Active shooter simulations: An agent-based model of civilian response strategy

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial Engineering

Program of Study Committee:
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Iowa State University

Ames, Iowa

2017

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ACKNOWLEDGMENTS

I would like to thank my committee chair, Cameron MacKenzie, and my committee members, Richard Stone and Matthew DeLisi, for their support throughout the course of this research. This research would not have been possible without the guidance I have received from them.

In addition, I would also like to thank my friends, colleagues, and the department faculty and staff in the IMSE department for making my time at Iowa State University a wonderful experience. I truly think this department has the absolute best faculty and staff in the world and I will forever be grateful for the knowledge and advice I have received from all of them. I am thankful that the IMSE department has always felt like home for me through both my Bachelor's and Master's degree programs.

I would especially like to thank my amazing family for always supporting me throughout my education; I would not be where I am today without their endless help and encouragement over the years.

ABSTRACT

Active shooter situations are becoming increasingly more common in the United States. From 2014 to 2015, there were 40 active shooter incidents, with a total of 231 casualties. Because of this increase in the frequency of incidents, it is important for law enforcement officers to be able to quickly respond to these situations. Quicker response times by law enforcement can result in fewer casualties. It is also important for civilians to be properly trained on how to react if they are in an active shooter situation themselves; all civilians must be able to assess the situation and know the most appropriate response strategy.

This thesis describes an agent-based simulation model of an active shooter situation in a classroom environment. The simulation focuses on three parameters: law enforcement response time, civilian response strategy, and cognitive delay of the civilians. The model attempts to quantify the effect that these three parameters have on the number of casualties in an active shooter situation. The setting for the simulation model is a school building hallway with six individual classrooms.

The work completed in this research will increase the awareness of the benefits of building agent-based models for active shooter situations. Simulation models can help law enforcement officers better prepare for a wide variety of scenarios that could occur in an active shooting. The results of the model indicate that a slower police response time and having all civilians hide can result in an increased number of civilian casualties. Increasing the cognitive delay of civilians (i.e., increasing the time until civilians react to a shooter situation) can also increase the number of casualties although the effect of this parameter is less than that of the other two parameters. These results can help guide both law enforcement and civilian training.

CHAPTER 1

INTRODUCTION: ACTIVE SHOOTER INCIDENTS IN THE U.S.

Active shooter incidents have been prominent in national media in recent years. In 2014, the Federal Bureau of Investigation (FBI) released a study of all active shooter incidents in the United States. The definition of an active shooter, as agreed upon by U.S. government agencies, is “an individual actively engaged in killing or attempting to kill people in a confined and populated area” (Blair and Schweit, 2014). While not explicitly stated in the definition, it is implied that firearms are used in the incidents as well. Additionally, a federal statute passed in 2012 defines a mass killing as a single incident resulting in three or more individuals killed, not including the shooter.

The FBI, in conjunction with Texas State University, identified 160 active shooter incidents between 2000 and 2013, and an additional study performed by the FBI’s Katherine Schweit in 2016 identified 40 more incidents between 2014 and 2015. Throughout these periods, there were 1,274 casualties identified; this includes 578 individuals killed and 696 wounded. Figure 1 shows the number of casualties per year between 2000 and 2013 (Blair and Schweit, 2014).

Another worrisome fact related to active shootings is the clear trend showing that active shooter incidents are on the rise. Based on the data used by the FBI, the average number of incidents between 2000 and 2007 was 7.4 incidents per year and the average number of incidents between 2008 and 2015 was 17.6 incidents per year.

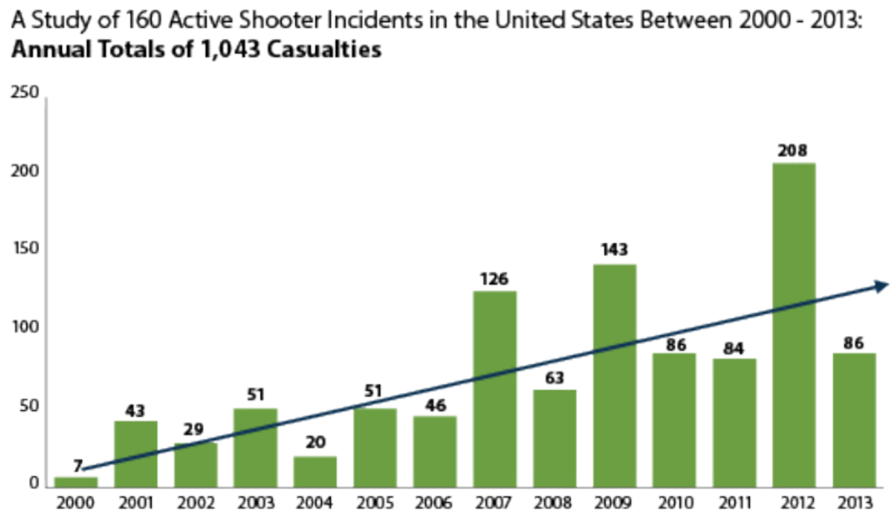

Figure 1: Number of casualties annually from active shooter incidents in the United States from 2000 to 2013 (Blair and Schweit, 2014)

Many active shooter incidents take place in school buildings, whether that be Pre-K through 12 or Institutes of Higher Education (IHEs). Based on the FBI reports, nearly one quarter of the incidents – 45 of the overall 200 – between 2001 and 2015 occurred at educational facilities (Blair and Schweit, 2014). The incidents from the years 2000 to 2013 are shown in Figure 2. The highest number of incidents – 88 in total – took place in areas of commerce, which includes businesses open to pedestrian traffic, business closed to pedestrian traffic, and malls.

Other important aspects of active shooter incidents are the duration of the incidents and the resolution of the incidents. Of the incidents in the FBI reports where the duration could be determined, 70% of the incidents ended in 5 minutes or less; 11.5% of the incidents ended in just 2 minutes or less. With average law enforcement response time being longer than 5 minutes, it is crucial for citizens to be trained in responding to these incidents. For resolution of the incidents, 40% of the incidents – 80 incidents in total – the shooter committed suicide. In another 39 of the 200 total incidents, the shooter was shot and killed by law enforcement officers. One surprising statistic from the study is that in 26 of the incidents, the shooters were apprehended by unarmed citizens (Blair and Schweit, 2014).

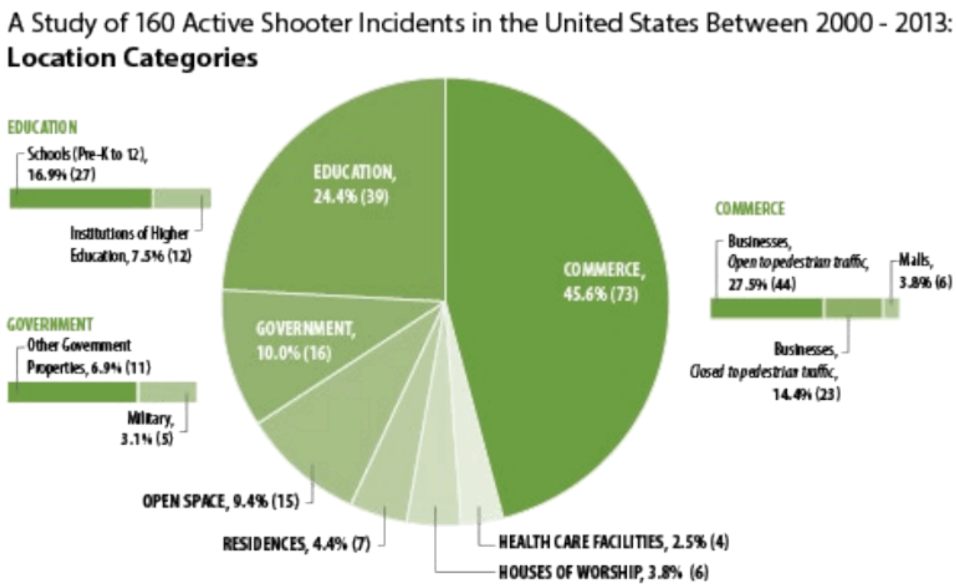

Figure 2: Location categories of active shootings from 2000 to 2013 (Blair and Schweit, 2014)

In regards to past active shootings, there are specific incidents that will always be remembered for many reasons, such as the number of individuals killed or the age of the individuals killed. Columbine is one tragic incident that will forever be in the minds of many. On April 20, 1999, two teens went on a shooting rampage in their high school in Littleton, Colorado. The teens killed 13 people and wounded over 20 others before taking their own lives. This was the worst high school shooting in U.S. history, and, for many reasons, it grabbed the attention of the American people. This was one of the first high-profile crimes where the motives of the shooter did not align with "traditional" criminals; the shooters were not motivated by financial gains or political or religious radicals. The incident also made many Americans realize that they cannot continue to be unprepared for these situations, as they can happen at any time and in any community.

The Columbine shooting was an important incident in regards to how police respond to active shootings. Prior to the Columbine shooting, police responded to active shooter situations as hostage situations or other situations in which a SWAT team would respond, and the law enforcement officers that arrived on the scene would wait for SWAT to arrive and respond. At Columbine in particular, law enforcement officers arrived on scene but did not enter the school for over 30 minutes. In the aftermath of the shooting, law enforcement agencies began to analyze their responses to active shooter situations based on what they were learning about the motives of the shooters. There were no hostages or ulterior motives, as the shooters were quite plainly focused on killing or wounding as many people as possible in a short amount of time. This lead law enforcement officers to realize that a faster response time would be critical to saving lives in these situations (Manger, 2013).

Though the need for quicker response time was realized, this requires a great deal of additional training and still increased the risk to officers. While SWAT teams and other specialized forces receive extensive specific training for dynamic and dangerous situations such as active shooter situations, it is not realistic for all line officers to receive this level of training. Training courses must be heavily condensed and given to the officers, who must all be prepared to respond to an active shooter situation. Training and response methods are also ever-changing based on new analyses and information from each shooting incident that occurs.

Another training method that has evolved since the Columbine shooting is civilian training. Since active shooter training became common in workplaces and schools, the typical training method was the “Lockdown” method. This method had civilians lock all doors, if possible, and hide as best they could from the shooter. After learning more about the habits and motives of active shooters, police realized this method may not be the best method in many shooting scenarios. Law enforcement officers across the country now often train using the "Run, Hide, Fight" method. The idea behind this method is that it is in the civilians' best interest to evacuate the building or escape the situation. The second option should be to hide, but only if it has been deemed that evacuating is not a safe or viable option. The third and final option would be to fight or distract the attacker, and this option would only be done if either of the first two were not possible. The "Run, Hide, Fight" training method is used by the U.S. Department of Homeland Security, as shown in Figure 3 (U.S. Department of Homeland Security, 2017). The Advanced Law Enforcement Rapid Response Training (ALERRT) Center at Texas State University was named the national standard in active shooter response training by the FBI in 2013. ALERRT uses a similar method by the name "Avoid, Deny, Defend" (Advanced Law Enforcement Rapid Response Training at Texas State University, 2017).

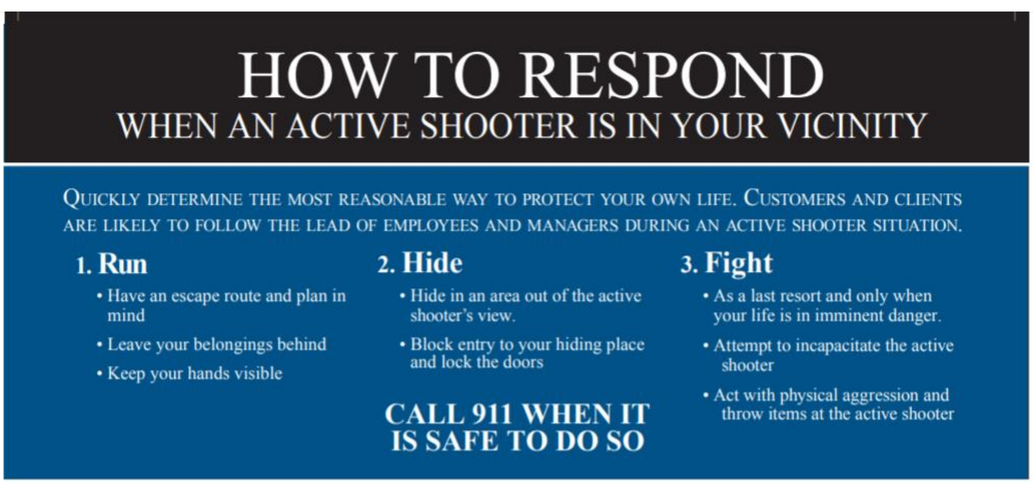

Figure 3: DHS active shooter response poster (U.S. Department of Homeland Security, 2017)

Studying past active shooter incidents and creating simulation models to further investigate the situations can provide valuable information to the individuals who are risking their lives each time one of these incidents occurs. A study by Blair (2013) includes 84 major active shooter incidents from the years 2000 to 2010. He finds that one-third of police officers who made a solo entry were shot. This finding indicates the importance of officer training and awareness of the risk they are taking.

