.13	1	0
2	169.82	19	32	2	147.65	0	3
2	189.81	20	29	2	179.31	19	35
2	126.70	0	-3	2	160.86	0	-3
2	198.63	18	33	2	238.08	31	45
2	172.18	1	0	2	166.00	27	41
2	154.40	5	10	2	215.68	16	29
2	154.83	9	18	2	177.26	7	12
2	142.59	8	15	2	223.95	21	38

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged

2	203.21	22	40	2	181.81	15	26
2	177.81	18	37	2	158.13	6	7
2	176.14	5	7	2	168.77	5	8
2	193.41	29	46	2	147.06	0	-3
2	160.84	0	-3	2	223.96	10	18
2	190.04	26	38	2	136.69	6	12
2	250.52	25	43	2	135.99	3	6
2	188.78	18	27	2	137.43	1	0
2	138.38	1	1	2	240.11	28	41
2	155.50	0	0	2	152.76	0	6

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
2	178.88	23	41	2	156.83	9	25
2	234.45	15	21	2	152.36	9	23
2	145.33	1	1	2	225.11	30	54
2	235.25	2	4	2	194.76	23	41
2	167.95	1	0	2	126.10	0	-3
2	154.25	14	19	2	177.14	26	36
2	174.94	8	10	2	184.04	22	42
2	181.93	12	24	2	129.89	2	2
2	189.56	26	40	2	137.64	5	13
2	148.50	15	28	2	198.87	26	40

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
2	189.28	18	37	2	181.32	12	27
2	122.15	3	6	2	186.14	18	27
2	148.23	1	0	2	224.12	28	36
2	165.21	3	11	2	186.15	26	41
2	162.24	12	24	2	167.05	10	28
2	262.91	36	55	2	224.00	9	15
2	164.04	6	7	2	123.30	1	2
2	108.96	0	-3	2	160.89	7	8
2	214.08	21	33	2	227.43	28	47
2	179.24	8	11	2	162.50	0	-3

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
3	184.19	16	30	3	188.51	13	27
3	136.56	9	10	3	132.74	1	3
3	256.68	0	-3	3	211.52	18	31
3	172.71	14	23	3	141.80	2	3
3	170.12	21	30	3	148.18	1	0
3	190.64	16	24	3	183.73	18	31
3	166.31	10	23	3	176.78	20	32
3	154.86	0	-3	3	223.76	13	21
3	175.53	24	41	3	162.72	14	29
3	218.07	3	10	3	146.84	6	7

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
3	154.98	13	36	3	154.19	4	7
3	232.43	23	47	3	151.44	4	5

3	119.25	1	10	3	149.49	5	14
3	176.13	14	22	3	228.59	17	31
3	202.77	3	7	3	161.40	0	6
3	121.43	4	6	3	164.94	7	10
3	156.04	14	21	3	199.24	0	0
3	199.98	16	23	3	121.35	0	0
3	152.16	8	18	3	223.37	22	37
3	127.84	0	-3	3	139.27	11	25

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
3	175.43	13	19	3	196.71	15	25
3	201.35	15	25	3	175.24	11	20
3	138.45	0	-3	3	180.38	16	31
3	123.67	1	0	3	153.49	6	12
3	151.89	0	3	3	167.80	16	27
3	165.69	14	30	3	186.95	13	29
3	175.88	18	34	3	130.29	1	0
3	128.51	2	1	3	160.71	10	15
3	182.95	6	13	3	190.25	20	30
3	227.02	29	44	3	211.10	23	36

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
3	189.66	16	23	3	139.41	0	6
3	177.12	16	30	3	141.05	8	17
3	161.63	12	21	3	166.24	17	32
3	147.89	2	7	3	166.77	12	19
3	138.21	1	0	3	136.10	7	24
3	188.11	19	33	3	179.01	24	40
3	171.13	7	7	3	156.62	5	8
3	163.72	8	12	3	109.35	0	0
3	158.21	4	4	3	156.01	5	16
3	224.37	14	21	3	167.02	15	21

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
3	187.94	24	31	3	110.67	1	0
3	140.25	8	11	3	168.29	16	24
3	143.73	1	1	3	139.00	1	0
3	131.20	3	3	3	160.91	24	29
3	190.72	27	41	3	152.88	4	12
3	193.00	14	27	3	131.46	5	10
3	205.67	19	33	3	238.65	4	16
3	196.79	29	41	3	194.63	10	20
3	166.38	19	32	3	208.23	12	23
3	218.77	6	8	3	167.00	4	3

