



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**FINDING SAFETY IN NUMBERS: EXPLORING THE  
POSSIBILITIES OF TERRORISM CONSEQUENCE  
MODELS AS PUBLIC SAFETY PLANNING TOOLS**

by

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December 2021

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**FINDING SAFETY IN NUMBERS: EXPLORING THE POSSIBILITIES OF  
TERRORISM CONSEQUENCE MODELS AS PUBLIC SAFETY PLANNING  
TOOLS**

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## **ABSTRACT**

Special events and mass gatherings present significant vulnerabilities across the United States and remain attractive targets for violent extremists. This study contends that a more realistic understanding of their human consequences (i.e., civilians killed or wounded) can help inform the deployment of limited resources and personnel to mitigate the potential consequences. Specifically, this thesis investigates how predictive analysis models could be developed, vetted, and implemented as public safety planning tools. The study examines the relationship between the crowd size and the killed or wounded rates of common terrorism attack types. When a relationship exists, the research explores how that relationship can be expressed as a mathematical model that predicts future lethality. The relationship between the crowd size, killed or wounded, and attack type is examined using regression analysis. Of the five attack types reviewed, only two yielded enough data for this level of statistical analysis. The results show a mostly weak relationship, which suggests that overall crowd size holds little influence over the total casualty rate. Instead, the weapon's effective range, crowd density, and ease of egress are recommended as future areas of continued study. This thesis also suggests continued research and development of probabilistic consequence models while identifying options for collaboration and implementation.

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## LIST OF ACRONYMS AND ABBREVIATIONS

|         |                                                                               |
|---------|-------------------------------------------------------------------------------|
| AI      | artificial intelligence                                                       |
| CETIS   | Center for Terrorism and Intelligence Studies                                 |
| CIA     | Central Intelligence Agency (U.S.)                                            |
| COE     | Center of Excellence (within DHS)                                             |
| COI     | community of interest (within HSIN)                                           |
| DHS     | Department of Homeland Security (U.S.)                                        |
| DNBI    | diseases and nonbattle injuries                                               |
| DNI     | Director of National Intelligence (U.S.)                                      |
| DOD     | Department of Defense (U.S.)                                                  |
| EMCAPS  | Electronic Mass Casualty Assessment and Planning Scenarios                    |
| FBIS    | Federal Broadcast Information Service                                         |
| GTD     | Global Terrorism Database                                                     |
| HSIN    | Homeland Security Information Network (within DHS)                            |
| IC      | intelligence community                                                        |
| IED     | improvised explosive device                                                   |
| ITERATE | International Terrorism: Attributes of Terrorist Events                       |
| KIA     | killed in action                                                              |
| MAPS    | Mass Attacks in Public Spaces                                                 |
| NPS     | Naval Postgraduate School                                                     |
| NTAC    | National Threat Assessment Center (within USSS)                               |
| OEM     | Office of Emergency Management (within City of Philadelphia government)       |
| OSC     | Open Source Center (within CIA)                                               |
| OSE     | Open Source Enterprise (within DNI)                                           |
| OSIF    | open-source information                                                       |
| OSINT   | open-source intelligence                                                      |
| PACER   | National Center for the Study of Preparedness and Catastrophic Event Response |
| PAI     | publicly available information                                                |
| PFD     | Philadelphia Fire Department                                                  |

|       |                                                                   |
|-------|-------------------------------------------------------------------|
| PGIS  | Pinkerton Global Intelligence Service                             |
| PPD   | Philadelphia Police Department                                    |
| RDWTI | RAND Corporation's Database of Worldwide Terrorism Incidents      |
| RISK  | Risk Management Division (within City of Philadelphia government) |
| S&T   | Science and Technology Directorate (within DHS)                   |
| SEAR  | Special Event Assessment Rating                                   |
| SETF  | Special Event Task Force (within City of Philadelphia government) |
| SEWG  | Special Event Working Group (within DHS)                          |
| START | Study of Terrorism and Responses to Terrorism                     |
| TRIA  | Terrorism Risk Insurance Act                                      |
| USSS  | United States Secret Service                                      |
| VBIED | vehicle-borne improvised explosive device                         |
| WIA   | wounded in action                                                 |
| WITS  | Worldwide Incidents Tracking System                               |

## EXECUTIVE SUMMARY

This thesis explores the development and application of probabilistic risk assessment tools that predict a domestic terrorist attack's possible human consequence (i.e., civilians killed or wounded) if conducted against a mass gathering or special event. Special events make up a significant part of the fabric of any healthy community yet are commonly targeted by violent extremists worldwide. The shared vulnerability of mass gatherings across the United States warrants a better suite of risk assessment tools for public safety planners and practitioners than what is currently available. This study contends that a more realistic understanding of these consequences can help inform the deployment of limited resources and personnel to mitigate an attack's lethal outcomes.

To model terrorism consequences, the research must first determine the relationship between common attack variables that influence their outcomes. This research examines the relationship between common attack types, the overall crowd size at the time of the attack, and the ultimate killed and wounded rates resulting from the attack. The five common attack types include attacks using improvised explosive devices (IEDs), firearms, vehicles as a weapon (ramming vehicles), edged weapons, and incendiary devices. The data used to analyze common attack types and their resulting casualties come from actual terror attacks documented in the Global Terrorism Database (GTD).<sup>1</sup> The crowd size for each incident selected for analysis represents documented, publicly available, open-source information.

The literature review identifies how terrorism databases evolved and explains the selection of the GTD as the most comprehensive and appropriate dataset available for this study. The literature review also examines how open-source information is now a standard component of terrorism research, which lends credibility to the research design. The available literature identifies a gap in risk assessment tools for public safety planners,

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<sup>1</sup> "Global Terrorism Database," National Consortium for the Study of Terrorism and Responses to Terrorism, accessed November 27, 2019, <https://www.start.umd.edu/gtd/>.

which highlights the need for continued and expanded quantitative research into terrorism risk and consequences.

After applying a series of exclusions and removing outliers, only two attack types (IEDs and firearms) yielded a large enough sample size for regression analysis. The statistical significance provided by regression analysis determines the confidence level to answer this study's secondary question: How can the results be used to develop a consequence model that predicts future lethality rates of terror attacks against mass gatherings? The results can be evaluated for their applicability as a consequence model only if a relationship exists.

The findings reveal a weak correlation between an IED attack and the overall crowd size's influence over the resulting casualties. Attacks involving firearms show a slightly stronger (moderate) correlation. Although the findings of this study indicate a lack of correlation between crowd size and casualty rates within the IED and active shooter attack vectors, the results still have merit. The descriptive analysis provides helpful markers that can be used to set parameters for Monte Carlo simulations. Monte Carlo simulations are computer-generated random samplings within a predefined set of boundaries. The historical data and analysis completed by this research can be used to establish those boundaries for the Monte Carlo simulations. Those simulations can then generate a large enough sample size for all five attack types within realistic, data-driven limits. Although this method may not be as accurate as creating a consequence model solely based on historical events, the use of Monte Carlo simulation is a good compromise and a common alternative when sample sizes are small. The appendices provide a prototype model using Monte Carlo simulation, as well as the detailed results of all statistical analyses completed in this study.

The implications of this thesis relate to the potential of the continued study and advancement of this topic that is only possible with more rigorous application of academic research and statistical analysis. Although this project stopped short of a fully developed consequence model for all attack types considered, the findings reveal some powerful benefits of thoroughly researched, tested, and vetted predictive analysis tools. Four key

implications were identified during this research. They serve as recommended topics for further study:

- (1) **The overall crowd size matters less than hypothesized.** Instead, the future pursuit of a probabilistic consequence model would benefit from research into other crowd dynamics, such as the maximum effective range of the attack type, crowd density, and ease of egress. An assessment into each of these components' impact on the attack type's outcomes can be incorporated into a more holistic model that factors in more than just the crowd size.
- (2) **Pockets of risk within an event are just as important as an overall risk score.** A model that can assess individual pockets of risk (to include variables like crowd size, crowd density, and ease of egress at those pockets) within a single event is worth pursuing since most attacks observed in this study only affected a fraction of the overall crowd. Providing these professionals with an easily accessible, predictive analysis tool that identifies the most probable outcomes of an attack within those individual pockets of risk supports better preparedness through data-driven prevention and mitigation strategies.
- (3) **Outlier events must be accounted for and merit additional research.** A clear implication of this study is the influence of outlier events. This research defined an outlier as a terrorist incident that exceeded 2.5 standard deviations ( $2.5\sigma$ ) from the norm. The findings indicate the value of appropriately accounting for outliers, as evidenced in the differences between initial and adjusted results. Furthermore, analyzing the variables and tactics that create casualties at such a high rate can be incorporated into a consequence model as a maximum of maximums. The result would be a simulation that would set realistic ranges of the most likely casualty rates while still noting potential worst-case scenarios based on historical data.
- (4) **Prioritize the use of artificial intelligence in public sector research.** The role and value of artificial intelligence (AI) in the future of public safety research cannot be understated. A properly written algorithm implemented as an AI function could scour the same open-source information to pair crowd sizes with GTD casualty rates in a fraction of the time it took this research team. In this way, AI can supplement this type of qualitative research, which reduces the overall burden on staff members. Such an AI program can also be modified to search for multiple characteristics of crowds or terrorist attacks in a way that is constantly learning and improving. Well-resourced organizations that host and maintain extensive

databases, such as the GTD, are ideal laboratories to experiment and refine AI's potential use in public safety research.

The overarching recommendation is to advance this research so that it may lead to a widely accepted and easily accessible casualty prediction tool for public safety practitioners. Just as the U.S. military developed and maintains a set of risk assessment calculations and products, the same set of resources should be created and implemented to help mitigate domestic threats against special events and mass gatherings. A pathway to implementation includes drawing on preexisting resources and networks because most of the pieces already exist within the Department of Homeland Security (DHS). The DHS Science and Technology Directorate oversees a Centers of Excellence network that can function as the academic, research arm of developing and vetting risk assessment tools for mass gatherings. Once ready, the DHS Special Event Working Group is an ideal host for providing broad access and training of these risk assessment tools through the DHS Homeland Security Information Network.

The threats against soft targets are unlikely to lessen. However, their consequences can be more effectively mitigated with properly researched, tested, and implemented risk analysis products. Regardless of whether the approach used in this thesis is followed or another methodology is chosen, the continued focus on developing easily accessible and realistic consequence models is greatly needed in the homeland security community. A clear understanding of the potential consequences is required for risk to be appropriately managed, mitigated, transferred, or accepted. Focusing the efforts of researchers, statisticians, and policymakers to develop and maintain a domestic terrorism consequence model is sorely needed but well within reach.