Research Motivation

The motivation for this research stems from the increasing number of active shooter incidents and prior work around active shooter incidents and law enforcement performance measurement. Upon doing some research in the field of active shootings for risk modeling and performance measurement, it was noticed that there has been very little done in the realm of agent-based models for these situations. Agent-based simulations are a type of computational model in which the actions of autonomous agents and interactions between the agents are simulated. These simulations are used to assess the effects the agents have on the entire system. Agent-based models can provide valuable information for both civilians and responding law enforcement officers. Simulation models enable us to quickly look at a wide variety of situations to ensure proper training for law enforcement and civilians in every situation.

The goal for this research is to observe the effects that three parameters have on the number of casualties in an active shooter situation by creating an agent-based simulation model. The three parameters include: law enforcement response time, cognitive delay of the civilians, and civilian response strategy whether the civilians all choose to hide, all civilians choose to run, or a combination of the two where some civilians hide and some civilians run).

After doing some initial research and meeting with local law enforcement officers, it was easy to see that their suggested training methods have change dramatically since the Columbine shooting in 1999. While the “Lockdown” method was widely used prior to Columbine, many law enforcement agencies are moving away from that strategy and towards a “Run, Hide, Fight” method instead. The changes in these training strategies were a motivation in this research, and the civilian response strategy element in the agent-based simulation will be a focus point in Chapter 3.

Thesis Organization

The remainder of this thesis is organized in the following format. Chapter 2 contains prior work and further motivation for researching active shooter situations and creating an agent-based simulation of an active shooter situation. Chapter 3 contains detailed information about the agent-based simulation model that was created, including model methodology, results, and discussion. It also includes a literature review of past agent-based shooting models. Finally, Chapter 4 includes general conclusions and future work. References are provided after Chapter 4, followed by the Appendices.

CHAPTER 2

PRIOR WORK AND MOTIVATION

Active shooter situations are often characterized as being unpredictable and unfolding quickly. In regards to where and when these situations happen, law enforcement is very rarely notified until the shooting has already started. If these situations were predictable, law enforcement would be able to intervene and prevent the tragic number of casualties we have seen come from these situations in recent years. In the aftermath of a shooting, law enforcement officers and investigators often find details in the shooter's life that would indicate that individual was at a high risk of doing something terrible; sometimes they even find specific details acknowledging that the individual was planning the shooting.

Because of the unpredictability of active shooter situations and the inability to be proactive and prevent every active shooter situation before it arises, training civilians and law enforcement officers on how to best react in these situations could be the best strategy to minimizing the number of casualties. To give the best possible trainings, it is important to analyze details that we have information for in past shooting situations. While there has been a great deal of research on active shootings, there is a noticeable gap where quantitative analysis should be done. Historical data is underutilized and subjective information is often used in place of objective quantitative analysis. In order to bridge this gap, a risk analysis was done to assess the risk of a school shooting taking place at a university.

Risk Analysis of School Shootings

It is difficult to prepare for active shooter incidents. Yet, with the increasing number of shootings happening per year, workplaces and schools must prepare and train for how to react and respond to these situations. Performing a risk analysis to analyze and quantify the risk of a shooting at a specific school or workplace could be beneficial in many ways. The results of the analysis could benefit both civilians and law enforcement officers in their training, along with giving information to the administrators or leadership at the school or workplace to help them make better decisions regarding risk mitigation strategies.

In order to begin analyzing the risk of a school shooting at a university, the first tool used to show the main factors in an active shooter situation was an influence diagram. Creating an influence diagram helps visualization and shows the relationships between key factors of the situation including: decisions, uncertainties, and the final consequence or value. It is important to keep in mind who the decision makers are when creating this diagram. The decision makers in this situation would be the administration or leaders of the school. The decisions would be possible risk mitigation strategies that could be put in place by the university to reduce the risk of a shooting happening or reduce the number of casualties in the event that a shooting did take place. In this research, these included increasing mental health resources, requiring mandatory active shooter training, increasing police presence, and allowing concealed carry weapons on campus.

The uncertainties in the situation are the motives and plans of the shooter. For this research, that included: the number of shooters, type of shooter (shooter motivation), location and time of the shooting, and the shooter selecting a specific university as their target. The overall goal is to minimize the number of casualties while also minimizing the cost of mitigation strategies. The influence diagram created for this analysis is shown in Figure 4. Creating an influence diagram can show the main factors affecting an active shooter situation and can pictorially represent why it may be beneficial to create a simulation model. This influence diagram is by no means a comprehensive diagram of every decision and uncertainty involved in an active shooting at a university; there are many other decisions and uncertainties that could be added or modified within the influence diagram.

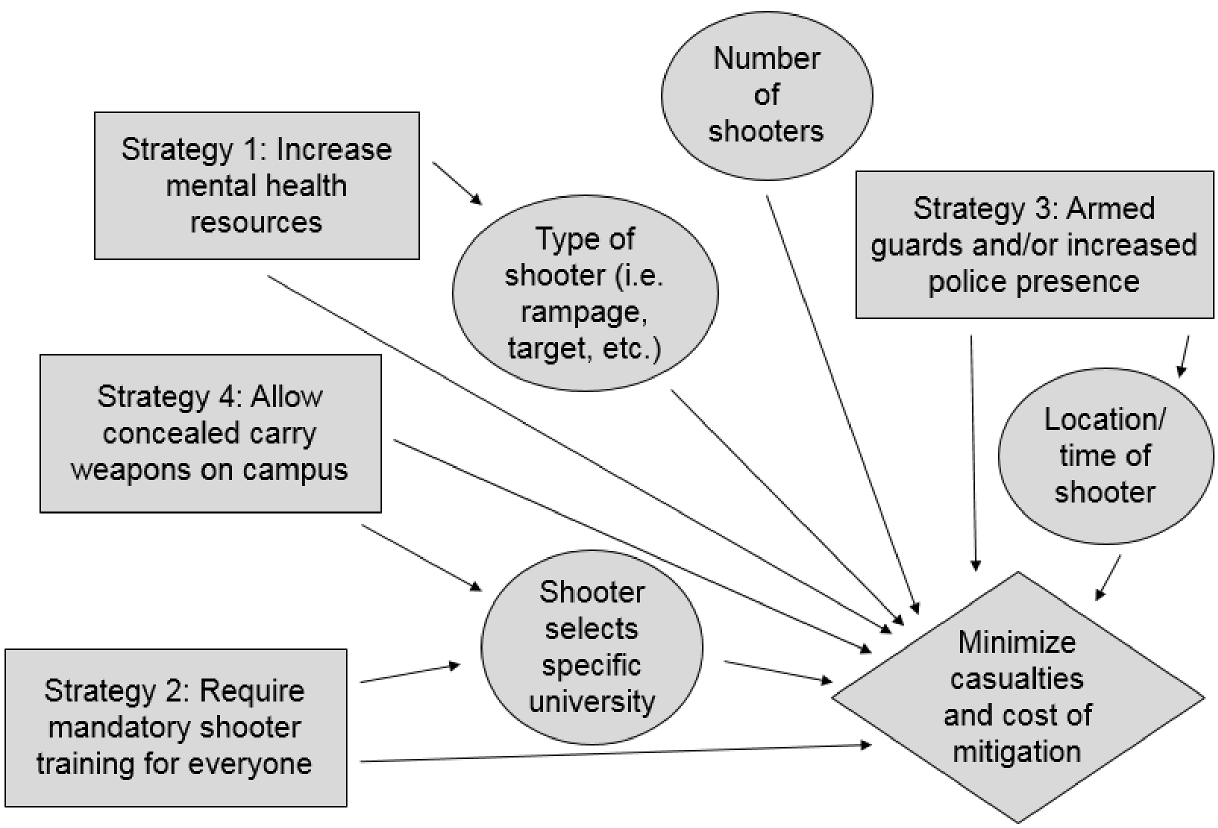

Figure 4: Influence diagram of an active shooting at a university

Historical data collected from 2000 to 2013 show the number of school shootings per year and the resulting number of deaths and injuries per year from these shootings. The focus in this research was to predict the possibility of a school shooting happening at a specific university, so the data was sorted into categories based on the education level at which the shooting took place. Then, additional data was collected on the number of universities in the U.S. to calculate the probability of a shooting at one specific university. Almost 33% of school shootings take place at universities, and university shootings have been more prominent in recent years. Based on the data, it was estimated that there would be 24 school shootings in 2016 and 8 of these would happen at a university. Based on an estimate of 7,800 postsecondary education institutions in 2016, the estimated probability of a school shooting happen at a specific university would be 0.1026%. It is important to note that some assumptions were made when calculating the probabilities. First, shootings at universities were on an upward trend based on the data, so it was assumed that this trend would continue to increase. It was also assumed that a school shooting was equally as likely at any university in the U.S.

Data was also collected on the type of shooting, with the shootings falling into five categories: rampage, mass shooting, terrorist, target shooter, or government official. The type of shooting is important because it plays a large role in the effect of some of the mitigation strategies. Historically, target shootings have accounted for the majority of school shootings. The type of shooting can also have an effect on the number of casualties, as target shootings, for example, typically have a lower number of casualties than mass or rampage shootings. The final data analysis piece was estimating the number of fatalities and injuries that occur in the event that a school shooting does take place, and distributions were created to predict these values. The expected number of deaths per shooting was calculated to be 1.26 and the expected number of injuries was calculated to be 1.74.

Once the decision makers are given the probability and estimated number of casualties, the next step in the analysis was suggesting mitigation strategies. These mitigation strategies would be considered and selected by the decision makers, and the decision makers would need to be aware of their risk attitude. The mitigation strategies used in this research were: increase mental health resources, require active shooter training for everyone on campus, increase police presence, and to allow concealed weapons on campus. An event tree was created showing each possible mitigation strategy and shooter type. This event tree is shown in Figure 5.

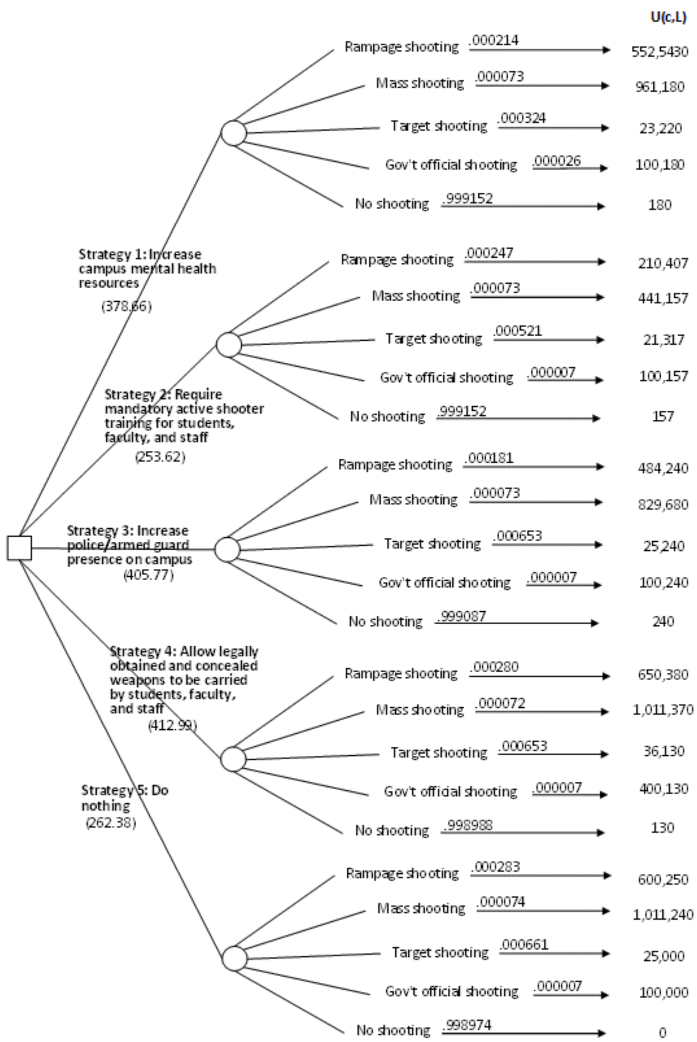

Figure 5: Event tree showing mitigation strategies and shooting type

The number of shootings for each type of shooter motivation was calculated based on the total expected number of school shootings and the historical percentages for each type of shooting. The estimated values were: 5 target shootings, 2 rampage shootings, and 1 mass shooting. The probabilities for the scenarios were estimated and assigned based on the effect the mitigation strategy would have on each type of shooting. The cost for each mitigation strategy was estimated as well. Then, the total utility of each scenario – shown in Figure 5 with the notation U(c, L) – was calculated based on the risk attitude of the decision makers. The decision makers were assumed to put a higher weight on the lives of the students and a lower weight on the cost of mitigation strategies; that being said, they also do not have unlimited funds, so they must keep financial aspects in mind.

Some mitigation strategies play a large role in minimize the number of lives lost if a school shooting does take place, and some strategies play a larger role in reducing the possibility of a school shooting taking place. For this reason, each mitigation strategy has a different effect on total utility. Overall, the analysis provides insight into risk management strategies that could be taken, depending on the risk attitude of the decision makers.