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
4	127.88	0	-3	4	145.72	0	-3
4	224.35	17	29	4	116.13	4	3
4	151.73	15	24	4	197.50	21	37
4	141.14	3	5	4	148.55	15	29

4	163.77	11	26	4	124.11	10	19
4	187.41	6	10	4	127.29	0	0
4	159.87	1	1	4	176.21	2	2
4	146.94	15	24	4	183.37	14	24
4	143.47	3	5	4	169.60	2	1
4	214.24	23	33	4	175.32	15	23
4	127.88	0	-3	4	145.72	0	-3
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
4	175.17	2	2	4	121.55	2	1
4	131.64	5	4	4	160.99	5	8
4	162.80	19	40	4	179.59	13	37
4	171.37	6	8	4	142.41	0	-3
4	165.24	4	4	4	168.16	0	0
4	231.70	17	30	4	193.03	16	33
4	161.23	16	28	4	127.91	4	7
4	123.18	9	10	4	193.25	0	-3
4	161.22	1	0	4	196.42	8	18
4	127.23	1	6	4	151.04	13	21
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
4	154.58	0	9	4	157.36	9	15
4	173.81	20	28	4	208.90	7	10
4	150.77	7	11	4	184.07	1	2
4	155.89	1	2	4	189.06	17	28
4	177.81	0	-3	4	149.90	0	0
4	138.50	2	1	4	130.56	2	5
4	124.57	2	1	4	132.48	0	0
4	185.16	24	34	4	204.33	12	25
4	122.17	2	6	4	146.74	1	3
4	159.10	3	5	4	149.09	13	28
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
4	108.04	0	0	4	158.91	0	0
4	185.73	18	25	4	129.57	0	-3
4	161.41	0	-3	4	176.69	0	-3
4	154.54	2	2	4	174.81	0	0
4	152.04	23	40	4	139.44	13	25
4	172.17	0	0	4	160.65	0	-3
4	139.84	2	1	4	164.62	0	0
4	135.65	4	11	4	150.21	11	12
4	181.14	7	12	4	149.58	7	12
4	175.42	26	39	4	141.36	2	10
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
4	226.20	19	27	4	140.55	12	25
4	204.30	20	40	4	190.46	16	38
4	212.54	13	27	4	168.98	0	-3
4	185.71	7	11	4	158.21	1	2
4	177.12	14	27	4	126.37	5	10

4	180.22	0	3	4	201.96	2	4
4	143.32	0	0	4	128.04	1	1
4	168.51	13	27	4	139.74	6	6
4	153.19	5	4	4	143.78	0	0
4	129.95	1	0	4	184.43	19	32

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
5	158.75	17	34	5	212.54	0	-3
5	184.43	17	30	5	146.40	5	14
5	160.21	4	5	5	110.05	2	1
5	138.64	3	2	5	140.95	1	0
5	192.89	15	22	5	129.30	10	11
5	139.44	9	13	5	167.90	0	6
5	141.86	1	0	5	140.67	8	12
5	134.77	0	0	5	181.05	24	37
5	161.53	0	0	5	137.50	1	3
5	221.50	20	33	5	135.00	1	3

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
5	143.04	4	5	5	125.34	0	-3
5	122.37	1	9	5	238.68	14	21
5	134.92	2	9	5	161.37	11	17
5	160.00	7	11	5	184.76	2	7
5	149.99	21	35	5	151.22	12	26
5	149.43	1	1	5	153.77	1	1
5	243.19	2	4	5	136.18	0	-3
5	136.74	3	2	5	111.86	1	0
5	183.84	27	37	5	171.51	10	22
5	168.71	15	29	5	204.39	3	3

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
5	202.84	16	37	5	245.15	8	16
5	153.13	1	0	5	126.92	2	2
5	159.86	18	27	5	253.81	16	23
5	110.63	1	0	5	181.87	19	31
5	137.96	1	1	5	149.58	2	1
5	135.73	4	8	5	173.74	18	22
5	160.69	11	23	5	181.90	11	21
5	183.99	13	22	5	154.98	6	9
5	131.36	0	-3	5	181.75	0	0
5	183.45	16	28	5	132.43	4	9

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
5	176.37	11	22	5	114.40	4	4
5	129.19	0	-3	5	179.44	14	26
5	134.37	1	3	5	155.28	1	1
5	228.48	1	0	5	128.97	3	9
5	172.10	1	0	5	171.44	1	0
5	156.70	5	7	5	165.46	14	25
5	160.80	7	8	5	119.43	1	1