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## I. INTRODUCTION

“The thing on my mind all the time, and Norm’s, was the question constantly asked: What will this war cost in casualties? How many young men and women will we lose?”<sup>1</sup> General Colin Powell shared this haunting and prevailing thought as he reflected on the weight of the decisions he and General H. Norman Schwarzkopf Jr. wrestled with in advance of Operation Desert Storm. General Powell, then serving as the chairman of the Joint Chiefs of Staff, noted that some pre-invasion casualty predictions included ranges of 10,000 to 20,000 killed.<sup>2</sup> For example, the *Los Angeles Times* reported in September 1990 that officials in the Bush Administration estimated as many as 30,000 U.S. servicemembers might be killed in the effort.<sup>3</sup> By January 9, 1991, just eight days before the invasion, the Pentagon ordered over 16,000 body bags.<sup>4</sup>

In hindsight, the Persian Gulf War lasted less than 100 hours and is regarded as one of the most successful military campaigns in U.S. history.<sup>5</sup> The U.S. military casualties totaled 382 total in-theater deaths, which included 147 hostile deaths (i.e., death caused by direct combat) and 235 non-hostile deaths (often referred to as casualties from disease and

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<sup>1</sup> “Colin Powell Remembers Desert Storm 25 Years Later,” *Military Officers of America Association*, January 2016, 66–67.

<sup>2</sup> *Military Officers of America Association*, 67.

<sup>3</sup> “Potential War Casualties Put at 100,000: Gulf Crisis: Fewer U.S. Troops Would Be Killed or Wounded than Iraq Soldiers, Military Experts Predict,” *Los Angeles Times*, September 5, 1990, <https://www.latimes.com/archives/la-xpm-1990-09-05-mn-776-story.html>.

<sup>4</sup> Joseph P. Englehardt, *Desert Shield and Desert Storm. A Chronology and Troop List for the 1990–1991 Persian Gulf Crisis* (Carlisle Barracks, PA: Strategic Studies Institute, U.S. Army War College, 1991), 47, <https://doi.org/10.21236/ADA234743>.

<sup>5</sup> “Persian Gulf War” or “First Gulf War” refers to Operations Desert Shield and Desert Storm between the dates of August 2, 1990, and February 28, 1991.

nonbattle injuries or “DNBI”).<sup>6</sup> Of the 147 U.S. servicemembers killed in combat, 35 died as a result of friendly fire.<sup>7</sup>

For centuries—perhaps as long as the history of armed conflict—military officers, politicians, policymakers, frontline troops, and common citizens who find themselves at the precipice of armed conflict confront the same sobering question as General Powell, what will be the cost in human life? The underlying question persists, “Is the sacrifice of human life worth the effort?” In response, the practice of estimating casualties emerges to help decision-makers determine the overall risk and anticipate logistical demands.

Just as the tools and tactics of warfare greatly evolved over the 20th century, so did the means of predicting the killed and wounded in combat. General axioms or rules of thumb were replaced by a hyper-focused application of statistical analysis. The rate of killed in action (KIA) and wounded in action (WIA) varies throughout U.S. military history largely due to advancements in weapons and tactics. The lethality of combat is then counterbalanced by improvements in body armor and field medicine, which improve survivability. The Naval Health Research Center identifies additional variables commonly included in the calculus of war:

Casualty rate estimates can be refined through a number of adjustment factors, including type or number of troops engaged, battle intensity, geographical region, and the type or phase of an operation...adjustment factors are weather, terrain, posture (offensive or defensive attacks), troop size, opposition strength, surprise of attack, sophistication of enemy, and pattern of operations.<sup>8</sup>

These fundamental factors influence battle plans and shape military strategy throughout the ages to the present day.

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<sup>6</sup> “DCAS Reports—Persian Gulf War Casualty Summary,” Defense Casualty Analysis System, accessed July 11, 2020, [https://dcas.dmdc.osd.mil/dcas/pages/report\\_gulf\\_sum.xhtml](https://dcas.dmdc.osd.mil/dcas/pages/report_gulf_sum.xhtml).

<sup>7</sup> Michael O’Hanlon, “Estimating Casualties in a War to Overthrow Saddam,” *Orbis* 47, no. 1 (December 2003): 26, [https://doi.org/10.1016/S0030-4387\(02\)00172-2](https://doi.org/10.1016/S0030-4387(02)00172-2).

<sup>8</sup> James Zouris, Edwin D’Souza, and Vern Wing, *A Statistical Approach for Estimating Casualty Rates during Combat Operations*, Report No. 13–61 (San Diego, CA: Naval Health Research Center, 2013), 3, <https://apps.dtic.mil/dtic/tr/fulltext/u2/a621488.pdf>.

The U.S. military uses casualty predictions to assess the opportunity cost of action compared to the estimated loss of life in return. Thankfully, the United States severely overestimated the casualty rates before the Gulf War, which resulted in far fewer killed and injured than first expected. Nevertheless, the United States was willing to risk losing over 10,000 service members by invading Iraq as opposed to pursuing any remaining alternatives at the time. At some point during the pre-invasion planning, the estimate of 10,000–20,000 killed during this campaign was calculated and delivered to Generals Powell and Schwarzkopf for what was surely a difficult decision. However, the focus of this thesis is not on the decision itself, nor on any leadership lessons to be gained from the Gulf War. The focus, here, is the calculation.

This thesis explores the potential need and practicality of adopting a similar casualty projection model (or “consequence model”) for domestic purposes. Instead of predicting a range of killed or wounded among U.S. service members in direct combat, a repurposed consequence model for use by public safety professionals could estimate casualties caused by violent extremism within the United States. Specifically, this research examines the impacts of terrorism upon a common vulnerability found in nearly every community across the nation, mass gatherings and special events.

## **A. STATEMENT OF THE PROBLEM**

Threats against mass gatherings and special events are pervasive. The U.S. Secret Service’s (USSS) National Threat Assessment Center (NTAC) began an annual threat assessment in 2017 titled *Mass Attacks in Public Spaces* (MAPS). The USSS identified 89 mass attacks between 2017–2019 in communities across the nation.<sup>9</sup> Of note, the MAPS assessment is not focused solely on attacks against public gatherings or special events. However, the report does illustrate the vulnerabilities present in public spaces. The U.S. Department of Homeland Security’s (DHS) 2018 report titled *Soft Targets and Crowded Places—Security Plan Overview* also acknowledges that places of common, public

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<sup>9</sup> United States Secret Service, *Mass Attacks in Public Spaces—2019* (Washington, DC: National Threat Assessment Center, 2020), 3, <https://www.secretservice.gov/sites/default/files/reports/2020-09/MAPS2019.pdf>.

assembly have frequently been targeted. The report states, “The Intelligence Community has assessed that, for the foreseeable future, soft targets and crowded places will continue to remain attractive targets for various threat actors.”<sup>10</sup> This thesis accepts the inherent vulnerabilities present at mass gatherings, such as a planned event, and identifies a gap in readily accessible planning tools to predict potential consequences if an attack were to occur.

Presently, few resources are available to help public safety planners realistically assess the possible consequences of an attack. The literature review highlights some advances in probabilistic consequence models, but none that specifically assess the impacts of common terrorism attack methods against mass gatherings. The DHS dedicates personnel and resources to collect special event data from across the United States and evaluate those events in the context of their national significance. Although this analysis is helpful to federal partners, further examination reveals a gap of information available to local planners and practitioners.

Every September, the DHS Special Event Working Group (SEWG) initiates a data call that asks each county in the nation to submit known special event data to an online repository. After gathering a large amount of data for each event, jurisdictions submit the special event information to the DHS-SEWG, which then uses this dataset to perform risk and threat assessments. The DHS provides local jurisdictions with a single number rating that reflects the DHS’ determination of the event’s national significance, as shown in Table 1.

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<sup>10</sup> Department of Homeland Security, *U.S. Department of Homeland Security Soft Targets and Crowded Places Security Plan Overview* (Washington, DC: Department of Homeland Security, 2018), 1, <https://www.dhs.gov/publication/securing-soft-targets-and-crowded-places>.

Table 1. Department of Homeland Security Special Event Assessment Rating (SEAR).<sup>11</sup>

| Rating | Definition                                                                                                                    |
|--------|-------------------------------------------------------------------------------------------------------------------------------|
| SEAR 1 | A significant event with national and/or international importance that may require extensive federal interagency support.     |
| SEAR 2 | A significant event with national and/or international importance that may require some level of federal interagency support. |
| SEAR 3 | An event of national and/or international importance that requires only limited federal support.                              |
| SEAR 4 | An event with limited national importance that is managed at the state and local level.                                       |
| SEAR 5 | An event that may be nationally recognized but generally has local or state importance.                                       |

However, the DHS shares a more complete risk profile developed from this data with a select group of federal partners. The local jurisdiction that originally provided the information can only receive the numerical SEAR score.

Homeland security practitioners are placed on a better footing to mitigate those outcomes when they understand the potential consequences (i.e., civilian victims) of common attack methods against public spaces. This research advocates the need for widely available, standardized, and vetted risk assessment tools for special events. Additionally, the thesis attempts to model consequences using common variables present during attacks against mass gatherings. The variables analyzed include crowd size at the time of attack, the type of attack method used, and the resulting casualty rate. The research examines what relationship exists between these three variables. If a relationship or correlation exists, the study determines to what degree those correlations can be used to develop a realistic consequence model. Several mathematical and statistical analysis approaches can be applied to developing a consequence model. The research design implemented in this study is deliberately simplified and is intended as a proof of concept.

## B. BACKGROUND

The background section expands on the problem statement by providing deeper insight into two resources used in this study as a means of establishing their credibility for this research. These resources include the evolution and application of publicly available

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<sup>11</sup> Source: Department of Homeland Security, “National Special Events Data Call Background Information,” July 11, 2019.

information to terrorism research. The other is the Global Terrorism Database (GTD). A third section summarizes how this research project originated.