Risk analysis techniques such as the ones used in this research could be used in conjunction with simulation models to create more comprehensive risk models. Once the model was created, trials could be run and the data from the simulation model could be put back into the risk model to create a more accurate risk model. One of the difficulties of doing risk analysis on active shooter situations is the limited amount of available data, and the assumptions that must be made. Other risk models could be created to match the simulation discussed in Chapter 3, and the data from the agent-based simulation models would be useful in creating the best possible risk analysis.

Performance Measurement in Law Enforcement

Another topic in the realm of policing work that prior research has been done in is performance measurement within law enforcement. In many aspects of life, such as school or work, people are accustomed to being rated by grades or performance reviews. Even when trying to book a hotel or go to a new restaurant, the ranking given to the business by prior customers will impact the opinions of potential future customers. It is agreed that everyone wants police forces to have high quality, but what does that mean in regards to policing? To determine if law enforcement officers are of high quality, it must first be determined what measures will be used for their performance measurement; this often includes number of arrests, number of citations, or low crime rates. Over the years there have been many suggestions as to how quality should be measured in policing. They have ranged from something as simple as using two measures consisting of "the number of cases cleared and the value of stolen property recovered", as suggested by Donald Stone, to using something as complicated as an extensive instrument that included 685 specific items "completed by expert police analysts asked to render a professional judgement on each item", as suggested by Arthur Bellman (Maguire, 2003). Other suggestions have included using surveys filled out by citizens to gauge the level of public confidence in local law enforcement.

Additionally, Compstat is a tool that is frequently used in the realm of police performance measurement; Compstat combines management, philosophy, and organizational management tools for police departments. It stands for 'computer statistics' and originated in the NYPD in 1995. Compstat includes four components: accurate and timely information, rapid deployment of resources, effective tactics, and relentless follow-up. Compstat is frequently confused for a computer program. Software programs play a role in the data tracking aspect, but overall, it is a program that is larger than that. The key principal of Compstat is “gathering and analyzing data to produce solutions” (Police Executive Research Forum, 2013). There has also been some debate as to whether policing performance measurement should be used only to gauge the performance of a police department relative to previous performance of the same department, or whether measures can be used to gauge a police department against other police departments against the United States.

Standard policing measures included quick response to calls and crime-focused statistics, such as controlling crime, generating arrests, citations, and clearances. Measures such as these are still used in some law enforcement agencies today, but these measures ignore very important aspects of policing, such as morale, community relations, resources required, and many more. Specifically, crime rates have dominated many department’s success claims. Crime rates were frequently used as a ‘bottom line’ in policing performance measurement. Critics began to note that many other factors were playing a role in overall crime rates, so those should not be sole focuses for law enforcement performance measurement. Another large criticism was that police are performing many other tasks that they are not being measured on, because they may not be crime related. Arrests and citations were some of the most visible and widely-used measures of police output. After time, and objections by many, an obvious need was shown for multidimensional police performance measurement.

According to Maguire (2003), just as businesses use performance statistics showing performance in operations, finance, customer service, etc., policing should be using performance measures that show their overall quality. In 1980, Michael O’Neill and his colleagues developed a performance measurement system containing five dimensions: crime prevention, crime control, conflict resolution, general service, and police administration. The use of multifaceted measures can be traced back to the balanced scorecard approach, written by Kaplan and Norton in 1992. Maguire details ways to develop proper measurements for each police department using general community surveys, contact surveys, employee surveys, direct observations, and independent testing or simulation studies (Maguire, 2004). He also recommends proper weighting for the measures.

It is easy to see that law enforcement agencies can choose from many performance measurement metrics. Choices range from using only a couple of crime-related statistics to using a multidimensional performance measurement system that contains many measures. It is important to focus on all the measures that are crucial to ensuring high quality policing without spending resources focusing on measure that are not necessary. The difficult task for a law enforcement agency is deciding which measures are important to them.

With the implementation of a system such as Compstat, performance measures are already laid out for the department and can be easily compared with performance measures of any other police department across the nation that also uses that program. Compstat focuses on crime-related statistics and leaves out many of the other important metrics, such as community-related metrics or any resources metrics. If police departments are solely using this system and ignoring other important metrics, they are missing out on key information that could greatly help increase their performance.

For performance measures to influence performance and drive change in the organization, each metric must be aimed to accomplish some goal. As an example, crime rates is one metric that is measured by most police departments. The goal in using crime rates as a performance measure is so the department can work on lowering crime rates, but first they must know where they stand with their current crime rates. Additionally, if they make changes to try to lower crime rates, they need the metric to show if their change had an effect, and if it was a positive or negative effect. Often, agencies have a very large number of performance measures, and many of them are hardly used. This can create a negative impact on all performance measures, because they seemingly become less important as the number of measures increases. On the other hand, some organizations have too few performance measures, which could also have a negative impact on performance. Not having enough metrics would mean the department isn't measuring important areas, and therefore not making changes that could have a positive impact on the performance in that area.

In this research, performance measurement metrics were broken down into three categories: crime-related, community relations and perceptions, and administrative and financial. While some metrics are very objective and easy to define and measure, others have a large amount of subjectivity and may be rather difficult to measure. Crime-related measures include: crime rates, arrests, citations, clearances, response time, crime prevention, conflict resolution, and apprehension of offenders. Community relations and perception measures include: community morale, community opinion, feeling of security, fairness, courtesy, helpfulness, honesty, attentiveness, reliability, responsiveness of police, and transparency. Finally, administrative and financial measures include: productivity, general service, officer morale, use of resources, training hours, training effectiveness, and officer competences.

Choosing the right metrics can be a difficult process, but there are some tools that police departments can use to assist them. One method, as mentioned earlier, is the balanced scorecard method. This method for performance measurement allows managers to use four important perspectives to look at their business. Each law enforcement agency should utilize the balanced scorecard method, but still choose which performance measure to include. Some performance measures are going to be more relevant – or more important – for certain law enforcement agencies than they are for other agencies. Use of resources, for example, may be more important to departments that are tight on resources. Additionally, some measures may be relevant to police departments but should not be compared across departments. Response time, for example, is going to be different for police departments in large cities versus police departments in small, rural towns.

The first category the agencies should think about are the crime-related statistics. Every department needs metrics in this area. The metrics that departments might choose from include: crime rates, arrests, citations, clearances, response time, crime prevention, conflict resolution, and apprehension of offenders. Regardless of the location of a police department, these metrics are going to be important to measure. While law enforcement agents spend time performing tasks that are not crime-related, they do spend a majority of their time focusing on crime-related tasks. Some of these metrics will be easy to measure and track, while others, such as crime prevention and conflict resolution, will be difficult to measure and track. Each agency must decide if these metrics are important to measure and how they will benefit from measuring the metrics.

The second category that should be considered is the community relations and perception category. This is one category that was traditionally left out of policing performance measurement, but is very important to having a high quality police department. Police departments and other law enforcement agencies all want to provide high quality services to their citizens. Without measuring the perception of the citizens in their jurisdiction, how would a police department know what level of quality they are being measured at? Metrics pertaining to this area must be measured and tracked, and processes should be implemented to improve these metrics if needed. For this category, departments might choose from metrics including: community morale, community opinion, feeling of security, fairness, courtesy, honesty, helpfulness/cooperation, attentiveness, reliability, responsiveness of police, and transparency. These measures can assist the department in getting a better understanding of how the community feels they are doing, and knowing where they stand in the community's eyes can help them improve performance. Some of the metrics listed above may overlap, and a police department may choose to omit some of them. The key is that the department is paying attention to and measuring some of these metrics.

The third category the department should consider is that containing administrative and financial measures. These metrics include: productivity, general service, law enforcement morale, use of resources, training hours, training effectiveness, and officer competence. This category includes many metrics that are going to be more difficult to measure and may consume more resources if the department chooses to focus on them. Metrics such as productivity and training effectiveness will be difficult to measure and will greatly depend on how the department chooses to define terms in these metrics. Departments may choose not to measure these, especially if they believe they are already particularly strong in these areas.

In any organization, metrics should only be measured if the organization is going to use the results of the metrics and make necessary changes based on those results. If the organization is not willing to make any changes, then the metrics are essentially useless and resources are being wasted on the collection of the data. Police departments and police officers must have a desire to improve their metrics in order for the collection and compilation of the metrics to be beneficial.

CHAPTER 3

ACTIVE SHOOTER SIMULATION: METHODOLOGY

Introduction

Active shooter events have become increasingly common in recent years. The FBI identified 200 active shooter incidents from 2000 to 2015 (Blair and Schweit, 2014). These incidents caused a total of 1,274 casualties. The average number of incidents was 7.4 per year from 2000 to 2007 but increased to 17.6 from 2008 to 2015. As active shootings are on the rise, law enforcement officers across the country must be prepared to respond to these situations in a timely and effective manner. Since 70% of the incidents end in 5 minutes or less, it is crucial for law enforcement to quickly respond to minimize the number of casualties in each incident. Another key to minimizing the number of casualties is to make sure that civilians are trained how to properly respond.

Agent-based simulations provide one way to study the effect and importance of different parameters during an active shooter event. Agent-based simulations are a type of computational model in which the actions and interactions of autonomous agents are simulated. These simulations are used to assess the effects that agents have on the system as a whole and to analyze complex systems with interacting decision makers. Agent-based simulations are used in many domains, as seen in Figure 6 (Davidsson P., et. al, 2007). The most common domain for is a simulation of a social system, which consists of a set of human individuals with individual goals, some of which may be conflicting. Simulating an organizational structure is second-most common, and these types of simulations contain agents working together towards a common goal. Agent-based simulations have been applied frequently across the healthcare industry, especially in the area of epidemiology, which deals with the distribution and control of disease.

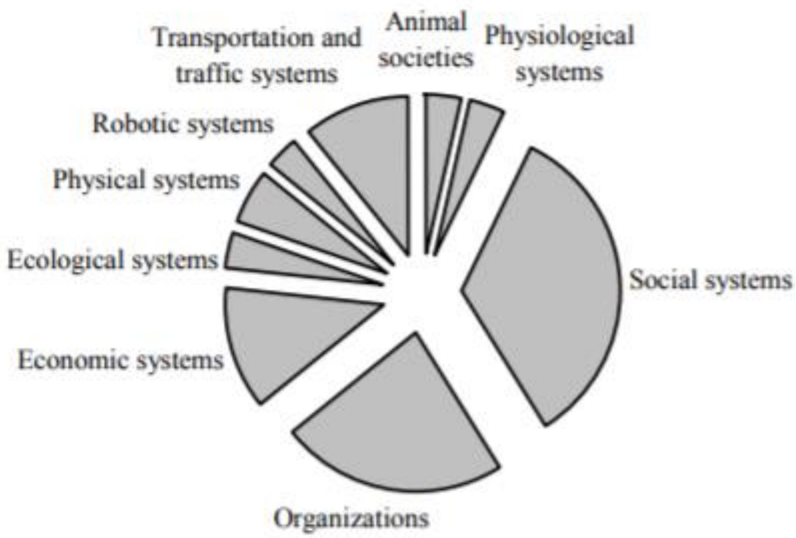

Figure 6: The distribution of types of agent-based model domains (Davidsson P., et. al, 2007)

Agent-based simulations of active shooter situations allow researchers to assess many situations in a short time period, with different attributes given to each agent – the shooter(s), the civilians, and the responders. Real-life data on active shooter situations is extremely limited by the relative infrequent number of shootings and the amount of information obtained from each shooting. After an active shooter incident, law enforcement pieces together information from the shooting, but gaps still exist in the collected data. For example, it is often difficult for law enforcement to know details about the situation, such as the moves of the shooter throughout the building. Assumptions are sometimes made to fill in these gaps based on recollections from survivors. Additionally, because of the limited amount of data, it is difficult to draw conclusions on the effects of parameters such as firearm type or capacity. An agent-based simulation can enable researchers to analyze the effect that various parameters can have on the situations, such as the firearm capacity of the shooter, unarmed civilian fighters, concealed carry civilians, the number of shooters, the accuracy of the shooters, the presence of a security guard, and the cognitive delay of the civilians. Despite these positives, limitations of the simulations exist, and it is especially difficult to accurately simulate human responses in stressful situations.

The purpose of this research is to understand how police and civilian responses to an active shooting can impact the number of casualties. An agent-based simulation model quantifies the impact of three parameters and the effect they have on the number of casualties in an active shooter simulation taking place at a school. The three parameters include: police response time, cognitive delay of the civilians, and civilian response strategy. The police response time is the time it takes the law enforcement officers to arrive on scene. The cognitive delay of the civilians is the time it takes the civilians to realize a shooting is occurring and to respond. The civilian response strategy is the reaction that the civilians will have once they realize they are in an active shooter situation. The civilians can all attempt to evacuate the building, all attempt to hide in their classrooms, or do a mixture of both. To the best of our knowledge, this research is the first to quantify and analyze the effect of civilian response strategy and police response time on the number of casualties in an active shooter situation at a school.