5	152.83	5	8	5	140.38	0	0
5	167.11	2	11	5	130.31	15	20
5	176.23	4	8	5	154.28	1	1

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
5	139.05	11	20	5	175.60	0	-3
5	202.59	9	12	5	185.35	1	4
5	124.55	1	0	5	150.11	1	0
5	189.58	12	22	5	160.65	6	10
5	149.51	3	5	5	197.95	0	-3
5	144.20	1	0	5	189.63	7	8
5	177.19	12	30	5	185.34	11	20
5	143.04	4	9	5	137.05	5	5
5	154.09	0	-3	5	123.13	3	3
5	130.04	4	9	5	159.89	0	3

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
6	152.30	5	14	6	133.42	0	-3
6	125.86	5	7	6	174.58	7	13
6	220.05	1	0	6	136.23	3	2
6	138.37	1	4	6	228.71	15	19
6	162.77	19	24	6	195.41	19	38
6	160.21	3	3	6	200.12	5	19
6	175.09	2	2	6	225.11	1	0
6	123.43	1	0	6	139.94	7	14
6	124.24	0	-3	6	189.85	3	7
6	170.56	22	31	6	119.25	0	-3

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
6	132.66	1	0	6	171.53	1	4
6	143.25	0	0	6	172.64	14	32
6	194.17	1	0	6	121.29	0	-3
6	157.21	10	21	6	206.60	3	5
6	153.74	9	22	6	125.77	9	14
6	182.16	0	-3	6	192.63	2	4
6	175.25	4	4	6	123.84	4	6
6	182.57	9	11	6	174.33	3	5
6	151.78	7	16	6	159.49	9	16
6	129.96	0	0	6	160.25	1	3

Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
6	129.08	0	3	6	232.08	0	0
6	167.42	16	26	6	152.90	0	0
6	136.78	0	0	6	160.44	1	9
6	154.03	2	1	6	161.28	2	1
6	163.26	12	25	6	134.93	1	0
6	193.21	11	28	6	143.61	0	3
6	202.41	11	27	6	147.79	8	13
6	161.04	4	7	6	134.51	2	1
6	217.55	17	34	6	160.86	0	-3

6	150.66	0	0	6	123.69	1	5
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
6	160.30	3	5	6	182.71	3	3
6	161.51	0	0	6	138.36	2	2
6	139.28	2	4	6	155.35	3	3
6	118.62	1	0	6	173.48	17	21
6	124.31	1	0	6	162.03	18	23
6	182.82	3	2	6	134.59	0	-3
6	145.81	8	11	6	194.01	11	29
6	150.16	1	0	6	150.10	2	2
6	163.43	1	1	6	144.54	0	0
6	206.21	3	4	6	181.46	12	22
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
6	181.14	9	10	6	142.04	2	9
6	155.42	0	6	6	117.40	1	0
6	150.70	0	0	6	122.73	4	3
6	199.26	3	12	6	159.27	1	1
6	155.85	15	24	6	137.04	2	3
6	212.52	1	6	6	162.73	16	24
6	129.15	0	6	6	123.99	1	0
6	144.52	0	0	6	102.36	0	0
6	162.69	13	26	6	158.64	14	27
6	208.55	20	34	6	183.26	10	23
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
7	180.87	15	24	7	130.96	1	0
7	130.36	2	6	7	157.71	1	3
7	179.11	3	5	7	200.43	9	11
7	165.00	2	1	7	135.56	1	3
7	183.87	12	21	7	219.85	11	23
7	192.73	8	20	7	188.39	1	0
7	154.23	3	4	7	128.58	11	15
7	134.11	1	3	7	138.29	0	3
7	199.42	5	8	7	184.07	0	3
7	154.25	2	1	7	140.79	6	10
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
7	159.04	1	0	7	129.82	2	2
7	200.16	19	23	7	245.14	7	10
7	201.00	9	12	7	131.45	7	10
7	234.99	14	23	7	123.33	0	-3
7	191.21	4	7	7	134.65	1	0
7	223.06	12	28	7	169.25	11	30
7	163.41	14	17	7	185.42	6	9
7	179.41	12	26	7	156.82	6	9
7	116.09	1	0	7	134.43	7	10
7	139.20	6	10	7	182.52	0	12