## **1. Use of Publicly Available Information in Terrorism Research**

The use of publicly available information (PAI) in defense research is far from a new concept. Open-source information (OSIF) and the application of that information to develop open-source intelligence (OSINT) products can be traced back as far as February 1941. The Foreign Broadcast Monitoring Service (renamed Federal Broadcast Information Service or FBIS in 1942) used PAI to keep a watchful eye on Axis propaganda.<sup>12</sup> The Central Intelligence Agency (CIA) absorbed FBIS in 1947, where it applied the lessons learned from World War II to the Cold War by monitoring and translating foreign press releases or other PAI often provided by foreign bureaus and embassies. The rapid development of information sharing platforms ushered in a new era of PAI during the 1990s as a 24/7 news cycle and the internet reduced the dependency on foreign networks. By 2005, important online advances ushered in the second generation of OSINT. These advancements included Web2.0 (a shift to user-generated content), which principally introduced new social media platforms (i.e., launch of Facebook in 2004, YouTube in 2005 and Twitter in 2006). Notably, the CIA also launched the Open Source Center (OSC) in 2005, which underscores the renewed importance the intelligence community (IC) placed on PAI.<sup>13</sup>

Gary LaFree of the University of Maryland's Study of Terrorism and Responses to Terrorism (START) Consortium argues that PAI plays a key role in terrorism research by offering certain advantages compared to more traditional crime or violence reporting

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<sup>12</sup> Heather Williams and Ilana Blum, *Defining Second Generation Open Source Intelligence (OSINT) for the Defense Enterprise* (Santa Monica, CA: RAND, 2018), 4, [https://www.rand.org/pubs/research\\_reports/RR1964.html](https://www.rand.org/pubs/research_reports/RR1964.html).

<sup>13</sup> On October 1, 2015, the OSC was rebranded as the Open Source Enterprise (OSE) under the Director of National Intelligence (DNI), which included a significant reduction in the publicly available distribution of the organization's analysis products. Source: Steven Aftergood, "Open Source Center (OSC) Becomes Open Source Enterprise (OSE)," *Federation of American Scientists* (blog), October 28, 2015, <https://fas.org/blogs/secrecy/2015/10/osc-ose/>.

methods.<sup>14</sup> LaFree contends that terrorism research is unique. Metrics that are typically relied upon for illegal violence do not produce an accurate representation of terrorism. The three common metrics LaFree cites are as follows: (1) official data collected by legal agents, (2) victimization data collected from victims, witnesses and non-victims, and (3) self-reported data from offenders.<sup>15</sup> These sources are considered either unreliable or unavailable in the context of terror attacks, which leaves open-source, unclassified information as a more reliable source of collecting information on terror attacks. For example, “official” sources, such as terrorism data collected by government entities, can be politically influenced or viewed as having the potential to be politically influenced, as well as deemed as being subjective or biased toward government purposes.<sup>16</sup> Also, unlike crime statistics, data related to terrorism is difficult to compile using traditional crime reporting and data collection methods. Terrorists are not often arrested. Those who are arrested—at least in the United States—may have charges levied other than their specific acts of terror. International data collection is even more uncertain as inconsistencies occur with how governments or international databases collect and organize data, vet the information, or even how they define terrorism.<sup>17</sup>

Terrorist attacks, however, are highlighted in the media and many terrorist organizations claim responsibility for attacks using social media platforms. This tendency makes second-generation OSIF a more accessible and accurate source of information than the crime reporting methods. These unique factors of PAI and OSIF in the use of terrorism research lend weight to the current open-source methodology employed by this thesis project.

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<sup>14</sup> Gary LaFree, “Using Open Source Data to Counter Common Myths about Terrorism,” in *Criminologists on Terrorism and Homeland Security*, Cambridge Studies in Criminology (Cambridge: Cambridge University Press, 2011), 412–14.

<sup>15</sup> LaFree, 412–14.

<sup>16</sup> Gary LaFree and Laura Dugan, “Introducing the Global Terrorism Database,” *Terrorism and Political Violence* 19, no. 2 (2007): 182, <https://doi.org/10.1080/09546550701246817>.

<sup>17</sup> LaFree and Dugan, 182–83.

## 2. Emergence of the Global Terrorism Database

The GTD is central to the research topic and serves as the cornerstone for the thesis. All analysis and future findings provided by this research project stem from the wellspring of information found in the GTD. Therefore, understanding the development and evolution of these varying sources in the terrorism database and why the GTD has been selected as the most comprehensive and authoritative source for this project is vital to the validity of future findings.

The GTD began in 2005 by absorbing a much larger dataset from the Pinkerton Global Intelligence Service (PGIS).<sup>18</sup> The PGIS documented 67,717 terror attacks from 1970 to 1997, a far greater number than seven other terrorism databases of a similar period.<sup>19</sup> A trailblazer in terrorism research, the PGIS used worldwide connections and special interest networks to compile terrorism data from wire services well before the dawn of the Information Age. As the PGIS standardized its codification and typology of terrorist attacks, the small team of researchers continued to refine its process to be more inclusive of new information streams over almost three decades of research.

As early thought leaders in terrorism research and data collection, the PGIS defined terrorism for its study as “the threatened or actual use of illegal force and violence to attain a political, economic, religious or social goal through fear, coercion or intimidation.”<sup>20</sup> Pinkerton—a private company—used this data to develop well-informed risk analyses for its clients. Therefore, the PGIS team was more apt to include incidents in its database. This strategy, coupled with an established worldwide network, may explain why the PGIS was able to compile the most comprehensive terrorism data collection, codification, and archiving system.

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<sup>18</sup> National Consortium for the Study of Terrorism and Responses to Terrorism, *Global Terrorism Database Codebook: Inclusion Criteria and Variables* (College Park, MD: University of Maryland, 2018), 3, <https://www.start.umd.edu/gtd>.

<sup>19</sup> LaFree and Dugan, “Introducing the GTD,” 183–84.

<sup>20</sup> LaFree and Dugan, 184.

By 2001, the PGIS transferred its original data under the stewardship of the University of Maryland. With the help of a grant from the National Institute of Justice, the University of Maryland began migrating the original handwritten PGIS records to computer databases.<sup>21</sup> This digitization process was complete by 2005. Additional databases like those provided by RAND and International Terrorism: Attributes of Terrorist Events (ITERATE) were either incorporated or used as a means of comparison.<sup>22</sup> The incorporation of the PGIS, RAND, and ITERATE then became rebranded as the GTD. Additional funding was secured through the DHS. A partnership with the Center for Terrorism and Intelligence Studies (CETIS) was formed to backfill missing data from 1997 to 2005. This absent dataset and subsequent additions to the GTD used a new standard coding methodology that evaluated each incident for over 120 variables using openly available sources.<sup>23</sup> Since 2011, the START Consortium maintained ownership and oversight of the GTD data collection, codification, and analysis. The database is updated annually and released to the public in early August with the previous year's incidents included. The August 2018 release contained over 180,000 total terrorism incidents since 1970. Given the GTD's sheer volume of events and the care and consistency devoted to maintaining sound methodological coding of all events, the GTD is chosen as the best dataset for this research of terror attacks against mass gatherings.

### **3. Philadelphia's Development of Special Event Planning Tools Using Global Terrorism Database and Publicly Available Information**

The City of Philadelphia hosts over 4,000 events or mass gatherings of all types, causes, and sizes every year. Like any other jurisdiction, Philadelphia has limited public safety resources and personnel to protect and mitigate every single event against all threats. The decision on which resources to dedicate to one event over another falls to a public

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<sup>21</sup> National Consortium for the Study of Terrorism and Responses to Terrorism, *Global Terrorism Database Codebook*, 3–4; LaFree and Dugan, “Introducing the GTD,” 186.

<sup>22</sup> LaFree and Dugan, 186.

<sup>23</sup> LaFree and Dugan, 187; National Consortium for the Study of Terrorism and Responses to Terrorism, *Global Terrorism Database Codebook*, 4.

safety planning team of about 12 agencies known as the City’s Special Event Task Force (SETF).

Mayor Rendell’s Executive Order 6–93 established the SETF on April 13, 1993.<sup>24</sup> Originally, the SETF’s main goal was to manage the use of public spaces, roadways, and buildings for special events to ensure fair access to all event organizers. The SETF also coordinated City of Philadelphia resources and any shared access to public spaces that required a closure of a public right-of-way.<sup>25</sup> Chaired by the City’s Office of Special Events, the oversight afforded by the SETF provided organization, proper permitting, and a more orderly distribution of events occurring on public spaces.

The changing threat streams against special events and mass gatherings (i.e., active shooter, edged weapons, ramming vehicles, improvised explosive devices (IEDs), and incendiary devices) since 9/11 required the SETF to evolve by incorporating a more public safety centric planning and operational element. The Philadelphia Police Department (PPD), the Philadelphia Fire Department (PFD), the Risk Management Division (RISK), and the Office of Emergency Management (OEM) are the primary members of the SETF’s public safety workgroup. As the SETF began to mature and take heed of attacks against mass gatherings worldwide, it developed new planning tools and decision-making rubrics.

The Philadelphia OEM’s risk and vulnerability assessment began out of necessity in 2014. As a participant in the DHS-SEWG event reporting, the Philadelphia OEM gathered large amounts of data to submit to the DHS. Since this large dataset had already been collected and the DHS was limited in its ability to share more in-depth risk analysis to the host jurisdiction, the Philadelphia OEM decided to use the same dataset to create its own risk and vulnerability assessment. The risk and vulnerability assessment methodology, outputs, and deliverables evolved to provide the SETF planning team with a more accurate, comprehensive, and complete analysis. Its outputs included considerations for critical

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<sup>24</sup> Edward Rendell, *Mayor’s Executive Order 6–93* (Philadelphia: City of Philadelphia, 1993), <https://www.phila.gov/ExecutiveOrders/Executive%20Orders/6-93.pdf>.

<sup>25</sup> Rendell, sec. 2.

infrastructure density, proximal events, dignitary presence, and a prototyped consequence model that predicted killed and wounded rates among common attack types.<sup>26</sup>

However, the OEM dropped the consequence model from the risk and vulnerability assessments in 2017 because the estimates represented gross generalizations based on available research estimates. Although the results of this initial model were realistic, the methodology was somewhat unreliable because assumptions of hypothetical events drove outcomes. An example of the original model is provided in Appendix A. This thesis focuses on the redevelopment of that consequence model.

Instead of altogether abandoning the idea of providing a consequence model, the Philadelphia OEM began considering ways to reconstruct the consequence model by basing the methodology on the lethality (i.e., those killed or wounded other than the attacker) of actual terror attacks. The OEM hypothesized that a large enough study of historical terror attacks against mass gatherings could yield a statistically reliable dataset to more confidently predict future casualty rates of attacks against similar crowd sizes. The GTD provided by the University of Maryland's START Consortium supplied the most comprehensive dataset that serves as a foundation of killed and wounded rates for over 180,000 terror attacks easily sortable by 120 different criteria. However, the GTD stops short of providing crowd sizes or estimates of crowd sizes at the time of the attack. The hypothesis or guiding assumption is that terrorism casualty rates were proportional to crowd size. The lack of information regarding crowd size at the time of a terror attack was both a gap in research and an opportunity for the Philadelphia OEM.