The remainder of this chapter is organized in the following format. Section 2 reviews the literature of prior agent-based simulations for active shooter incidents. Section 3 discusses the model setup and parameters. Section 4 explains the results from the trials that were run on the different variations of the model. Section 5 concludes the chapter with a discussion of the results.

Literature Review

In active shooter situations, the number one priority is to remove civilians from the situation as effectively and efficiently as possible. Active shooter simulations can help prepare law enforcement officers and civilians for these situations in order to mitigate the effects of the situations. Modeling and simulation are increasingly becoming more important in planning effective response and recovery operations because of the inability to obtain data in other ways. (Bryant and Herrle, 2014). Simulations can ensure proper training in order to reduce the number of casualties and help law enforcement officers be proactive about preparing for these situations instead of reactive. Law enforcement officers can learn how to train for and respond to these situations.

Bryant and Herrle discuss additional uses for active shooter simulations. The authors say it is important to know what next steps the shooter is likely to take and what the most effective response is to end the situation given the shooter's actions. Simulations such as these could open the door for a much better prepared response team. The duo also discusses the importance of agent-based simulations versus other simulation methods; they state that agent based simulations are the future for active shooter modeling and analysis due to the fact that each agent has its own defined characteristics and knowledge.

Advanced modeling and simulation can also provide useful tools for effective planning to respond to and recover from life-threatening incidents (Smith et. al, 2010). Simulation provides a means to quickly and effectively examine many "what-if" situations and adjust their response techniques and methods based on the outcomes of the situations. Simulation models are also limited in depicting real world scenarios, especially in chaotic situations. It is difficult to model how people are going to react in active shooter situations because emotional states, individual knowledge of the situations, and cognitive-decision making cannot accurately be taken into account.

Research in active shooter simulations was relatively unheard of until a few years ago. As active shootings became more prominent, researchers understood that simulations could help understand factors that could reduce the number of casualties in one of these situations. Various researchers have created models looking at different aspects of active shooter simulations and comparing the changes in those factors to the casualty count of the simulations. Some of those factors include the percentage of concealed carry permit civilians, unarmed resistance towards the shooter, number of shooters, weapon type, time between shots, shooter accuracy, and shooter magazine capacity. Observing the effects of these types of factors can help law enforcement officers better respond to the situations and better train for the situations.

Anklam et al. (2015) create an active shooter simulation in an educational environment with different scenarios, including the type of security control, whether or not civilians are armed, and the availability of a designated resource officer. Having a resource officer and armed teachers reduced the number of casualties the most. The conclusion of the study was that a quicker response—whether it be by the resource officer or the concealed carry staff—is key to reducing the number of casualties.

Kirby et al. (2016) design a simulation for a one-story office building with 15 individuals in the workplace. The results from this model suggest that if 10% of the employees carry concealed weapons, it slightly reduces the time to engage the shooter and the number of casualties. The results also show that the presence of a security guard significantly reduces the number of casualties. Additionally, the results suggest that locking doors does not influence the time to engage the shooter but does appear to reduce the number of casualties in the incidents by almost 25%.

Hayes and Hayes (2014) detailed three active shooter simulation models to observe the potential effectiveness of an assault weapons and high-capacity magazines bill. Three simulations were created: two indoor scenarios and an outdoor scenario. One model replicated the events of the 2012 movie theater shooting in Aurora, Colorado. The second model is set in a large outdoor space. From the results of their simulation models, they concluded that the assault weapons ban would not decrease the number of casualties. The reason for this is that the ban did not include decreasing the rate of fire of any firearm. The authors found that the weapon’s rate of fire has the greatest effect on the number of casualties; this was especially true for indoor simulations. They also concluded that the high-capacity magazine ban would result in a small number of lives saved during a mass shooting.

Briggs and Kennedy (2016) created a model in NetLogo that was the basis for some pieces of the model code in this thesis. The model was set in a large, open outdoor area, and included unarmed civilians who fight back against the shooter. The user can vary parameters regarding the population, such as the number of people, percent of people who fight, cognitive delay, and fighter chance of overcoming shooter. They can also vary many shooter parameters including number of shooters, magazine capacity, firearm effective range, shot accuracy, field of view, and shooter chance of overcoming fighters. The shooter is randomly placed at the start of the simulation and begins shooting at the closest civilians. While most civilians will flee, a small portion will head towards to shooter to try to subdue them. The simulation ends when the shooter is subdued or all civilians have been hit or have escaped outside the perimeter of the simulation.

The results of the Briggs and Kennedy model suggest that unarmed resistance may reduce the overall number of casualties in an active shooter situation. The risk of being shot does greatly increase for the individuals who choose to fight the shooter. Importantly, the authors discuss limitations of the model and note that all active shooter models are limited by the amount of forensic information from past active shootings; this lack of information increases the complication of validating active shooter models.

While past models have quantified and analyzed the effects of many parameters in active shooter situations, they have not looked at the effect that civilian response strategy can have on the number of casualties. In all prior models the civilians either do not move to react to the situation or they have one set response throughout the trials, which would be to evacuate the area. These prior models also have not looked at the effects on the number of casualties in this type of school setting given varying police response times. Additionally, the analyses of past models have not shown the effects of interactions between parameters such as cognitive delay, police response time, and civilian response strategy.

Model

An agent-based simulation of an active shooter incident in a school setting was created. The purpose of this simulation is to observe the impact that civilian response strategy, cognitive delay, and police response time have on the number of casualties in an active shooter situation. The simulation is set in an educational environment with students (civilians) in six separate classrooms. Three types of agents exist in this simulation: one active shooter, two law enforcement officers, and civilians. The civilians can have different actions for how they will react to the active shooter situation.

Figure 7 depicts the simulation at setup to model a hallway in a school building, with six classrooms full of students. The agent-based simulation model created using the NetLogo software version 6.0, and some of the model is based off the Briggs and Kennedy (2016). The simulation has a total of 384 civilians in the six classrooms. Each of the two rooms on the left have 48 civilians; each of the two middle rooms have 60 civilians, and each of the two rooms on the right have 84 civilians. The building has two entrance or exits at each end of the hallway. The shooter starts at the left entrance of the building. If civilians attempt to exit the building, they will all exit at the right door. The law enforcement officer is not present at the beginning of the simulation but arrives after the response time at the right entrance of the hallway.

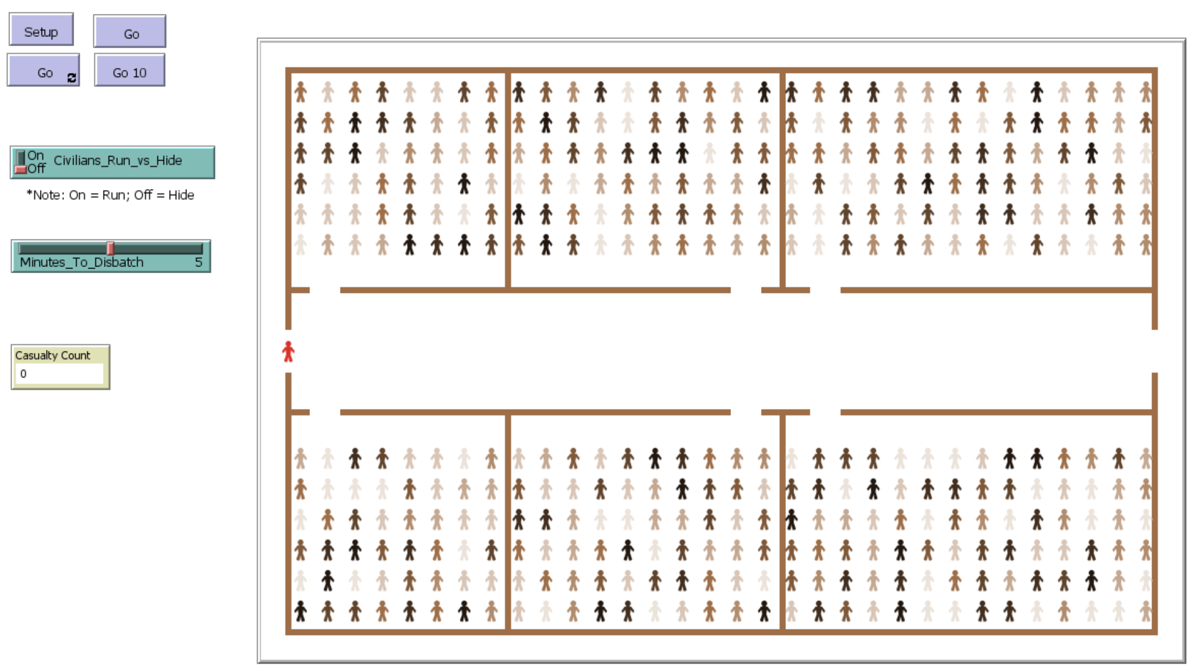

Figure 7: Setup of the agent-based simulation model

The setup procedure creates the 384 civilian agents and places them in predetermined locations. The shooter is created and the shooter's running speed is randomly chosen according to a normal distribution. The firearm effective range, field of view, and shot accuracy are also determined. The firearm effective range was set low so that the shooter would be at point blank range with the civilians in the simulation, at about 2 feet. The field of view is 135 degrees and the shot accuracy of the shooter is 75%. Each civilian is assigned a running speed, also based on a normal distribution. The law enforcement officers running speed is set, and based on a normal distribution just as the running speed of the shooter and civilians. All of the running speeds are in patches per second, which can be approximated to feet per second in this simulation. The mean of the distributions was .7874 and the standard deviation was .1125.

The simulation begins with the shooter targeting a civilian. The shooter looks for the closest civilian and walks to enter the classroom that civilian is in. The shooter targets and shoots that civilian and continues to target and shoot civilians closest to them. After all of the civilians in the room have become casualties or are evacuating the room, the shooter exits the room and either targets and shoots civilians in the hallway or enters another room to target and shoot civilians.

The civilian response strategy is one of the main parameters that was analyzed in this simulation. Three response strategies are examined: run, hide, or run and hide. For the run strategy, the civilians follow a coordinate based system to know which direction to head. They will head, at their designated running speed, towards the door of the room or towards the right exit once they are in the hallway. If there is another civilian on the patch in front of them, the civilians will shift over slightly and try to move forward again. Civilians cannot all exit the building simultaneously due to space restrictions, and only a certain number of people can fit through the doors. The doors become a bottleneck during an evacuation. Once a civilian reaches the exit at the right end of the hallway, the civilian is considered safe. For the hide strategy, the civilians move toward a corner of a room and remain at the corner when they reach it. For a combination response strategy of both run and hide, a random number between 0 and 1 is chosen for each civilian. If the number is less than 0.5, the civilian will run; if the number is greater than or equal to 0.5, the civilian will hide.

Before the civilians respond, they will have a cognitive delay. The cognitive delay is the amount of time it will take the civilians to acknowledge that they are in an active shooter situation and begin to respond. The cognitive delay is set by the user before the simulation.

Two law enforcement agents arrive through the door on the hallway on the right. The law enforcement agents arrive at the time set by the police response, which is anywhere between 1 and 10 minutes. The law enforcement agents move toward the shooter. Once the agent is within the firearm effective range of one of the law enforcement officers, the shooter becomes a casualty. The simulation ends when a law enforcement agent shoots the shooter.

Table 1 depicts the values selected for each of the three factors examined in this simulation: civilian cognitive delay, police response times, and civilian response strategy. There are four cognitive delay times, three police response times, and three civilian response strategies considered, resulting in 36 different simulation sets. Each set is run for 50 trials to gather data on the number of casualties.

The output variable for this model is the number of casualties, where a casualty is any civilian who has been shot. The results section uses the percentage of civilian casualties to analyze the effect of the three factors.

Table 1: Parameter values for the agent-based simulation

Parameter	Values	Notes
Cognitive delay	0.5 min, 1 min, 2 min, 5 min	Time it takes civilians to process and respond to situation
Police response time	2 min, 5 min, 10 min	Time it takes police to arrive at the scene
Civilian response strategy	All Run, All Hide, Some Run & Some Hide	Whether civilians choose to evacuate or lockdown

Results

This section discusses the results from the simulation and the effects the three factors (cognitive delay, police response time, and civilian response strategy) have on the percentage of casualties. Average percentages from each of the 50 trials will be compared followed by more extensive statistical testing to quantify the effects of those three parameters.

Raw data

The results from the simulation trials are shown in the following graphs and the percentages are listed in Appendix B. Figure 8 shows the percentage of casualties when the civilian response strategy was run grouped according to police response time and cognitive delay. A 5-minute cognitive delay time increases the number of casualties, but there was little difference between the shorter three cognitive delay times for each police response time. This is likely due to both the smaller difference between the tested parameters and the way the simulation was set up. For a short cognitive delay, the shooter does not enter very far into the classroom. The civilians will still follow their response strategy to evacuate and head towards the door where the shooter is standing, which causes additional civilian casualties near the door. Casualties increase as the police response time increases. If the police respond in 2 minutes, casualties average 7-8% for the shorter cognitive delay times. If the police respond in 10 minutes, casualties average 25-27% for the shorter cognitive delay times.