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
7	221.12	12	40	7	167.02	13	23
7	202.01	0	0	7	137.28	5	10
7	153.55	9	12	7	143.65	2	1
7	192.76	4	6	7	147.61	0	-3
7	181.62	11	19	7	153.27	0	-3
7	137.14	2	3	7	118.04	3	7
7	134.53	3	7	7	195.23	12	27
7	142.61	0	-3	7	146.86	9	20
7	165.47	14	30	7	149.66	18	30
7	161.79	0	0	7	150.08	1	12
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
7	124.48	1	3	7	147.75	6	12
7	149.00	12	22	7	114.64	0	-3
7	145.69	2	1	7	162.30	7	13
7	149.70	5	8	7	186.53	3	2
7	152.55	5	12	7	141.44	0	-3
7	197.23	0	0	7	108.37	2	1
7	146.00	1	0	7	281.00	2	1
7	148.47	0	-3	7	216.20	0	-3
7	160.42	5	14	7	179.08	12	26
7	233.38	8	14	7	196.94	6	10
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
7	129.65	2	1	7	197.19	18	26
7	167.83	3	7	7	151.29	3	5
7	203.58	2	5	7	164.25	0	-3
7	142.32	1	2	7	128.13	0	-3
7	122.05	1	5	7	122.05	1	0
7	143.87	0	12	7	153.67	5	5
7	131.75	2	1	7	145.15	0	9
7	141.68	1	3	7	169.37	7	22
7	134.70	0	0	7	166.35	7	11
7	175.35	1	3	7	143.89	3	2
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
8	155.49	10	26	8	185.91	1	0
8	152.46	2	1	8	146.13	4	8
8	183.06	2	3	8	193.68	5	10
8	132.83	3	3	8	210.36	1	2
8	194.24	19	29	8	179.37	0	0
8	156.76	1	0	8	174.61	0	0
8	185.58	0	0	8	161.16	0	-3
8	151.23	7	9	8	121.22	0	-3
8	154.30	4	9	8	153.68	11	22
8	154.39	2	1	8	143.65	4	10

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
8	140.65	1	0	8	220.18	0	-3
8	159.05	2	4	8	138.94	2	2
8	129.65	1	0	8	123.37	1	0
8	154.04	3	9	8	161.29	6	7
8	164.06	14	27	8	183.33	3	6
8	123.75	5	10	8	126.99	1	3
8	133.74	1	0	8	148.18	0	0
8	183.03	5	12	8	168.80	9	15
8	155.64	2	2	8	157.10	5	8
8	118.66	1	3	8	146.43	0	-3
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
8	161.15	2	1	8	134.51	1	3
8	119.85	0	-3	8	209.70	7	15
8	129.48	0	-3	8	242.65	13	18
8	170.17	1	1	8	138.05	6	10
8	151.62	1	0	8	143.96	13	17
8	143.11	0	3	8	159.83	2	2
8	141.79	1	0	8	129.97	2	1
8	152.22	4	3	8	211.42	4	5
8	129.55	1	1	8	275.22	7	15
8	173.57	1	0	8	209.75	24	39
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
8	144.42	0	-3	8	128.99	0	-3
8	155.00	0	-3	8	166.89	0	-3
8	135.91	0	-3	8	154.57	20	30
8	184.82	2	2	8	153.36	1	0
8	163.37	12	21	8	132.49	1	0
8	112.62	0	-3	8	155.43	3	2
8	155.05	0	0	8	162.31	0	-3
8	164.08	0	0	8	145.10	1	1
8	152.73	0	-3	8	171.35	8	12
8	179.71	1	3	8	115.23	2	5
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
8	142.32	0	-3	8	173.76	0	-3
8	124.66	0	-3	8	177.62	10	29
8	140.39	2	7	8	187.91	2	5
8	140.45	1	8	8	122.51	1	3
8	141.89	2	1	8	125.17	0	-3
8	142.56	0	-3	8	151.84	12	24
8	130.27	2	2	8	160.63	1	3
8	159.80	2	2	8	164.56	0	9
8	160.85	1	3	8	172.64	1	4
8	166.29	0	-3	8	195.82	3	8

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
9	119.62	1	0	9	125.05	1	1
9	141.32	3	4	9	156.47	15	23
9	117.50	1	0	9	173.04	4	3
9	120.26	0	0	9	234.48	3	3
9	182.57	14	24	9	138.39	4	6
9	143.88	2	1	9	165.28	4	4
9	147.70	1	0	9	145.05	6	9
9	158.44	3	3	9	182.35	11	18
9	165.23	1	3	9	134.09	2	2
9	175.04	13	15	9	192.99	11	17