By spring 2018, the Philadelphia OEM approved a large research project that analyzed terrorist attacks against mass gatherings by examining five common attack type against the crowd size at the time of the attack. The attack types examined included those using: (1) firearms (i.e., active shooter), (2) edged weapon attacks, (3) incendiary devices (i.e., fire used as a weapon), (4) ramming vehicles, and (5) IEDs and vehicle-borne improvised explosive devices (VBIEDs).

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<sup>26</sup> The killed and wounded rates of common attack types against special events are referred to as the "Consequence Model," which is incorporated into the overall risk and vulnerability assessment of an event.

The research design used the existing OEM fellowship program to recruit a research team to begin reviewing each qualifying terror attack for crowd estimates. Using the fellowship model allowed the OEM staff to maintain oversight of the project, ensure a consistent methodology across fellow groups, and provide an analysis of their results. This research is relevant and warranted given several factors: (1) the current lack of information and an apparent research gap, (2) direct application to the Philadelphia OEM and public safety leadership, and (3) future impact to homeland security and public safety practitioners and researchers.

## **C. RESEARCH QUESTIONS**

### **1. Primary Question**

What relationship exists between the known or estimated crowd size and the killed and wounded rates of common terrorism attack types?

### **2. Secondary Question**

How can the results be used to develop a consequence model that predicts future lethality rates of terror attacks against mass gatherings?

## **D. SIGNIFICANCE**

This research supports homeland security, emergency management, and public safety professionals in both practical and analytical ways. The practical value is ultimately provided in the form of an objective tool to measure the potential consequences of terrorism against mass gatherings and special events. Analytically, the data is assessed to determine the statistical significance between variables. The statistical significance establishes the level of confidence to answer the secondary question. The results can be evaluated for their applicability as a consequence model if a relationship exists, which thus addresses the secondary research question.

Furthermore, this study contends that a more realistic understanding of the human consequences (i.e., civilians killed or wounded) can help inform the deployment of limited resources and personnel to mitigate the potential consequences. In doing so, jurisdictions

can take a more data-driven approach when planning special events. This information can then supplement individual judgment and the institutional knowledge of decision makers. However, using an objective starting point based on historical results is a more defensible position for justifying the use of limited resources.

A less tangible contribution—but common to all good research—is the furtherance of scholarly debate and inquiry. At a minimum, the hope is to ignite a discussion regarding the use of historical data to develop planning tools, such as consequence models. Whether or not the models proposed by this research are ultimately successful and adopted by public safety agencies, the attempt to model terrorism impacts is a debate worth having and a hill worth climbing.

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## **II. LITERATURE REVIEW**

The literature review first examines the existing body of knowledge related to currently used terrorism databases, like the GTD, for statistical analysis and methodological approaches. Although some studies have focused on the morbidity of terror attacks, none focused on terrorist attack lethality against mass gatherings and public spaces. This thesis aspires to fill this void in scholarly research. As such, the literature review examines the use of risk analysis models as applied to terrorism. It reviews the use of OSIF, OSINT, and PAI in terrorism research and analysis to address questions about the validity of PAI. Finally, this section highlights several documents that recommend continued research in this field of study to support a more accurate risk assessment of terrorism.

### **A. USE OF THE GLOBAL TERRORISM DATABASE TO ASSESS TERRORISM LETHALITY**

Scholarly research validates the use of terrorism databases for quantitative analysis. Although this thesis employs the GTD, several other active databases appear in the literature, such as the U.S. National Counterterrorism Center's Worldwide Incidents Tracking System (WITS) and RAND Corporation's Database of Worldwide Terrorism Incidents (RDWTI). However, with over 89,000 full dataset downloads since 2007, which increased from 500 per month in 2014 to over 2,000 per month in 2018, the GTD is the most widely used.<sup>27</sup> Examples of the GTD's use in terrorism research span an impressive range of peer-reviewed topics. From geospatial studies to measuring the effectiveness of counterterrorism spending to assessing the likelihood of future terror attempts after a highly successful terror attack, the broad application of this descriptive and predictive analysis is highly informative. To date, no studies have specifically attempted to measure the lethality rate of adversarial attacks against mass gatherings by their chosen attack method.

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<sup>27</sup> Erin Miller, "Message from the Global Terrorism Database Manager," National Consortium for the Study of Terrorism and Responses to Terrorism, August 15, 2018, <https://www.start.umd.edu/news/message-global-terrorism-database-manager>.

A body of literature examines other aspects of terrorism morbidity using various statistical analyses. A 2004 *Terrorism and Political Violence* journal article by Webb and Cutter used the GTD to investigate the consequence of domestic terrorism within the United States.<sup>28</sup> Part of their analysis included frequency and lethality of terrorist incidents that revealed no significant increase in the frequency of terrorism within the United States between 1970–2004. Still, the lethality trends rose in the United States while declining globally during the same period.<sup>29</sup> Webb and Cutter attribute this overall increase in U.S. lethality rates to large mass casualty events like the Oklahoma City bombing and the 9/11 attacks.<sup>30</sup> This study also included decadal trends of chosen attack and weapon types, but the correlation between attack type, weapon, and lethality was not the primary aim of their research. Target selection (i.e., mass gatherings) was not included in the study since Webb and Cutter focused on using empirical GTD data to develop geographic trends of terrorism within the United States.

Marco Nilsson examined terrorism lethality using the GTD in the context of suicide bombings against hard and soft targets.<sup>31</sup> Nilsson separates suicide bombings from other types of suicide attacks by arguing that hardened targets may be more susceptible to suicide bombings. Other attack methods are deemed less effective against a defended target, which makes suicide attacks a preferable option for inflicting the most damage.<sup>32</sup> On the other hand, firearms may be a more likely weapon against softer targets since a greater opportunity exists to inflict damage before being confronted by any resistance.<sup>33</sup> Nilsson used a multivariate regression analysis approach quite similar to the methodology used in

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<sup>28</sup> Jennifer Webb and Susan Cutter, “The Geography of U.S. Terrorist Incidents, 1970–2004,” *Terrorism and Political Violence* 21, no. 3 (2009): 428–49, <https://doi.org/10.1080/09546550902950308>.

<sup>29</sup> Webb and Cutter, 433–34.

<sup>30</sup> Webb and Cutter, 434.

<sup>31</sup> Marco Nilsson, “Hard and Soft Targets: The Lethality of Suicide Terrorism,” *Journal of International Relations and Development* 21, no. 1 (2018): 101–17, <https://doi.org/10.1057/jird.2015.25>.

<sup>32</sup> Nilsson, 103.

<sup>33</sup> Nilsson, 106.

this thesis.<sup>34</sup> Although his statistical analysis included an examination of casualty rates based on tactics (suicide or non-suicide) and weapon types, the correlation of the casualty rates to hardened or soft targets falls short of identifying specific target types (i.e., a hardened government facility vs. a more vulnerable shopping mall). Instead, hard vs. soft targets are analyzed through a more general lens of attacks in Israel (hardened) vs. Palestine and Afghanistan (less hardened). Nilsson's research sets a good methodological blueprint for this thesis, a multivariate regression analysis. Since soft and hard targets were generalized in Nilsson's study, this thesis builds upon these findings by adding more detail to casualty rates specific to the soft target of mass gatherings.

In a similar study published in the *Journal of Research in Crime and Delinquency*, Hsu and McDowall employ the GTD in a cross-sectional, time-series regression analysis to assess whether target hardening unintentionally increases terrorism morbidity rates.<sup>35</sup> Again, assuming that a terrorist is making rational choices of target selection, tactics, and weapon type to maximize the overall benefit of an attack, the researchers ask whether the hardening of a target diverts the threat to a softer target. Unlike Nilsson, Hsu and McDowall address target selection rather than attack type to maximize lethality. They use a situational prevention framework to assess the impact of denial (hardening) of a particular target. The increased security at airports in the 1970s—following a series of hijackings and the heightened U.S. diplomatic security in the 1980s after several bombings and assassination attempts overseas—were selected as their areas of analysis. The GTD is used to evaluate whether target hardening would result in more intensive attacks of the same targets or whether terrorists would select more vulnerable targets.

Additionally, Hsu and McDowall assess whether hardening had unintended consequences on lethality rates. They determined that once a specific target was hardened, the casualty increases of a subsequent attack could be linked to the terrorists' more

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<sup>34</sup> Nilsson, 108.

<sup>35</sup> Henda Hsu and David McDowall, "Does Target-Hardening Result in Deadlier Terrorist Attacks against Protected Targets? An Examination of Unintended Harmful Consequences," *Journal of Research in Crime and Delinquency* 54, no. 6 (2017): 930–57, <https://doi.org/10.1177/0022427817719309>.

determined efforts to overcome those defensive mechanisms.<sup>36</sup> However, elevated casualty rates could not be considered an unintended consequence of hardening a target. As with Nilsson's report, elements of Hsu and McDowall's study are replicated in this thesis. Specifically, the use of a time-series study with a narrowed focus on target selection is used. Hsu and McDowall also recommend that more empirically based terrorism research, in general, is necessary.<sup>37</sup>

Less academically rigorous uses of the GTD to examine lethality rates are available. The Cato Institute, for example, features a short blog post using GTD in conjunction with RAND and other sources to estimate the likelihood of being a terrorist's casualty in the United Kingdom.<sup>38</sup> The *Washington Post* used the database to illustrate the shift of lethal terror attacks from Western to Eastern Europe and highlight the most lethal attack method.<sup>39</sup> Here again, the terrorist's target selection is not considered in the descriptive analysis. The selected examples highlight the GTD's ubiquitous use for a plethora of terrorism research topics, including lethality rates. However, an analysis of terror attacks against mass gatherings and the correlations of lethality by attack type against these gatherings have not been attempted.

## **B. RISK MANAGEMENT PRINCIPLES AND MODELS APPLIED TO TERRORISM**

The development of a terrorism risk model is of particular interest to this thesis. Kaplan and Garrick's findings, published in the first issue of *Risk Analysis* in 1981,

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<sup>36</sup> Hsu and McDowall, 944–45.

<sup>37</sup> Hsu and McDowall, 945.

<sup>38</sup> Alex Nowrasteh, "The Chance of Being Murdered or Injured in a Terrorist Attack in the United Kingdom," *Cato Institute* (blog), August 15, 2018, <https://www.cato.org/blog/chance-being-murdered-or-injured-terrorist-attack-united-kingdom>.