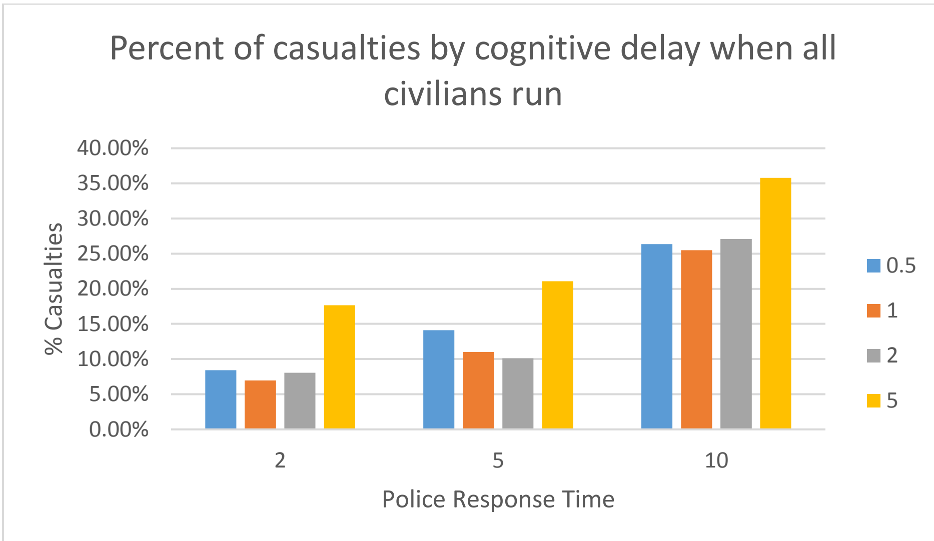

Figure 8: Percent of casualties by cognitive delay and police response time when all civilian response strategy is all civilians run

Figure 9 shows the percentage of casualties when the civilian response strategy is for all civilians to hide. Unlike the response strategy of run, the cognitive delay does not impact the percent of casualties for quicker police response times. If the police respond within 2 minutes or 5 minutes, the number of casualties is very similar regardless of the cognitive delay time. If the policy respond within 10 minutes, a 30-second and 5-minute cognitive delay slightly decreases the casualties compared to a 1 or 2-minute cognitive delay. Some of this can be attributed to the variation in the model, as it is more evident when the model is running for 10 minutes. For the 5-minute cognitive delay, the decrease is caused by the fact that the civilians are more spread out during the initial 5 minutes, so it takes the shooter a long time to get through each classroom. Additionally, casualties increase significantly as the police response times increases.

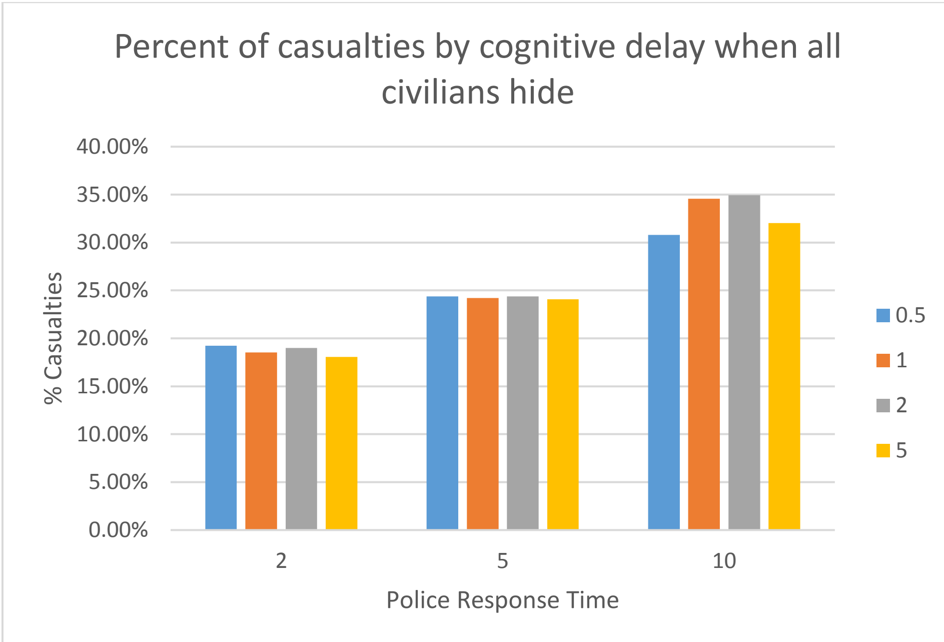

Figure 9: Percentage of casualties by cognitive delay and police response time when all civilian response strategy is all civilians hide

Figure 10 depicts the percentage of casualties when the civilian response strategy was for some civilians to run and some civilians to hide. This response strategy suggests a more obvious increasing trend in the number of casualties as the cognitive delay time increased. As the police response time increase from 2 minutes to 5 minutes to 10 minutes, the cognitive delay appears to have less of an impact on the number of casualties. This can be attributed to the length of the scenarios; in the 2-minute scenarios, the longer cognitive delays have a larger impact on the number of casualties. As with the other civilian response strategies, casualties increase as the police response time increases although the difference in the average number of casualties between the 2 and 5-minute police response times is smaller than with the other two civilian response strategies. The average percent of casualties increases from 8.5% to 10.5% between the

2-minue and 5-minute police response times, and then jumped up to 22.5% for the 10-minute police response time.

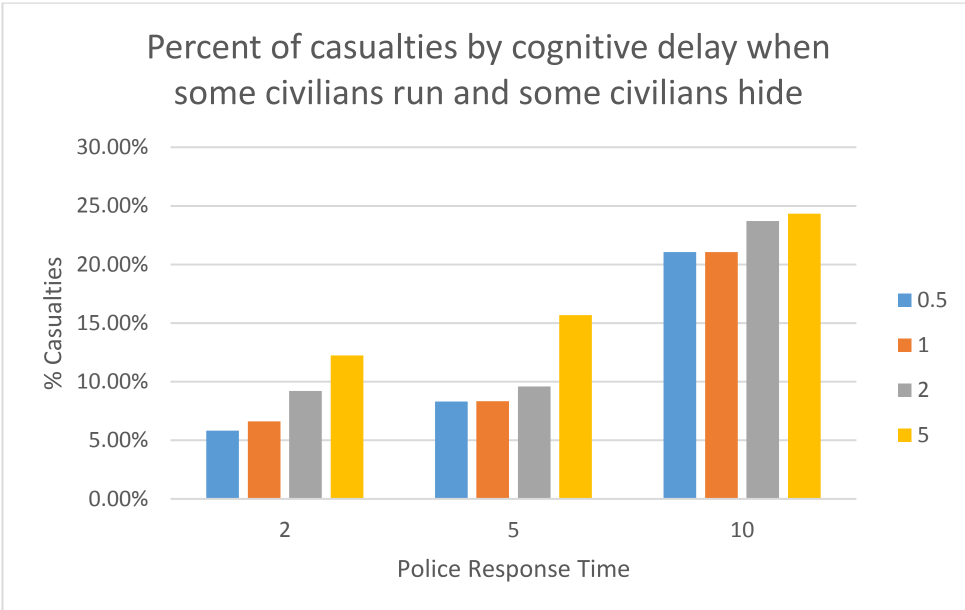

Figure 10: Percentage of casualties by cognitive delay and police response time when all civilian response strategy is for some civilians to run and some civilians to hide

Figure 11 shows the percent of casualties across all cognitive delays for each civilian response strategy. The all hide response strategy averages the largest number of casualties across all police response times and the some run and some hide strategy averages the smallest number of casualties across all police response times. Civilians are more dispersed when some run and some hide than if they all hide or all run. Additionally, in the some run and some hide scenario, they do not have the bottlenecks at doorways like they sometimes do in the all run scenario. If the police respond in 2 minutes, the some run and some hide strategy and the all run strategy average a similar percentage of casualties, between 8.5 and 10%. If all the civilians hide, the percentage of casualties averages 19%. As the police response time increases from 5 to 10 minutes if all the civilians run, the average percent of casualties increases significantly and moves closer to the average casualties when all civilians hide.

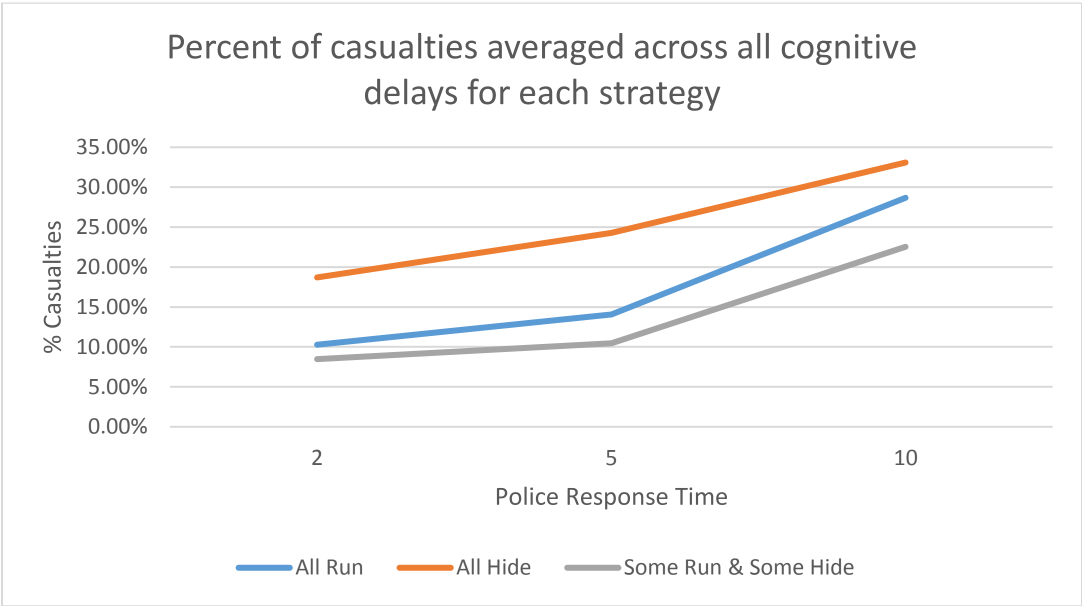

Figure 11: Percentage of casualties averaged across all cognitive delay times for each civilian response strategy

Statistical analysis

A Tukey test is performed on each of the three factors to analyze if the mean for each parameter is statistically different from each other. The results from these tests are shown in Appendix C, Figures 16-18. For the civilian response strategy, the Tukey analysis revealed significantly different means for each of the three strategies. For police response time, the analysis also showed significantly different means for each of the three response times. For cognitive delay, the analysis showed that the 5-minute delay was significantly different from the other three delay times, but the other three were not significantly different from each other.

Each individual scenario's distributions were observed as well. Examples of some of these distributions and summary statistics can be seen in Appendix C, Figures 21 and 22, as well as in Figure 12 below. These distributions are of interest, as they show the variation present in each scenario. The example given here in Figure 12 is for the response strategy of some civilians run and some civilians hide, police response time of 10 minutes, and cognitive delay of 5 minutes. The distribution appears to be pretty normal, with a mean of 0.243 and a median of 0.246. The values range from 0.180 to 0.294.

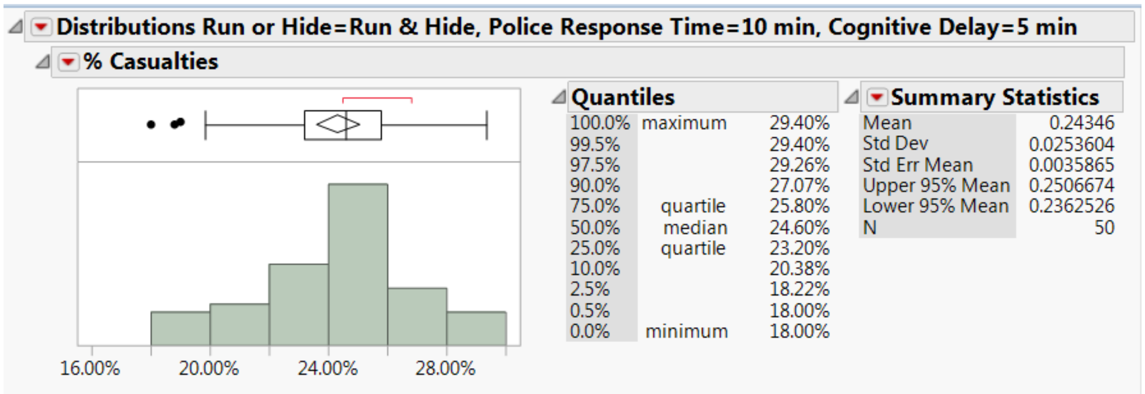

Figure 12: Distribution and summary statistics for the response strategy of some civilians run and some civilians hide, police response time of 10 minutes, and cognitive delay of 5 minutes

A regression model with an analysis of variance (ANOVA) is constructed using all of the 1800 data points over the 36 different scenarios. Appendix C contains the ANOVA table. All three factors are significant at the 0.0001 confidence level, and two interactions are significant (civilian response strategy with police response time, and civilian response strategy with cognitive delay). The F-ratio in the ANOVA table is 1211.17, which results in a p-value of less than 0.0001. The R^2 value from this model (3 main effects and 2 interactions) is 0.84. The ANOVA table indicates that much of the variability is accounted for by the model, and the unexplained random error is low.