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
9	176.49	1	0	9	158.42	3	3
9	167.20	2	1	9	173.82	4	4
9	128.31	1	0	9	139.43	3	3
9	203.35	5	15	9	131.60	6	5
9	146.73	12	23	9	120.81	0	0
9	136.96	5	6	9	141.00	2	2
9	182.75	1	0	9	189.92	1	0
9	135.80	0	0	9	170.66	1	0
9	153.07	1	0	9	152.28	2	8
9	120.45	0	-3	9	208.72	3	2

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
9	210.27	10	14	9	151.80	12	22
9	189.83	1	1	9	183.62	6	34
9	175.88	9	15	9	126.59	0	-3
9	126.15	1	4	9	134.44	3	2
9	116.99	1	0	9	135.65	1	4
9	194.11	5	9	9	132.03	0	-3
9	154.60	6	5	9	145.88	0	-3
9	147.29	8	15	9	152.25	15	26
9	130.72	0	0	9	142.05	2	3
9	143.58	3	4	9	117.21	1	1

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
9	156.78	1	0	9	134.09	8	9
9	153.74	1	0	9	200.69	8	19
9	166.17	17	24	9	123.74	0	0
9	128.06	0	-3	9	134.73	0	0
9	115.37	1	0	9	212.76	1	1
9	157.67	3	3	9	125.52	0	-3
9	178.55	0	-3	9	114.94	3	3
9	154.84	0	-3	9	145.26	6	8
9	166.14	1	0	9	119.94	0	-3
9	132.17	0	0	9	155.50	10	12

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
9	157.00	1	0	9	160.28	0	3
9	127.10	0	3	9	132.76	1	3
9	179.76	4	7	9	123.95	3	4
9	120.92	7	12	9	152.05	0	-3
9	233.10	4	10	9	124.40	2	1
9	211.69	10	10	9	238.62	5	9
9	219.85	5	8	9	196.47	17	32
9	191.85	4	12	9	111.77	0	-3
9	137.43	1	0	9	149.44	0	0
9	152.69	0	-3	9	148.70	6	10
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
10	207.58	0	0	10	151.10	1	0
10	115.53	0	-3	10	140.50	2	1
10	152.15	1	0	10	211.01	1	0
10	147.39	2	5	10	178.62	2	1
10	180.72	1	3	10	201.74	5	22
10	131.93	0	0	10	127.33	1	0
10	144.98	2	2	10	168.21	2	5
10	199.96	9	11	10	201.92	2	5
10	138.57	2	4	10	136.37	2	12
10	156.16	5	9	10	131.07	1	3
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
10	136.29	3	3	10	126.56	3	4
10	167.99	0	6	10	125.09	0	-3
10	163.70	0	0	10	154.58	10	23
10	179.86	0	-3	10	140.65	1	0
10	129.52	0	-3	10	152.99	1	5
10	177.15	3	4	10	138.03	0	0
10	147.54	3	4	10	181.72	6	6
10	111.05	0	0	10	189.66	3	3
10	147.70	7	8	10	191.15	8	9
10	219.12	10	21	10	234.96	7	7
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
10	172.23	4	7	10	142.22	0	0
10	130.34	1	0	10	181.91	18	27
10	124.59	0	-3	10	151.54	3	7
10	184.05	0	3	10	170.94	5	11
10	131.92	3	2	10	133.59	0	-3
10	147.19	4	6	10	105.87	1	0
10	124.85	4	6	10	142.64	8	10
10	135.56	0	-3	10	135.90	5	8
10	113.01	0	-3	10	131.45	4	7
10	138.52	13	18	10	194.46	5	7

Police Count	Model Time	Average Casualties	Rounds Discharged	Police Count	Model Time	Average Casualties	Rounds Discharged
10	155.21	0	0	10	139.64	2	1
10	126.39	0	-3	10	128.90	0	0
10	120.27	0	0	10	187.61	0	0
10	165.81	9	11	10	130.39	1	2
10	150.17	2	6	10	181.19	2	3
10	150.97	0	-3	10	136.00	0	-3
10	140.28	1	5	10	146.57	0	-3
10	126.66	0	-3	10	185.76	1	0
10	142.15	11	19	10	145.83	1	2
10	158.99	0	0	10	179.29	9	23
Police Count	**Model Time**	**Average Casualties**	**Rounds Discharged**	**Police Count**	**Model Time**	**Average Casualties**	**Rounds Discharged**
10	171.15	1	11	10	138.57	4	3
10	132.15	13	21	10	228.08	3	10
10	164.66	1	1	10	148.86	2	6
10	139.47	13	18	10	144.48	1	2
10	137.56	2	2	10	165.34	1	0
10	153.69	0	-3	10	134.83	0	0
10	143.82	2	4	10	175.92	2	2
10	156.56	1	0	10	136.70	1	0
10	157.01	8	19	10	130.31	1	7
10	177.15	4	5	10	149.70	2	7
10	171.15	1	11	10	138.57	4	3