<sup>39</sup> Chris Alcantara, "46 Years of Terrorist Attacks in Europe, Visualized," *Washington Post*, July 17, 2017, <https://www.washingtonpost.com/graphics/world/a-history-of-terrorism-in-europe/>.

establish risk as a product of scenario, likelihood, and consequence.<sup>40</sup> Kaplan and Garrick explain that a hazard is the manifestation of a risk that can also be measured as a balance of that specific hazard's potential consequences after implementing mitigation techniques.<sup>41</sup> In 2005, Ezell et al. developed a commonly held risk formula referenced across multiple studies: Risk ( $R$ ) = Threat ( $T$ ) x Vulnerability ( $V$ ) x Consequence ( $C$ ).<sup>42</sup> Ezell et al. credit Kaplan and Garrick's foundation for being cited over decades and helping to inform the widely accepted  $R=TV C$  formula used today.<sup>43</sup> This formula will be the lens through which this thesis examines risk with a specific focus on the consequence component.

The  $R=TV C$  formula has complicating factors when applied to terrorism that leads some to abandon this approach in favor of an attacker-defender model. The insurance industry developed some helpful research and insights to create risk models after the passage of the Terrorism Risk Insurance Act (TRIA) of 2002, which was then reauthorized in 2015.<sup>44</sup> Before TRIA, standard commercial insurance policies included acts of terror.<sup>45</sup> Developing separate, risk-informed catastrophic coverage policies required a better understanding of the threats, vulnerabilities, and consequences related to terrorism. One report from the University of Pennsylvania's Wharton Risk Management and Decision

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<sup>40</sup> Stanley Kaplan and B. John Garrick, "On the Quantitative Definition of Risk," *Risk Analysis* 1, no. 1 (1981): 12, <https://doi.org/10.1111/j.1539-6924.1981.tb01350.x>; Barry Ezell et al., "Probabilistic Risk Analysis and Terrorism Risk," *Risk Analysis* 30, no. 4 (April 6, 2010): 577, <https://doi.org/10.1111/j.1539-6924.2010.01401.x>.

<sup>41</sup> Kaplan and Garrick, "On the Quantitative Definition of Risk," 12.

<sup>42</sup> Ezell et al., "Probabilistic Risk Analysis and Terrorism Risk," 577.

<sup>43</sup> Ezell et al., 577.

<sup>44</sup> Terrorism Risk Insurance Act of 2002, Public Law 107-297, *U.S. Statutes at Large* 116 (2002) <https://www.congress.gov/bill/107th-congress/house-bill/3210>; Terrorism Risk Insurance Program Reauthorization Act of 2015, Public Law 114-1, *U.S. Statutes at Large* 116 (2015), ch. 93 §§ 6, <https://www.congress.gov/bill/114th-congress/house-bill/26>.

<sup>45</sup> Howard Kunreuther, *Assessing, Managing and Financing Extreme Events: Dealing with Terrorism*, Working Paper Series 10179 (Cambridge, MA: National Bureau of Economic Research, 2003), 3, <https://www-nber-org.libproxy.nps.edu/papers/w10179.pdf>.

Processes Center reported “two conditions must be met before insurance providers are willing to offer coverage against an uncertain event,” like terrorism:<sup>46</sup>

Condition 1 is the ability to identify and quantify, or estimate at least partially, the chances of the event occurring and the extent of losses likely to be incurred. Condition 2 is the ability to set premiums for each potential customer or class of customers.<sup>47</sup>

This thesis directly addresses Condition 1 by detailing the human costs (i.e., consequences) of terrorist attacks against mass gatherings; many of which occur at insurable event venues like stadiums, outdoor arenas, or concert halls.

Several reports highlight the inherent difficulties in creating risk models for terrorism as compared to more traditional catastrophic insurance policies for natural hazards like flooding, wildfires, earthquakes, and hurricanes. The same article from Kunreuther states that traditional approaches using exceedance probability curves (that help risk professionals understand that the likelihood of a terror attack will meet or surpass predictable levels) is problematic because of a lack of historical data.<sup>48</sup> However, their study in 2003 predates the public availability of the GTD in 2007. With such a rich dataset of over 180,000 documented terrorist incidents each containing between 40–120 points of descriptive criteria, surely it is possible to at least attempt a more quantifiable risk-based model to frame a probabilistic range of terrorism consequences.

Kunreuther also correctly notes that other factors differentiate and complicate the application of a traditional risk approach ( $R=TVC$ ) to terrorism in comparison to natural hazards, such as the ambiguity of risk given the intelligence of human actors who can alter plans based on a variety of influencing factors. Terrorism threat factors are typically held within the secure control of government agencies, which makes it difficult for the private

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<sup>46</sup> Kunreuther, 5; Patricia Grossi, Howard Kunreuther, and Don Windeler, eds., “Catastrophe Modeling: A New Approach to Managing Risk,” in *An Introduction to Catastrophe Models and Insurance*, vol. 25, *Catastrophe Modeling* (Boston, MA: Springer, 2005), 35–36, [https://doi.org/10.1007/0-387-23129-3\\_2](https://doi.org/10.1007/0-387-23129-3_2).

<sup>47</sup> Kunreuther, *Assessing, Managing and Financing Extreme Events*, 5; Grossi, Kunreuther, and Windeler, 35–36.

<sup>48</sup> Kunreuther, 5–7.

sector to incorporate threat into a risk model. The variability in weapon and tactic selection creates a diverse range of potential outcomes. Kunreuther contends that the absence of necessary information on credible threats combined with variability infuses a high degree of subjectivity and judgment-based decisions based solely on the underwriter's experience.<sup>49</sup> Ezell et al. agree with this assessment and advocate for other probabilistic risk analysis approaches, such as event, decision and fault trees, influence diagrams, causal loop diagrams, network analysis, and game theory models.<sup>50</sup> Common sense supports their conclusion that no one-size-fits-all approach covers terrorism risk modeling and that researchers should attempt to develop a complete picture by employing multiple strategies.<sup>51</sup> The addition of a terrorism consequence model that measures the probable human cost will contribute to the array of analytical tools currently available.

### C. THE NEED FOR MORE QUANTITATIVE RESEARCH

The available literature highlights the need for continued and expanded quantitative research into terrorism risk and consequences. A study by LaTourrette et al. concludes, "Some attempts to estimate absolute terrorism risk have been put forth in insurance industry models, but these attempts are restricted to catastrophic events (greater than 100 fatalities or \$1 billion in losses)."<sup>52</sup> The standards of what constitutes a catastrophic event are derived from the Probabilistic Terrorism Model provided by Risk Management Solutions founded by Stanford University.<sup>53</sup> The observation from LaTourrette et al. highlights the need for estimating lethality rates for less catastrophic events, which this thesis can advance. In "Estimating Terrorism Risk," the authors conclude with five recommendations. The most notable recommendation to this research endeavor includes

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<sup>49</sup> Kunreuther, 15.

<sup>50</sup> Ezell et al., "Probabilistic Risk Analysis and Terrorism Risk," 579–87.

<sup>51</sup> Ezell et al., 588.

<sup>52</sup> Tom LaTourrette et al., *Reducing Terrorism Risk at Shopping Centers: An Analysis of Potential Security Options* (Santa Monica, CA: RAND, 2006), 61, [https://www.rand.org/pubs/technical\\_reports/TR401.html](https://www.rand.org/pubs/technical_reports/TR401.html).

<sup>53</sup> Henry H. Willis et al., *Terrorism Risk Modeling for Intelligence Analysis and Infrastructure Protection* (Santa Monica, CA: RAND, 2007), 2.

the development of event-based models since “they provide a coherent, defensible framework for selecting and combining information about threats, vulnerabilities, and consequences.”<sup>54</sup> Again, this research focuses on an event-based approach in the context of mass gatherings and special events with the objective of adding detail to the consequences of common attack types.

One publicly available example of a terrorism consequence model that also appears to be closest to the ultimate goal of this research is Johns Hopkins University’s Electronic Mass Casualty Assessment and Planning Scenarios (EMCAPS).<sup>55</sup> This tool, EMCAPS, is part of an extensive suite of predictive analytics products made available through the National Center for the Study of Preparedness and Catastrophic Event Response (PACER), a DHS Emeritus Center of Excellence (COE). Within EMCAPS, applications estimate the consequences of an open-air explosion, explosions against bus and rail, and indoor personal explosions (i.e., suicide bomber). EMCAPS also contains eight other scenarios to model, such as food contamination, toxic gas, or pneumonic plague. However, the explosive scenarios provided by EMCAPS are the most applicable and of greater interest to this thesis. Regarding the explosive models, PACER provides a similar outcome but differs from this study in a few key areas. First, EMCAPS methodology includes an extensive review of scholarly literature regarding the casualty rates caused by blast shrapnel and pressure waves. In contrast, this thesis uses an approach grounded in mining large databases for a comparison of crowd size against known killed and wounded rates for each attack.

Additionally, EMCAPS’ target audience or user is the hospital and first receiver community compared to this research, which includes four other attack types besides IEDs. This study focuses on the impacts of terrorism against mass gatherings and special events, while EMCAPS is generally agnostic of the attack setting. These differences distinguish the two predictive analysis approaches. As a more mature product, EMCAPS provides a

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<sup>54</sup> Henry H. Willis et al., *Estimating Terrorism Risk* (Santa Monica, CA: RAND, 2005), 56.

<sup>55</sup> “Electronic Mass Casualty Assessment & Planning Scenarios—EMCAPS,” Johns Hopkins University, accessed August 19, 2021, <https://www.hopkins-cepar.org/EMCAPS/EMCAPS.html>.

blueprint for modeling terrorism consequences and highlights how this research uniquely addresses a gap in terrorism research specific to mass gatherings. Products like EMCAPS can also serve as a means of cross-referencing outputs of newly developed models since EMCAPS is an already vetted product.

Ultimately, this thesis aspires to add to the body of knowledge and assist in filling an identified information gap. Developing a methodology based on a sound statistical analysis approach can help quantify the human cost of common attack types. The literature review indicates that the GTD is best suited to frame a probabilistic range of consequences since it is the most holistic and well-maintained dataset available. The range of consequences provided by the GTD is agnostic to threat and allows for a degree of variability in weapons and tactics selection against mass gatherings. This study hypothesizes that a correlation exists between common attack types against mass gatherings, crowd size, and casualty rates using the GTD. If established, the correlation can be measured and developed into a practical planning tool that objectively informs contingency guides and resource allocations to mitigate these consequences.