Equations 1, 2, and 3 show the individual equations broken out by civilian response strategy:

$$\% \, Casualties = \begin{cases} 0.155 + 0.018 * Police\ Response\ Time - 0.0012 * Cognitive\ Delay & \text{if all civilians hide} \quad (1) \\ -0.0037 + 0.024 * Police\ Response\ Time + 0.022 * Cognitive\ Delay & \text{if all civilians run} \quad (2) \\ 0.0076 + 0.018 * Police\ Response\ Time + 0.013 * Cognitive\ Delay & \text{if some civilians run and some hide} \quad (3) \end{cases}$$

The overall regression model is depicted in Appendix C. For the all hide scenario, the intercept vale is 0.155, or 15.5% casualties. The model predicts an additional 1.8% of casualties for each additional minute of police response time, and a decrease of 0.12% of casualties for each additional minute needed for cognitive delay. For the all run scenario, the intercept value is -0.37%. The model then predicts an additional 2.4% of casualties for each additional minute of police response time and an additional 2.2% of casualties for each additional minute of cognitive delay time. Finally, for the scenario where some civilians run and some civilians hide the intercept value is 0.76%. The model then predicts an additional 1.8% of casualties for each additional minute of police response time and an additional 1.3% of casualties for each additional minute of cognitive delay time.

On average, for every minute increase in police response time, the percentage of casualties increases by approximately 2%. The percentage of casualties in the hide scenario is significantly higher than for either of the other two scenarios, with an intercept value of 15.5% compared to very small intercept values for the other two. Cognitive delay has a very small effect on casualties if all civilians hide. Cognitive delay has a greater impact for the all civilians run strategy and the some civilians hid and some civilians run strategy. For those two strategies, each minute of cognitive delay increases casualties by 2.2% and 1.3%, respectively.

Discussion

The results indicates that the best civilian response strategy for situation simulated in this paper is for some civilians to run and some civilians to hide, regardless of police response time. The next best method would be for all civilians to run, followed lastly by all civilians hiding. When some civilians hide and others run, they are more scattered in the simulation than if they all run or all hide. When the civilians are close together, it is easier for the shooter to get a higher number of casualties in a short period of time, with little walking time between shots. In the situation where some civilians run and some hide, the shooter follows some of the civilians who are evacuating, and then goes back through some of the rooms, where there are less people than there would be in the all civilians hide scenario. In the scenarios where all of the civilians run there are many casualties that occur in the hallway, because that is where all of the civilians end up after whatever length cognitive delay they have. Specifically, they primarily end up towards the exit door, as they get backed up trying to get out the doorway. If there were multiple exits from the classrooms, such as windows, or if the civilians were exiting the building out of multiple doorways, the all-run strategy might then be the best strategy.

The results also suggest that a quick law enforcement response time is an effective way to decrease the number of casualties. Regardless of the cognitive delay time or the civilian response strategy, a faster law enforcement response time always resulted in a fewer number of casualties. This is not surprising, as the only way to neutralize the shooter in this simulation is by law enforcement intervention. In real world active shooter situations, the shootings often end without the arrival of police; often these situations end because the shooter commits suicide or civilians intervene and neutralize the shooter (Blair and Schweit, 2014). The simulation model could be modified to add in unarmed civilians to neutralize the shooter or to add in the scenarios in which the situation ends because the shooter commits suicide.

For cognitive delay affecting the number of casualties, it appears as though a 5-minute cognitive delay time increases the number of casualties. There is no significant difference between the shorter three cognitive delay times. The cognitive delay does seem to make more of a difference in the two scenarios where civilians are running versus having very little effect on the scenarios where all the civilians hide.

Finally, the parameter estimates give a good indication as to what the data from the simulation model is showing. Some key points include the response strategy parameter estimates; the response strategy for all civilians to hide adds an additional 6.4% of casualties per minute while the response strategy for some civilians to run and some civilians to hide subtracts 5.1% of casualties per minute. It is expected that there would be an additional 2% of casualties for each extra minute required for law enforcement officers to arrive on the scene. It is also expected that there would be an additional 1.1% of casualties for each extra minute required for cognitive delay time, though this is also impacted by the interaction between cognitive delay time and civilian response strategy.

CHAPTER 4

CONCLUSIONS AND FUTURE WORK

Conclusions

In active shooter incidents, there may not always be a clear optimal civilian response strategy. The strategy will depend on many factors such as emotional states, individual knowledge of the situations, and cognitive-decision making that cannot be accounted for in a simulation model and will be different for each civilian in the situation. Simulation models can assist in observing various response strategies for civilians and law enforcement officers. Changing the parameters in the simulations and observing the effects can assist law enforcement officers in ensuring proper training for the best possible response to minimize the casualties.

Data for active shootings is limited and researchers rarely get to understand the full picture of what happened leading up to that day and during the incident. Creating simulation models is a good way to assess parameters such as civilian response strategy, police response time, and cognitive delay, as done in this model, along with other variables used by previous researchers, such as shooter magazine capacity, the presence of security guards, or the percentage of unarmed civilians who are willing to engage the attacker.

The results from the simulation model indicate the police response time has the largest impact on the number of casualties. Especially if a building has few exits and all civilians are attempting to exit through the same door, this could increase the number of casualties because bottlenecks at the doorways can occur. A longer cognitive delay indicates an increase in the number of casualties if the delay is substantial – 5-minutes, for instance. Shorter cognitive delays – between 30-seconds and 1-minute – do not have much of an effect on the number of casualties.

Future Work

This model has focused on three parameters in an active shooter situation: the cognitive delay of the civilians, the response time of law enforcement officers, and the response strategy of the civilians. Future research could include additional factors into this model and simulation. One example would be to add in the effect of the civilians blocking the door to the individual rooms so the shooter cannot easily enter, and then hiding.. Other possibilities include varying the shooter accuracy, adding civilians with concealed carry weapons, or adding unarmed civilian fighters. Knowing that many incidents end due to civilian intervention, it would be interesting to add civilian fighters into the simulation to see what effect they had on the number of casualties.

Other possible future work would include doing studies to assess the accuracy of some of the variables in the model. For example, shooter accuracy is set at 75% in the simulation. It would be interesting to research what investigators believe is an approximate number for shooter accuracy in active shooter situations, and modify that number in the model to relate. Running speed of the civilian is another variable that could be modified to more accurately reflect real evacuation situations. Overall, data from past simulation models may make it possible to increase the accuracy of the model by altering some of the set variables.

Finally, as discussed in Chapter 2, future work could include combining simulation model work with a risk analysis like the one discussed to get a more comprehensive risk model. This work could help law enforcement officers ensure they are preparing in the best possible way to react to these situations. Simulation models for active shooter situations with various parameters could be run and the effects of police response time or police response strategy on the number of casualties in the situation could be observed. Law enforcement could then use the results of these simulations to modify the training methods used to prepare for these situations.

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APPENDIX A

SIMULATION MODEL EXAMPLES

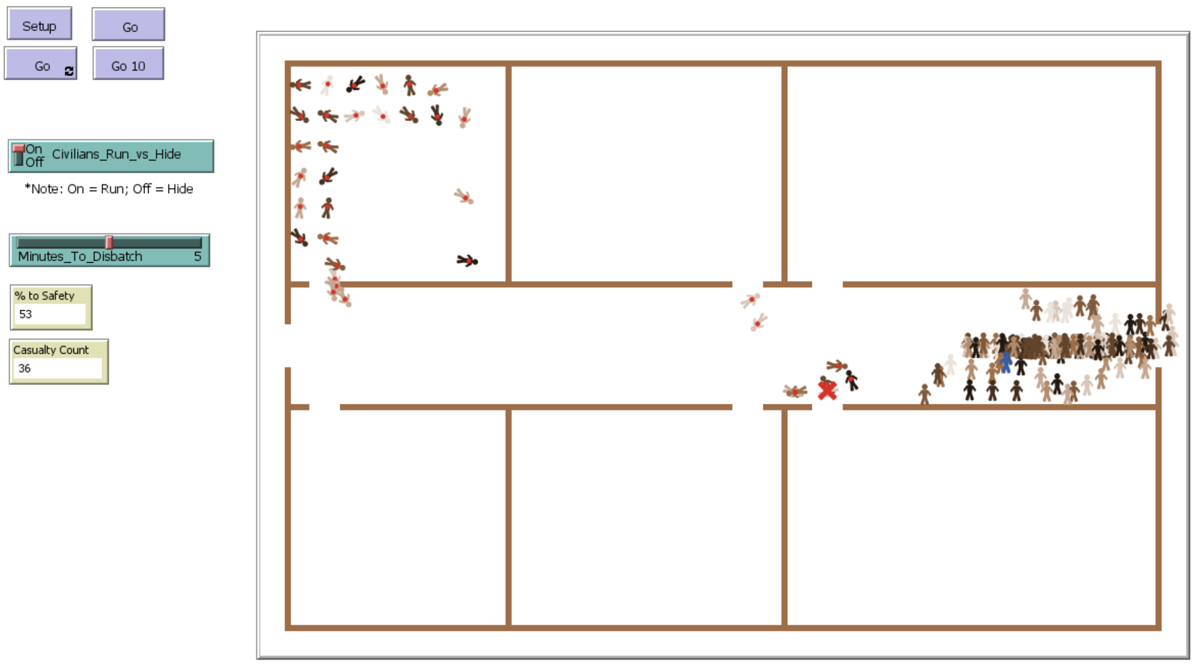


Figure 13: Civilian response strategy of ‘run’ with a 2-minute cognitive delay and 5-minute police response time.

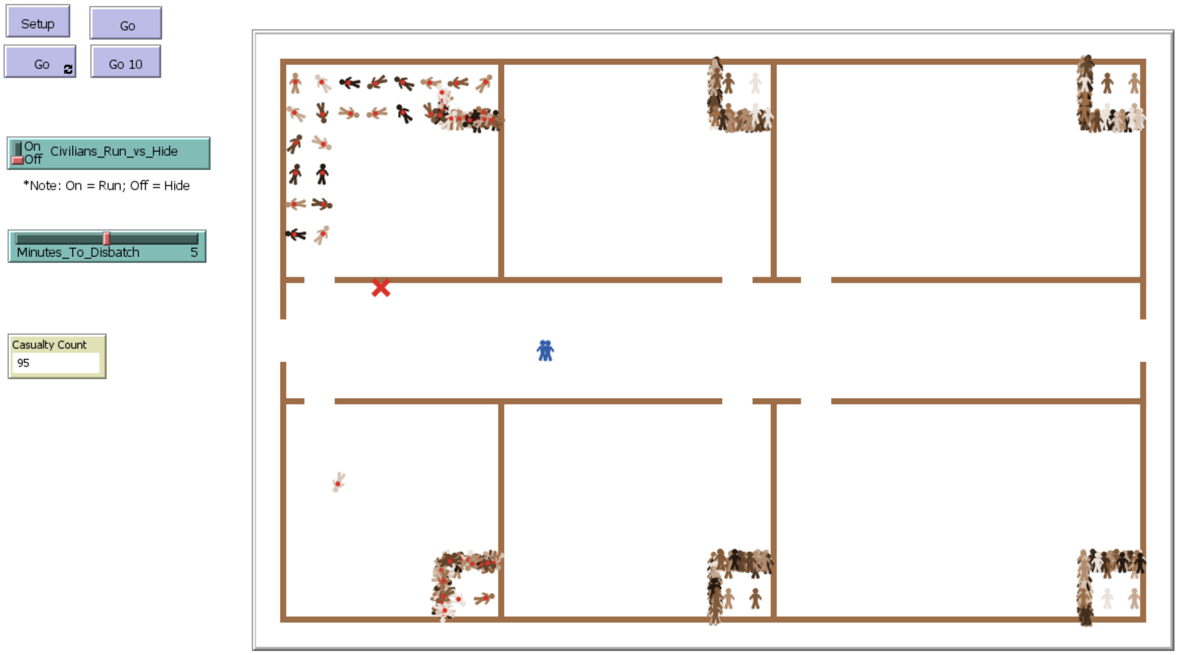


Figure 14: Civilian response strategy of ‘hide’ with a 2-minute cognitive delay and 5-minute police response time.