APPENDIX E. POLICE GATE TWO AND THREE DATA

Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties
0 Officers Gate 2			**1 Officer Gate 2**			**2 Officers Gate 2**		
0	600.00	187.43	0	552.03	168.67	0	529.16	160.61
1	344.80	85.64	1	327.39	80.56	1	342.96	87.40
2	297.21	67.60	2	289.62	63.22	2	282.33	58.62
3	268.74	55.01	3	256.14	50.62	3	262.10	52.25
4	253.30	47.80	4	249.06	47.28	4	257.47	48.14
5	247.42	46.73	5	250.77	47.76	5	247.99	46.01
6	242.86	45.18	6	247.70	45.83	6	249.33	45.19
7	237.48	42.32	7	247.11	43.72	7	246.16	45.00
8	244.18	42.94	8	242.92	42.96	8	246.88	44.13
9	245.22	43.62	9	240.87	43.15	9	238.78	41.58
10	242.83	43.55	10	248.34	44.21	10	238.89	43.42
Average	**293.09**	**64.35**	**Average**	**286.54**	**61.63**	**Average**	**285.64**	**61.12**

Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties
3 Officers Gate 2			**4 Officers Gate 2**			**5 Officers Gate 2**		
0	483.07	147.23	0	460.05	138.67	0	468.06	141.36
1	326.58	76.24	1	347.78	89.17	1	327.48	80.20
2	283.99	59.83	2	287.59	61.81	2	287.59	63.92
3	264.82	53.69	3	263.30	53.02	3	269.96	56.65
4	261.20	53.18	4	259.42	49.29	4	259.00	50.24
5	243.04	46.05	5	247.05	44.63	5	251.00	48.53
6	245.87	45.14	6	247.02	45.12	6	246.06	45.82
7	240.65	43.76	7	237.58	42.29	7	250.66	47.13
8	242.87	44.10	8	238.46	42.70	8	240.11	42.55
9	238.92	42.52	9	244.24	44.17	9	243.88	44.04
10	241.94	42.65	10	233.47	42.58	10	241.85	43.49
Average	**279.36**	**59.49**	**Average**	**278.72**	**59.40**	**Average**	**280.51**	**60.36**

Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties
6 Officers Gate 2			**7 Officers Gate 2**			**8 Officers Gate 2**		
0	440.85	131.78	0	439.30	129.70	0	438.89	129.10
1	327.71	80.84	1	317.66	76.70	1	313.53	74.67
2	279.74	58.62	2	288.55	64.07	2	287.82	63.58
3	267.09	54.96	3	265.95	54.20	3	266.79	54.19
4	253.06	47.81	4	252.42	47.27	4	260.20	51.85
5	260.33	50.54	5	253.22	46.81	5	250.90	47.93
6	246.79	44.80	6	252.87	45.70	6	249.42	45.33
7	243.35	43.53	7	239.46	43.70	7	243.84	42.66
8	244.02	43.89	8	247.85	45.57	8	247.00	47.37
9	241.42	42.88	9	240.56	43.01	9	245.84	43.21
10	241.11	41.61	10	239.19	41.34	10	247.13	45.06
Average	**276.86**	**58.30**	**Average**	**276.09**	**58.01**	**Average**	**277.40**	**58.63**

Police Gate 3	Model Time	Average Casualties	Police Gate 3	Model Time	Average Casualties
9 Officers Gate 2			**10 Officers Gate 2**		
0	433.23	127.20	0	426.57	126.33
1	313.14	75.98	1	317.42	75.08
2	274.08	56.29	2	281.12	60.59
3	271.18	55.74	3	265.94	53.04
4	261.77	51.35	4	263.16	50.10
5	250.26	47.44	5	252.27	48.81
6	245.79	44.27	6	250.52	46.66
7	246.33	45.16	7	245.81	44.19
8	245.78	43.52	8	242.65	43.00
9	249.14	44.05	9	244.52	42.23
10	236.82	41.76	10	249.12	45.49
Average	**275.23**	**57.52**	**Average**	**276.28**	**57.77**

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