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### III. RESEARCH DESIGN

This research design first set out to answer the primary research question: “What relationship exists between common terrorism attack types against mass gatherings of known population sizes and the killed and wounded rates of those attacks?” To answer the primary research question, the design applied regression analysis that examined an independent variable ( $X$ ) and a dependent variable ( $Y$ ) to determine the degree of correlation between the two. The independent variable was the explanatory or causal value, whereas the dependent variable was the response or outcome. In this study, terror attack types were the independent variable ( $X$ ), and the casualty rate of a known or estimated crowd size was the dependent variable ( $Y$ ). Expressed differently, the primary question can be restated as “What influence does the method of attack ( $X$ ) have on the casualty rates ( $Y$ ) of a crowd with a known or estimated population?” The degree of relationship (or lack thereof) between the two variables was expressed as a numerical value known as the correlation coefficient ( $r$ ) ranging from -1.0 to 1.0. An  $r$  value of 0 indicates no relationship exists between the variables of terrorism attack type ( $X$ ) and casualty rates ( $Y$ ). A relationship between the two variables was presumed to answer the primary research question of “What relationship exists between the known or estimated crowd size and the killed and wounded rates of common terrorism attack types?” Therefore, the null hypothesis ( $H_o$ ) for this research design reads that no correlation exists between the variables of terrorism attack type ( $X$ ) and casualty rates ( $Y$ ). The alternative hypothesis ( $H_a$ ) posited that a relationship exists between the variables of terrorism attack type ( $X$ ) and casualty rates ( $Y$ ).

The results of the regression analysis provide one of three outcomes. Should the correlation coefficient be expressed as  $r = 0$ , then the  $H_o$  cannot be rejected. In this case, the answer to the primary question is that no relationship can be established using regression analysis, which thereby disallows inquiring about the secondary research question. Another possibility is that of a weak correlation, which indicates a potential relationship that may not be statistically significant. A weak correlation coefficient ( $r$ ) is defined as  $r < 0.3$  in this study. Such a result indicates ambiguity regarding the impact of

$X$  on  $Y$  but fails to reject the  $H_o$ . By refusing to reject the null hypothesis, the alternative hypothesis can be considered plausible with the caveat of a statistically weak correlation. Finally, if  $r \geq 0.3$ , then the  $H_o$  will be rejected, which signifies that a relationship exists between terror attack types and their corresponding casualties. A stronger correlation between the variables will strengthen the degree of influence  $X$  has on  $Y$ . Unlike a weak but plausible correlation, a strong relationship with a large enough sample size denotes probable outcomes. These types of findings lay the foundation for answering the second research question: “How can the results be used to develop a consequence model that predicts future lethality rates of terror attacks against mass gatherings?”

If a terrorist’s attack type has no impact on the number of expected casualties, the two variables are unrelated and cannot be modeled with this dataset. However, if a correlation exists, then developing a predictive analysis model can be considered. In short, to determine if a model is feasible, the relationship between variables must first be established. To evaluate the relationship, each variable needs data.

Developing a statistical analysis model fundamentally required gathering good data. The GTD was selected for this study over less current or comprehensive datasets. The literature review detailed the history, evolution, and emergence of the GTD as a leader among other terrorism databases and was, thus, the most suitable for this research. With a good dataset in place, analysis—in this case, regression analysis—could begin. This research built on the work of the GTD by offering an additional criterion, crowd size at the time of the attack. A multi-phased process was employed to gather data for each variable. The first phase was an initial filter that identified the incidents with the minimum criteria desired for the independent variable. The incidents that passed the phase one threshold were earmarked for closer analysis. The second phase set the methodology for using publicly available information to determine the crowd size of those incidents identified in the first phase. The final phases set guidelines for a collaborative effort using a research fellowship program at the Philadelphia OEM, which was tasked with implementing this labor-intensive process. A detailed explanation of each phase appears in the following sections.

## A. PHASE 1: IDENTIFYING DATA FOR THE INDEPENDENT VARIABLE

To find the data within the GTD that could most accurately approximate the casualty rate of terror attacks against mass gatherings, the research design first identified and removed any incidents that did not meet the basic parameters of this study. A series of exclusions were applied to the GTD spreadsheet that culled the data into a more homogenous remainder. The second step set tighter parameters with the aim of leaving only those incidents that provided the most accurate representation of attacks against mass gatherings.

### 1. Cursory Exclusions

The first set of exclusions were relatively straightforward: (1) events before 2001, (2) unsuccessful attacks, (3) the attacker is the only one killed or wounded, (4) chemical, radiological, or biological attacks, (5) unarmed assaults, and (6) letter bombs. The Excel spreadsheet that warehoused this information and the accompanying *GTD Codebook* made filtering out events with these attributes a quick and straightforward process.<sup>56</sup>

The rationale for the first round of exclusions warrants explanation. The underlying factors of removing data at this point of the process were relevance, plausibility, and variability. Events before the year 2000 were less timely or relevant to this study since the aim was to find a dataset that represented casualty rates from the most current trends in tactics and available weapons. Each incident listed in the GTD received a determination of successful or unsuccessful. The definition of success varied by attack type that the *GTD Codebook* provided.<sup>57</sup> Any incident deemed unsuccessful by the GTD did not have relevance in this study. Similarly, incidents in which only the attacker was killed or wounded were considered irrelevant, given the study's focus on the impact of terrorism against crowds. The GTD delineates the killed and wounded rates by including how many among those casualties are the perpetrators. If the value of the killed and wounded was

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<sup>56</sup> National Consortium for the Study of Terrorism and Responses to Terrorism, *Global Terrorism Database Codebook*.

<sup>57</sup> National Consortium for the Study of Terrorism and Responses to Terrorism, 26–27.

zero or equal to the number of attackers killed, the event was removed from the study. Chemical, radiological, and biological attacks were excluded because of their lack of relevance, plausibility, and variability. In other words, these types of attacks were rare against mass gatherings (less relevant), significantly more difficult to conduct successfully (less plausible), and could produce a wide range of casualties, given a plethora of factors (variability). Unarmed assailants were removed since the scope of this thesis studied available weapons and tactics used to inflict maximum impact. An unarmed assailant's impact on a crowd was presumed negligible and not worth further analysis in this thesis. Finally, letter bombs were excluded since they were not a realistic threat to special events, mass gatherings, and public spaces.

Although not initially included in the list of exclusions, geographic location quickly became a consideration and was added as an additional parameter. Incidents occurring in areas of conflict were removed because they included a high quantity of incidents in vastly different operating conditions. That is to say, the high number of small arms engagements and IEDs in nations with active wars or armed conflicts did not reflect the threat environment of most special events, mass gatherings, or public spaces in developed countries. For this study, areas of conflict were defined as locations against which the Department of State placed a travel ban as of September 2018. These areas included Afghanistan, the Central African Republic, Iran, Iraq, Libya, Mali, North Korea, Somalia, South Sudan, Syria, and Yemen.<sup>58</sup> Attacks occurring in any of these locations were filtered out of the GTD master file.

The remaining dataset was the basis for the independent variable, yet still needed refinement. Similar to how a prospector might remove small rocks, pebbles, dirt, and then fine sediment through a series of filters in search of gold, the cursory exclusion phase removed the rocks and other obvious debris (i.e., the incidents that clearly did not pertain to this study). The next step of the methodology applied a finer filter to eliminate the dirt

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<sup>58</sup> "Travel Advisories," Department of State, accessed September 6, 2018, <https://travel.state.gov/content/travel/en/traveladvisories/traveladvisories.html/>.

and sediment (i.e., the incidents that required closer inspection), which left only the data with the greatest applicability to this study.

## **2. Narrowed Exclusions**

The incidents that passed the initial set of exclusions were examined for characteristics not relevant to crowd dynamics. Here, the principal aim was to purge the dataset of targeted killings and assassinations, as well as attacks only involving military, paramilitary, or police forces as the objective. An additional parameter was applied to set aside any incidents involving more than one weapon type in a single occurrence.

Targeted killings and assassinations contained a focused intent against one or several individuals. Of interest to this research were those occurrences where the casualties were indiscriminate and not individually targeted. The motivation to kill or injure as many victims as possible was not typically a characteristic of targeted killings, which limited its relevance to this study.

Attacks that involved only military, paramilitary, or police as targets (whether intentional or not) were removed because this population was not representative of eventgoers and bystanders. Military and police have access to training, firearms, and protective equipment not available to an average crowd of civilians. For this reason, an incident was excluded if only military or police suffered casualties.

The GTD documents all weapon types used in any incident. However, incidents involving more than one weapon type were removed from the study since no means were available to delineate which portion of the casualties were caused by the multiple weapon types used. The regression analysis examined the degree to which one attack type ( $X$ ) impacted casualty rates ( $Y$ ) given a known or estimated crowd size. The research model did not support the assessment of multiple independent variables (i.e., attack types or weapons) within the same incident.

The selection of data for the independent variable was now nearly complete. The exclusion process left only those incidents that contained the five attack modalities desired where only one weapon type was used in each occurrence. Moreover, the remaining attack

types represented incidents involving civilian casualties and those victims were indiscriminate. The final component necessary for regression analysis was the dependent variable ( $Y$ ), which is the count of killed and wounded per incident with known or estimated crowd sizes.

## **B. PHASE 2: CROWD ASSESSMENTS**

The focus now shifted to the arduous task of estimating crowd sizes at the time of the attack. To develop a modeling tool that estimated casualty rates given a specified attack-type of known crowd sizes, this study incorporated all three values into the regression analysis. The GTD is a powerful resource that contains both the killed and wounded totals and attack types for each incident. However, the GTD currently provides no information about the size of the crowd at the time of attack. By adding the estimated population size, a ratio of killed and wounded of a given crowd size can be established, given enough data. The inclusion of crowd size and supplemental data was the final phase of deciding which events were included or excluded. Even though an incident might have met all the qualifications of the previous filtering process, that incident was not included in the study if a crowd size could not be identified or estimated.

### **1. Use of Publicly Available Information to Research Crowd Size**

The method for researching crowd sizes relied solely on PAI. Although the GTD does not document crowd metrics, the GTD lists the open-source news sites or agencies with the news article's title for each event. In most cases, more than one source is provided for each incident. This information was useful as a breadcrumb trail that was the starting point for researching the population size. The source data was copied into an internet search engine to locate the original website where the GTD found its information. If the source was still available, the article was reviewed for any references to the crowd size. The ideal scenario happened if the article clearly stated the number of people in the area or facility at the time of the attack. In these rare cases, the crowd size was added to that incident on the GTD spreadsheet as a new category of "pre-attack size." Most often, the articles did not overtly report the crowd size, which required additional research to estimate total attendance.

Alternate sources for crowd data include images, video coverage, or social media reports of the crowd before the attack. In instances where these sources were available, the researcher (i.e., OEM Fellow) made an estimation of the crowd size, given source and documents. This information appears under the same “pre-attack size” column on the GTD spreadsheet. For example, video footage for several attacks was discovered in which the number of bystanders in that area could be counted. The same concept applied to photos and social media, which often provided information or photos showing the size of the crowd before or during the incident.