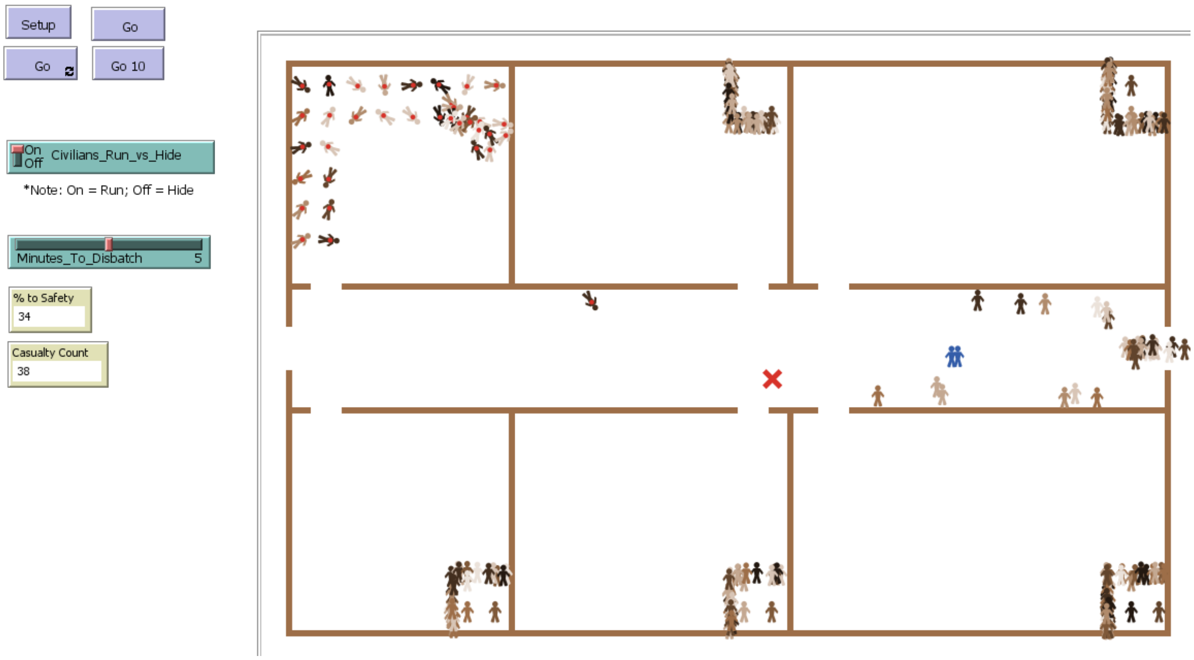


Figure 15: Civilian response strategy of 'some run and some hide' with a 2-minute cognitive delay and 5-minute police response time.

APPENDIX B

SIMULATION MODEL TRIAL RESULTS

Table 2: Averages across 50 trials for each of the 36 different parameter combinations.

All Civilians Run			
	2	**5**	**10**
0.5	8.42%	14.12%	26.35%
1	6.98%	11.03%	25.48%
2	8.05%	10.11%	27.07%
5	17.67%	21.08%	35.79%
Average:	**10.28%**	**14.08%**	**28.67%**

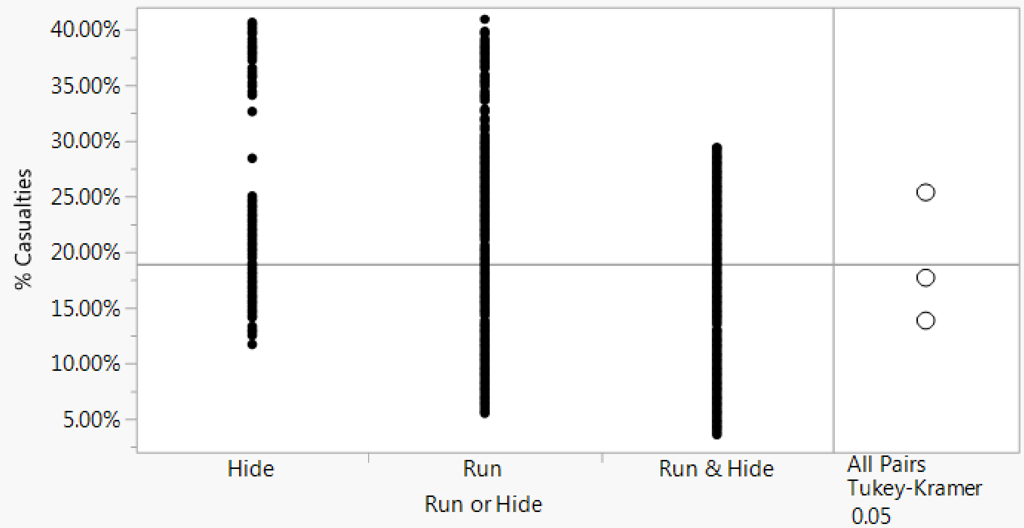
All Civilians Hide			
	2	**5**	**10**
0.5	19.23%	24.37%	30.80%
1	18.54%	24.22%	34.57%
2	18.99%	24.40%	34.94%
5	18.05%	24.09%	32.05%
Average:	**18.70%**	**24.27%**	**33.09%**

Some Civilians Run & Some Civilians Hide			
	2	**5**	**10**
0.5	5.82%	8.31%	21.05%
1	6.63%	8.32%	21.06%
2	9.21%	9.60%	23.70%
5	12.24%	15.67%	24.34%
Average:	**8.48%**	**10.48%**	**22.54%**

APPENDIX C

SIMULATION MODEL JMP OUTPUTS

Oneway Analysis of % Casualties By Run or Hide



Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.34565	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	Hide	Run	Run & Hide
Hide	-0.01086	0.06585	0.10433
Run	0.06585	-0.01086	0.02762
Run & Hide	0.10433	0.02762	-0.01086

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level				Mean
Hide	A			0.25353167
Run		B		0.17682500
Run & Hide			C	0.13834167

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
Hide	Run & Hide	0.1151900	0.0046292	0.1043316	0.1260484	<.0001*
Hide	Run	0.0767067	0.0046292	0.0658483	0.0875651	<.0001*
Run	Run & Hide	0.0384833	0.0046292	0.0276249	0.0493417	<.0001*

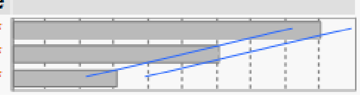
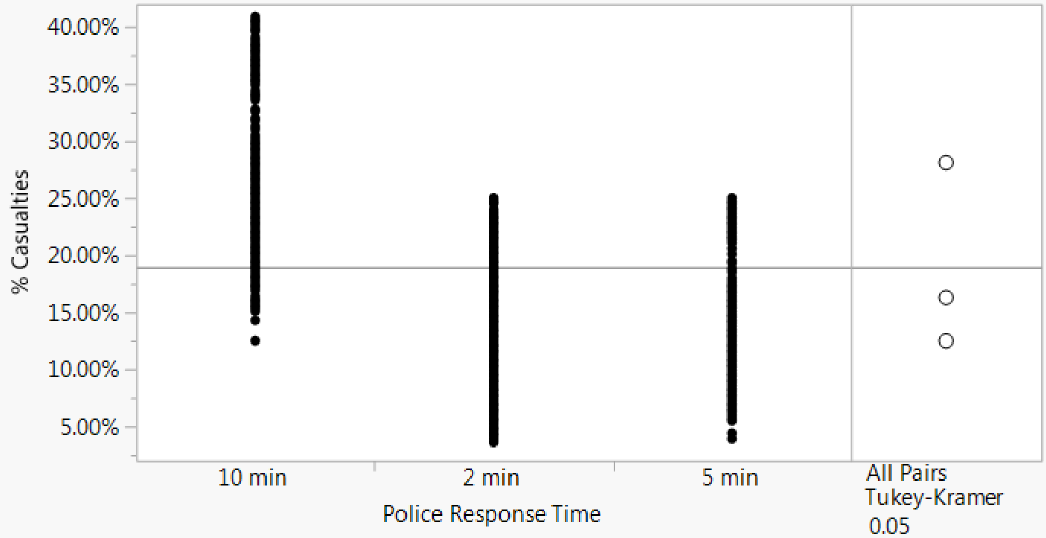


Figure 16: Tukey's method for civilian response strategy

Oneway Analysis of % Casualties By Police Response Time



Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.34565	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	10 min	5 min	2 min
10 min	-0.00888	0.10930	0.14717
5 min	0.10930	-0.00888	0.02898
2 min	0.14717	0.02898	-0.00888

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level				Mean
10 min	A			0.28097667
5 min		B		0.16279333
2 min			C	0.12492833

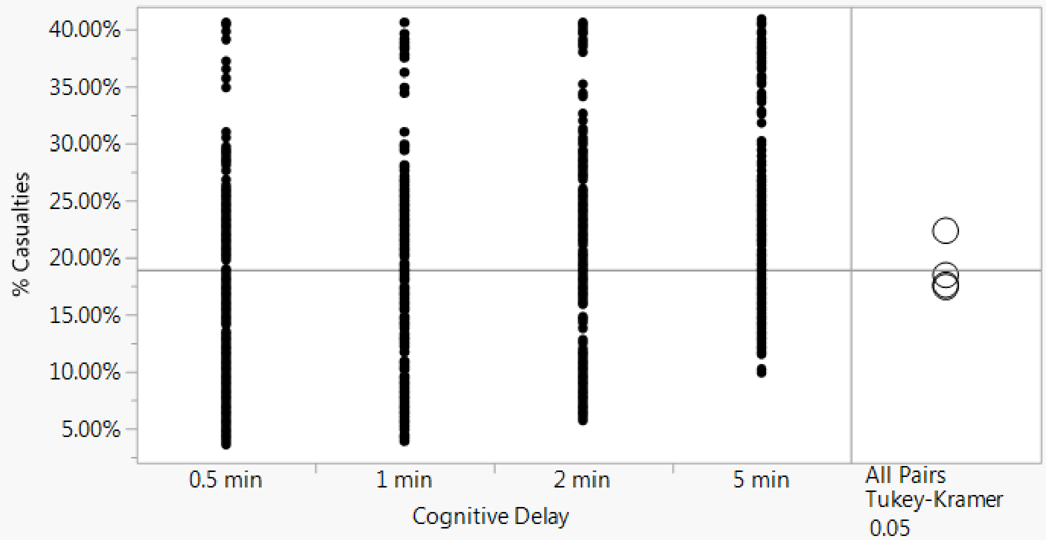
Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
10 min	2 min	0.1560483	0.0037863	0.1471669	0.1649298	<.0001*
10 min	5 min	0.1181833	0.0037863	0.1093019	0.1270648	<.0001*
5 min	2 min	0.0378650	0.0037863	0.0289836	0.0467464	<.0001*

Figure 17: Tukey's method for police response time

Oneway Analysis of % Casualties By Cognitive Delay



Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.57144	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	5 min	2 min	0.5 min	1 min
5 min	-0.01565	0.02316	0.03159	0.03341
2 min	0.02316	-0.01565	-0.00723	-0.00540
0.5 min	0.03159	-0.00723	-0.01565	-0.01383
1 min	0.03341	-0.00540	-0.01383	-0.01565

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level			Mean
5 min	A		0.22334444
2 min		B	0.18453111
0.5 min		B	0.17610667
1 min		B	0.17428222

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
5 min	1 min	0.0490622	0.0060860	0.033412	0.0647120	<.0001*
5 min	0.5 min	0.0472378	0.0060860	0.031588	0.0628876	<.0001*
5 min	2 min	0.0388133	0.0060860	0.023164	0.0544631	<.0001*
2 min	1 min	0.0102489	0.0060860	-0.005401	0.0258987	0.3324
2 min	0.5 min	0.0084244	0.0060860	-0.007225	0.0240743	0.5094
0.5 min	1 min	0.0018244	0.0060860	-0.013825	0.0174743	0.9906

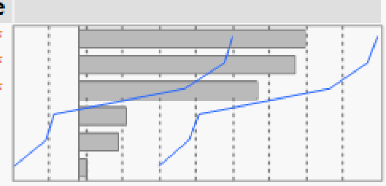


Figure 18: Tukey’s method for cogntive delay time

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	27	0.5800261	0.021482	20.3080
Pure Error	1764	1.8660191	0.001058	**Prob > F**
Total Error	1791	2.4460453		<.0001*
				Max RSq
				0.8810

Summary of Fit

RSquare	0.843994
RSquare Adj	0.843297
Root Mean Square Error	0.036956
Mean of Response	0.189566
Observations (or Sum Wgts)	1800

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	13.233129	1.65414	1211.166
Error	1791	2.446045	0.00137	**Prob > F**
C. Total	1799	15.679174		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0527897	0.00203	26.01	<.0001*
Civilian Response Strategy[Hide]	0.0639656	0.001232	51.93	<.0001*
Civilian Response Strategy[Run]	-0.012741	0.001232	-10.34	<.0001*
Police Response Time	0.0199275	0.000264	75.49	<.0001*
Cognitive Delay	0.0112253	0.000499	22.49	<.0001*
Civilian Response Strategy[Hide]*(Police Response Time-5.66667)	-0.002001	0.000373	-5.36	<.0001*
Civilian Response Strategy[Run]*(Police Response Time-5.66667)	0.0036889	0.000373	9.88	<.0001*
Civilian Response Strategy[Hide]*(Cognitive Delay-2.125)	-0.012428	0.000706	-17.61	<.0001*
Civilian Response Strategy[Run]*(Cognitive Delay-2.125)	0.0107386	0.000706	15.22	<.0001*

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Civilian Response Strategy	2	2	4.1267232	1510.798	<.0001*
Police Response Time	1	1	7.7832896	5698.943	<.0001*
Cognitive Delay	1	1	0.6910687	506.0021	<.0001*
Civilian Response Strategy*Police Response Time	2	2	0.1336773	48.9394	<.0001*
Civilian Response Strategy*Cognitive Delay	2	2	0.4983702	182.4539	<.0001*

Figure 19: ANOVA analysis with significant interaction parameters

$$
\begin{aligned}
&0.05279 \\
&+\begin{pmatrix} All\ Hide & \rightarrow & 0.06397 \\ All\ Run & \rightarrow & -0.01274 \\ Some\ Run, Some\ Hide & \rightarrow & -0.05122 \end{pmatrix} \\
&+ 0.01993 \bullet Police\ Response\ Time \\
&+ 0.01123 \bullet Cognitive\ Delay \\
&+\begin{pmatrix} All\ Hide & \rightarrow & (Police\ Response\ Time - 5.66667) \bullet -0.00200 \\ All\ Run & \rightarrow & (Police\ Response\ Time - 5.66667) \bullet 0.00369 \\ Some\ Run, Some\ Hide & \rightarrow & (Police\ Response\ Time - 5.66667) \bullet -0.00169 \end{pmatrix} \\
&+\begin{pmatrix} All\ Hide & \rightarrow & (Cognitive\ Delay - 2.125) \bullet -0.01243 \\ All\ Run & \rightarrow & (Cognitive\ Delay - 2.125) \bullet 0.01074 \\ Some\ Run, Some\ Hide & \rightarrow & (Cognitive\ Delay - 2.125) \bullet 0.00169 \end{pmatrix}
\end{aligned}
$$

Equation 4: Prediction expression given all significant interaction terms

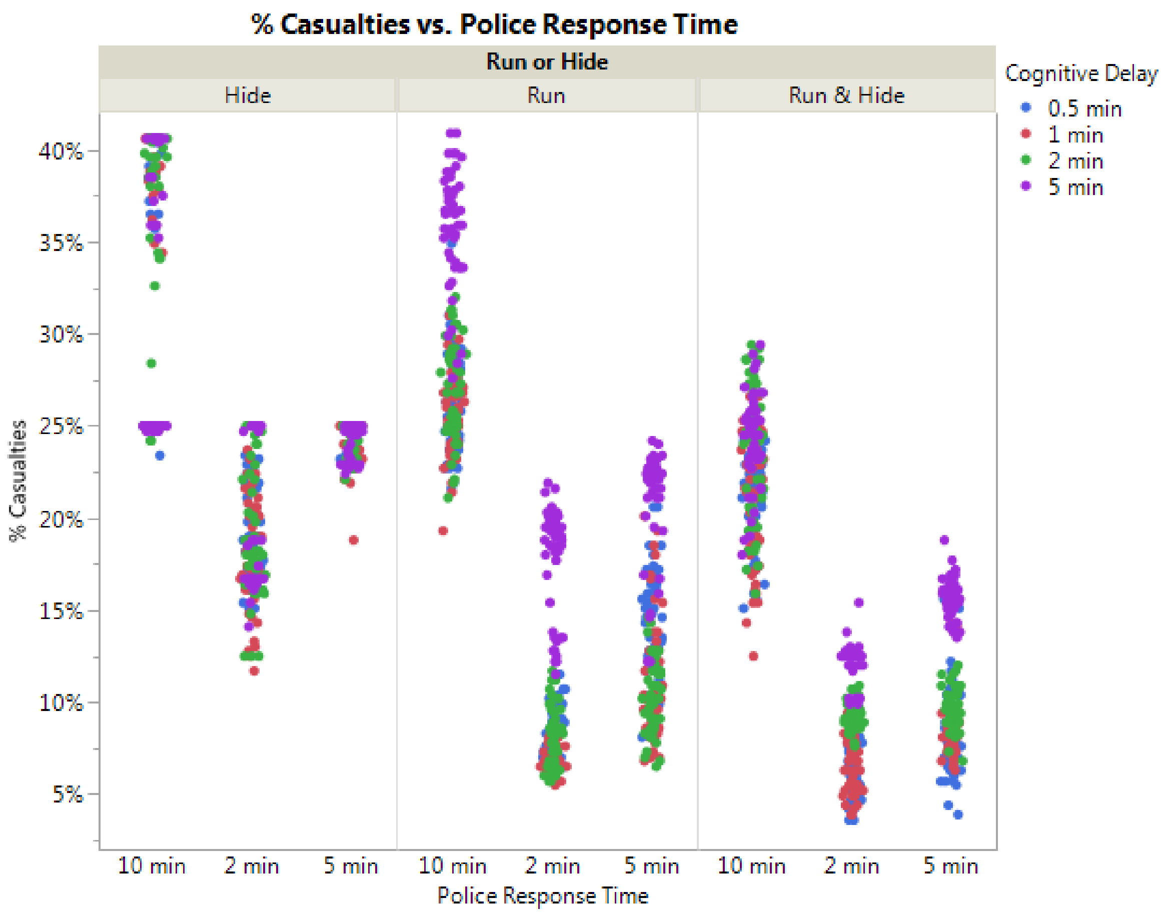


Figure 20: Graph builder output with all data points

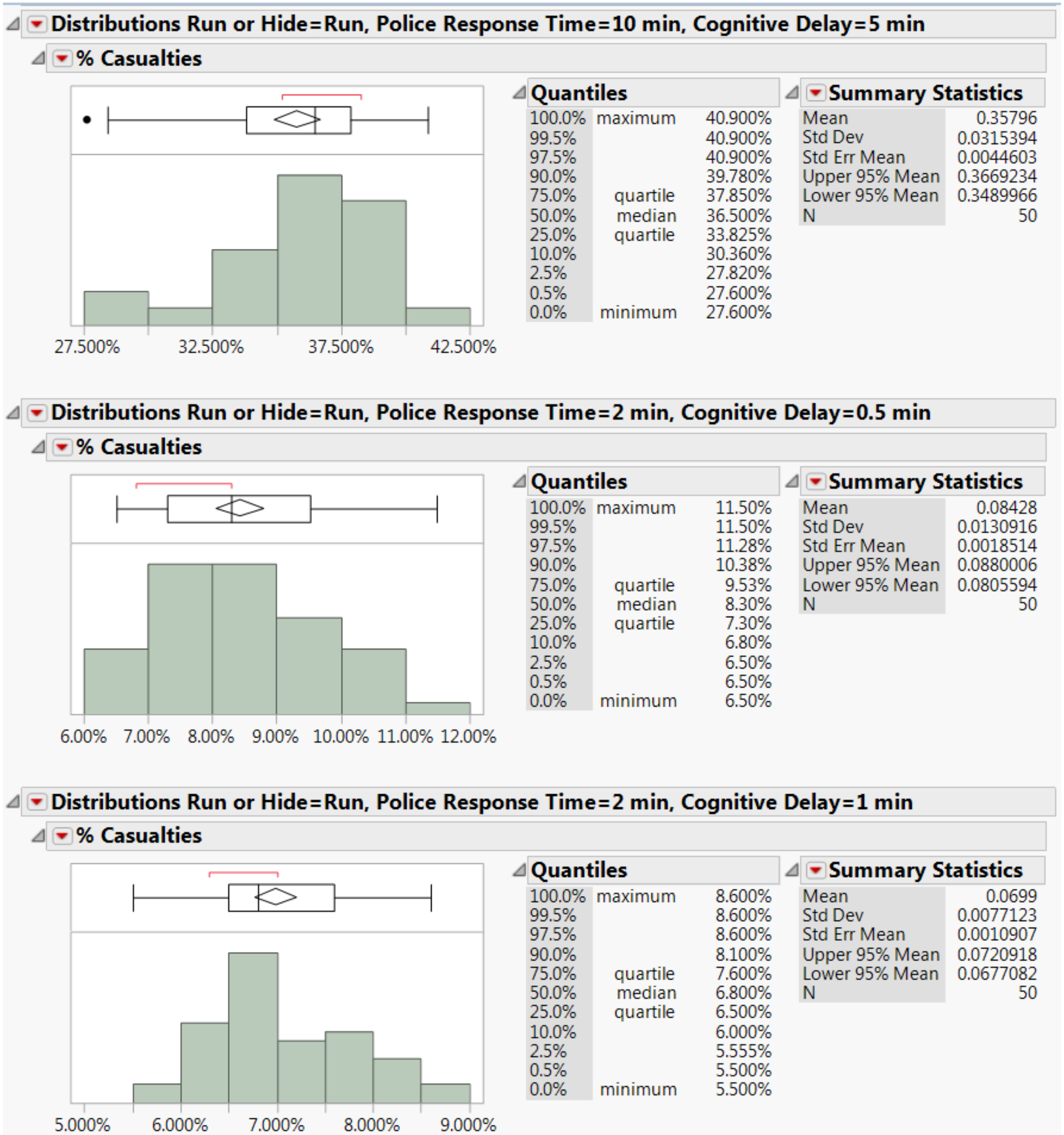


Figure 21: Examples of individual distributions for each of the 36 scenarios

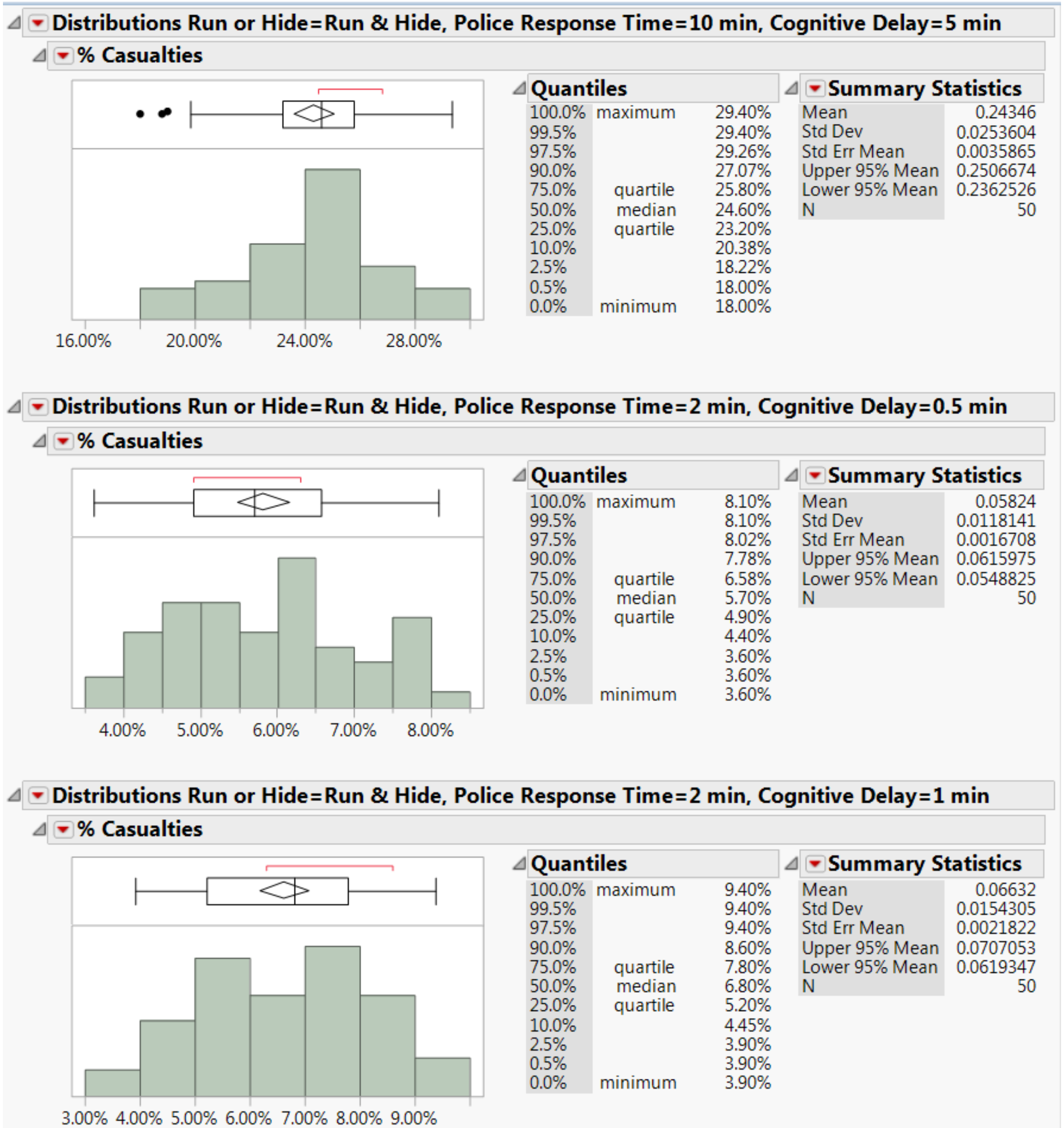


Figure 22: Examples of individual distributions for each of the 36 scenarios