When the pre-attack size could not be established, the average attendance was used. Most often, it included information at locations, such as schools, universities, churches, and tourist locations, where the typical daily attendance could be approximated. For example, a school website may report the total number of students enrolled in that facility or a tourism website may list the average visitors per day, week, or month, etc. These numbers were much less desirable than a more defined pre-attack value, but were still a good benchmark to gauge the probable population size when the incident occurred. These values were listed in a second column titled “average size.” If an estimate was not available, the last resort was to search for the maximum occupancy of the event venue.

Estimating maximum occupancy was limited to attacks at a physical facility or building. For example, an incident at a concert venue may not have any media that specifically reported the crowd size or alternate sources to estimate the attendance, but the maximum occupancy of that venue might be available. This approach was often used with attacks against a vehicle. Even though no other population size was located, the total passenger occupancy could be found and was used as necessary. Using the maximum occupancy was a last resort before excluding the incident from the study. Since the total number of people in that space was unknown, using the maximum occupancy assumed that the ratio of killed and wounded for that incident was based on a fully populated vehicle, venue, or space. However, if maximum occupancy was found and no other information was available, the number was documented under a separate column.

If pre-attack, average, or max occupancy values were not discovered, the incident was discarded and removed from further consideration. This last piece of the selection

process was the most rigorous filter and eliminated the majority of incidents available after phase one. The tedious and time-consuming efforts were meant to leave only those incidents that had the desired attack type, casualty rate, and crowd size for each event's regression analysis. The utmost care was taken to conduct analysis that develops a model with the best data possible. With that in mind, the events that cleared all filters underwent an additional quality assurance review before being entered into the final dataset for analysis.

## **2. Supplemental Data and Review Process**

The data collection process concluded with additional documentation of supplemental information and a rating of the sources. These final steps were additional, self-imposed requirements that required more time, but merited the extra effort. Supplemental data added a level of granularity that might be important to this study or future research, while the review process ensured a level of consistency or data integrity.

The supplemental data requested included three criteria relating to special events, protective measures, and crowd density. No incidents were excluded at this point based on the answers to the additional input. These items were simply of interest and that might or might not be used in this research. First, the researcher marked "Yes" or "No" as to whether the sources used to research the incident indicated it had occurred at a special event. In doing so, the dataset could easily be filtered between attacks that occurred at a formal event (e.g., parades, festivals, concerts) versus other types of mass gatherings and public spaces (e.g., a marketplace). The next field asked whether any protective measures were evident in the sources. For this study, protective measures did not involve passive surveillance systems, such as security cameras, for instance. The intent, here, was to identify incidents that had proactive or preemptive measures in place like blocking vehicles, police, or security guards, magnetometers, bag searches, etc., that acted as a visual deterrence. Again, a simple "Yes" or "No" response was recorded in the event that this datapoint might be of interest in later analysis. The final element was approximating crowd density. This metric

was borrowed from the DHS Special Events Working Group that estimated crowd density by the following values:<sup>59</sup>

- Category A: 90–100% of the population is present at the same time
- Category B: 65–90% of the population is present at the same time
- Category C: <65% of the population is present at the same time

Since the crowd density metric was unique to special events, only those incidents previously marked as a special event had a crowd density estimate.

Just as the GTD documents its sources, this research documented the sources used to find crowd size information. This research design went one step further by requiring the source's value to be rated according to the following scale created for this study:

- —: Source cannot or should not be included in analysis.
- 1: Estimation, conjecture, etc.
- 2: Any other sources with pre-attack population data
- 3: Reputable or trusted source with no source identification. (e.g., news article saying the population is based off eyewitness reports or other less reputable information)
- 4: Reputable or trusted news agency using an identifiable source (e.g., either an individual or a department is identified)
- 5: Official documents from government or more official sources other than news articles, etc. (e.g., police reports, court documents, congressional hearings, peer-reviewed studies, think tank reports, or after-action reports)

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<sup>59</sup> Department of Homeland Security, *[FOUO] 2018 National Special Events Data Call Contributor Guidance* (Washington, DC: Department of Homeland Security, 2017), 8–9.

Once completed, a second person reviewed the source and provided the rating of the source quality. Finally, I personally review all events a third time before they are cleared for inclusion in the regression analysis. As may be evident at this point, this methodology required a team of researchers to implement. The next section details the creation, organization, and collaboration of a 23-member research fellowship program supervised by two others.

### **C. PHASE 3: RESEARCH IMPLEMENTATION STRATEGY**

The amount of effort and time required to complete this research went far beyond the ability of a single researcher. To fill this gap, research fellows were recruited each semester to work on the project. This effort was organized through a well-established fellowship program at the Philadelphia OEM and approved by the Naval Postgraduate School (NPS) to be used for this thesis.

The division of labor was organized as follows. As the originator of the research project, I organized the data and completed all the work required in phase one to prepare the dataset for the fellows in phase two. With the assistance of another member of OEM, Homeland Security Planning Coordinator Mike Giardina, I interviewed and selected the research fellows each semester who were then tasked with researching crowd sizes, as well as all supplemental data and source ratings listed in phase two. To maintain consistency between groups of research fellows, I created user guides to direct the methodology. Each group also received a two-hour block of instruction at the start of the fellowship followed by weekly meetings with either Mike Giardina or me to discuss progress and answer questions. Each fellowship group summarized its progress at the end of the semester, at which point, I reviewed all the findings before entering them into a GTD master file. The extent of the fellowship group's or any other OEM member's assistance ended with the aggregation of crowd data.

The timeframe and organization of the research team is illustrated in Figure 1.

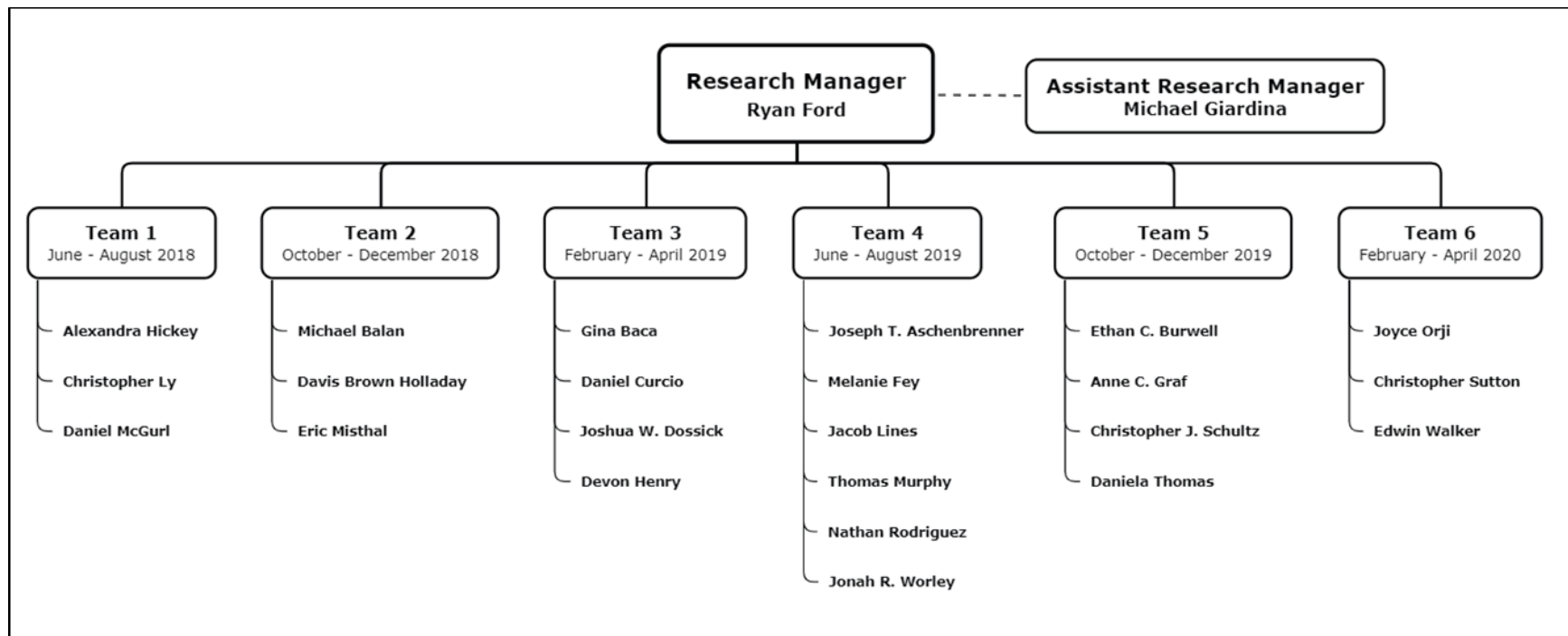


Figure 1. Research Team Organization and Timeframe

With the completed dataset compiled, the GTD master file was reorganized by attack type. I did so by filtering the master file by the type of weapons used. Each attack type was transferred to its own spreadsheet in the Excel workbook to help segregate, organize, and review the data. The data was then migrated to JMP® statistical discovery software for regression analysis and any other type of statistical investigation.<sup>61</sup>

## **D. LIMITATIONS AND CONSIDERATIONS**

Limiting an individual researcher's subjectivity as they reviewed thousands of GTD datapoints was key to providing the subsequent findings and analysis. A key priority throughout this endeavor was ensuring the GTD data be evaluated in a consistent and uniform manor across the six different research teams and 23 different researchers. This section addresses in more detail how individual subjectivity and group variance was mitigated to the greatest degree possible.

### **1. Subjectivity**

To help minimize subjectivity among individual researchers, two procedures were created. The first involved providing foundational knowledge, user guides, and an open-ended feedback mechanism to all research groups. The second incorporated an internal peer-review process as a means of quality assurance.

Foundational knowledge began with the onboarding of each fellowship group. At the start of each internship, the group received an initial presentation outlining the overall goal and research methodology. Following that briefing, additional resources and a contributor guide helped reinforce the process. Each group was afforded upwards of two weeks to familiarize themselves with these resources and begin reviewing data from the GTD database. The group would reconvene weekly to review questions and discuss how the research methodology applied to more complex incidents. These meetings inserted an appropriate level of oversight and opened an active feedback loop to ensure adherence to the research design by all team members.

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<sup>61</sup> SAS Institute Inc., *JMP*®, version Pro 14 (Cary, NC: SAS Institute Inc., 1989).

Team members were also asked to review each other's work. As outlined in the Phase 2—Crowd Assessment section of the Research Design, each terrorism incident that was recommended for inclusion in the study was then assessed by another researcher. Once the second team member agreed the GTD incident data and supporting PAI sources fit the research design, the incident was then included in the final list pending the approval and final review by the research manager. The weekly team meetings were used to review any incidents where ambiguity or a lack of agreement occurred during the peer-review process.

Admittedly, subjectivity can never be completely eliminated. Verifying that each incident entering the first phase of filtering was assessed in a consistent manner was a central component to this research design and received careful consideration. Nonetheless, a degree of variance surely exists but not to the extent that skews overall outcomes. This consideration of variance and subjectivity was mitigated to the greatest extent possible given the time and resources available.

## **2. Maintaining Methodological Integrity between Research Groups**

The methodology of aggregating and assessing crowd size and dynamics in phase two evolved with the project insofar as it became more rigid or selective. The first research fellowship group was quite experimental. This group received the overarching goals of the research but not the research design itself, which was intentionally withheld. The fellows had two weeks to familiarize themselves with the GTD and develop their own plan to query, review, assess, and catalogue the crowd size data. At the end of this period, we compared strategies. Their suggested approach closely aligned with what I had envisioned. The first fellowship group then began its research and adjusted the methodology to eliminate many of the recurring criteria that fell outside the profile of the original goal. For example, the first group originally researched all terrorism incidents across the world. After a few weeks, it became apparent that most of their time was spent reviewing events in Afghanistan, Iraq, and other areas of conflict. These events did not match the data profile befitting a study aimed at investigating attacks against civilian populations in developed countries. With this input, exclusions for areas of conflict were developed and applied before the second fellowship group started, thereby maximizing their time and providing a

more focused research effort. Any incidents reviewed by the first group in areas of conflict were retroactively removed from the study.

The second group was then better equipped with a clearer set of guidelines, and the group continued to flag incidents for review that were difficult to categorize. Their work helped clarify and narrow the scope for the third research fellowship group through this process of observation, feedback, inquiry, consensus finding, and refinement. Additional criteria, like assessing crowd density using the DHS Special Event Working Group's metric, were applied after the third group finished and then added to all the preceding incidents with an identified crowd size.<sup>62</sup> Additionally, the qualitative process of assessing crowd size and dynamics had stabilized enough for me to create a more complete contributor guide before the arrival of the fourth group. As the research ended its first year with three separate research fellowship groups, the growing pains had subsided, and twice the number of fellows was recruited for the fourth group.

No additional exclusions or changes to criteria happened during the fourth group's research fellowship, which signified the process in place was adjusted as accurately as possible for the needs of this project. However, this group made important strides in developing a data management system that significantly expedited the speed of incident processing in a more organized manner. In this way, each fellowship research team continually improved because of the hard work and successes of its predecessors. The quality of data is of highest importance. To that end, the process of mining the data evolved to become more detailed and exclusive as demonstrated in the findings.

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<sup>62</sup> Department of Homeland Security, *[FOUO] 2018 National Special Events Data Call Contributor Guidance*, 8–9.

## **IV. FINDINGS AND ANALYSIS**

This chapter details the results of the research design's first and second phases while documenting the number of incidents eliminated through the exclusion process. Only two attack types had a large enough sample size to allow further statistical analysis. A summary of the events appears for descriptive analysis. Next, the chapter discusses the outcomes of the regression analysis. It examines the findings of the regression analysis in the context of the primary and secondary research questions. Where correlations exist, the chapter offers strategies for how a predictive consequence model may be developed from the findings.

### **A. FINDINGS**

As designed, the exclusionary process successfully filtered the GTD database to find incidents meeting the criteria for inclusion in this study. This section documents the results of each phase of the filtering and vetting processes. A total of 379 incidents of the total 181,857 GTD incidents were selected for continued analysis.

#### **1. Results of Cursory Exclusions**

The full GTD dataset was downloaded in Spring 2018. At that time, the terrorist attacks from 2017 had not been released by the GTD. In September 2018, 2017 was included, totaling 181,857 incidents on record between the years 1970–2017. The first exclusion eliminated all events before 2000, which left 71,346 incidents for review. Removing areas of conflict reduced the total number of remaining incidents to 35,211. The research teams began their work on this dataset of over 35,000 incidents with the most recent set of events and worked backward. Teams 1–4 reviewed the events from 2008–2017 for a total of 28,369 incidents out of the 35,211. The fifth and sixth research teams continued their assessment of the remaining 6,842 incidents but those results are not included in this discussion due to the time constraints of this report. Table 2 provides a summary of the cursory exclusion results.

Table 2. Data Summary: Phase 1 Cursory Exclusions

| <b>Phase 1 Cursory Exclusions (Initial <i>n</i> = 181,857)</b>       | <b>Initial</b> | <b>Excluded</b> | <b>Remaining</b> |
|----------------------------------------------------------------------|----------------|-----------------|------------------|
| Cursory Exclusion 1: Removal of incidents occurring before 2000      | 181,857        | 110,511         | 71,346           |
| Cursory Exclusion 2: Removal of incidents in areas of conflict       | 71,346         | 36,135          | 35,211           |
| Cursory Exclusion 3: Withholding unassessed incidents from 2000–2007 | 35,211         | 6,842           | 28,369           |

## 2. Results of Narrowed Exclusions

The research teams used open-source information to eliminate any remaining incidents that showed evidence of a targeted killing, an attack against military, paramilitary, or police units, and attacks involving multiple weapon types. This process removed 10,177 incidents that targeted a particular individual or small group of individuals for assassination. Research teams identified another 6,000 incidents in which the attack involved an assault on only military, paramilitary, or police units and therefore were excluded. An additional 2,454 incidents were eliminated from the study since they included more than one weapon or attack type. Table 3 shows that the remaining 9,738 incidents met the minimum qualifications to begin crowd assessments.

Table 3. Data Summary: Phase 1 Number of Incidents with Narrowed Exclusions

| <b>Phase 1 Narrowed Exclusions (Initial <i>n</i> = 28,369)</b>                 | <b>Initial</b> | <b>Excluded</b> | <b>Remaining</b> |
|--------------------------------------------------------------------------------|----------------|-----------------|------------------|
| Narrowed Exclusion 1: Removal of targeted killings                             | 28,369         | 10,177          | 18,192           |
| Narrowed Exclusion 2: Removal of assaults on military, paramilitary, or police | 18,192         | 6,000           | 12,192           |
| Narrowed Exclusion 3: Removal of assaults using multiple weapon types          | 12,192         | 2,454           | 9,738            |

## 3. Crowd Assessment Exclusions

As the research progressed into crowd assessments, the methodology stretched to include a means for setting aside failed attacks, attacks that occurred in an area with a poorly defined space, and a final category that served as a “catch-all” for flagging an incident for further review. The failed attack category was necessary since some attacks passing the cursory and narrowed exclusions involved an incident in which only the attacker(s) were killed or wounded, or the planned attack was disrupted with no civilian

casualties. A total of 1,696 incidents met the criteria as a failed attack. A total of 3,221 incidents were set aside since no information was available to establish the size of the space or crowd within the open area where the attack occurred. For example, an active shooter's attack on a random sidewalk might be listed as an undefinable space if no photo or film of the attack were available, and no means of assessing the average footfall for that sidewalk. An additional 236 are flagged for further review and are not included in the study at this point.

This phase of the exclusion process left 4,585 incidents for possible inclusion in the study. Research Teams 1–4 found the actual or estimated crowd size for 755 of the remaining events. I reviewed each of the 755 individually as a final quality assurance check and withheld 376 incidents due to mostly minor issues. The results of the Phase 2 exclusions are documented in Table 4.

Table 4. Data Summary: Phase 2 Crowd Exclusions Using Open-Source Information

| <b>Phase 2 Crowd Exclusions (Initial <math>n = 9,738</math>)</b>       | <b>Initial</b> | <b>Excluded</b> | <b>Remaining</b> |
|------------------------------------------------------------------------|----------------|-----------------|------------------|
| Crowd Exclusion 1: Removal of failed attacks                           | 9,738          | 1,696           | 8,042            |
| Crowd Exclusion 2: Removal of incidents lacking crowd/space data       | 8,042          | 3,221           | 4,821            |
| Crowd Exclusion 3: Withholding incidents that are flagged/questionable | 4,821          | 236             | 4,585            |
| Crowd Exclusion 4: Removal of incidents with undetermined crowd size   | 4,585          | 3,830           | 755              |
| Crowd Exclusion 5: Final withholding of questionable/flagged incidents | 755            | 376             | 379              |

Finally, Table 5 summarizes the distribution of the 379 incidents categorized by attack type to be included for regression analysis:

Table 5. Data Summary: Incidents Available for Analysis by Attack Type

| <b>Attack Type (Total <math>n = 379</math>)</b> | <b>Incidents</b> |
|-------------------------------------------------|------------------|
| Improvised Explosive Device (IED)               | 223              |
| Firearms/Active Shooter                         | 104              |
| Incendiary Device                               | 32               |
| Edged Weapon/Melee                              | 14               |
| Vehicle Used as Weapon                          | 6                |

## **B. ANALYSIS**

Analysis of the findings includes both a statistical description of the initial results related to casualty rates and crowd size estimates caused by IEDs and firearms. Next, the analysis focuses on the primary effort of this study and uses regression analysis to examine the relationship between those two attack vectors and their casualty rates in proportion to the estimated crowd size. The regression analysis results are then used to explore this study's primary and secondary research questions, which determine final outcomes and recommendations.

### **1. Descriptive Analysis**

In total, 379 incidents of the 28,369 reviewed between 2008–2017 meet the qualifications for inclusion in the study. Stated as a percentage, 1.33% of the sample met the profile of the type of incident to be included in this study. Of the 379 incidents left for analysis, two attack types had a large enough sample size to warrant a deeper examination. In the instance of vehicles used as a weapon ( $n = 6$ ), edged weapon or melee attacks ( $n = 14$ ), and incendiary device attacks ( $n = 32$ ), the sample was too small to develop a meaningful statistical inference on casualty rates as a ratio of the estimated crowd size. However, IED attacks ( $n = 223$ ) and firearms and active shooter attacks ( $n = 104$ ) could be more confidently evaluated.

The analysis includes the initial findings (“Initial”) of both killed and wounded for IED and firearms attacks, as well as the adjusted findings (“Adjusted”). The adjusted findings represent the dataset when statistical outliers are removed. For the purposes of this study, any killed and wounded rates in the initial results greater than 2.5 standard deviations ( $2.5\sigma$ ) of the norm are considered statistically improbable (albeit not impossible). The outliers—to include “black swan” anomalies like the 2017 Las Vegas Shooting—are undoubtedly worth closer examination but lie beyond the scope of this thesis. Outliers are removed since the goal is to create a consequence model that sets realistic expectations of killed and wounded rates based on most likely real-world events. The outliers skew the outputs to the degree that can significantly undermine the validity of any models derived from the data. As a means of comparison, both the initial and adjusted results are presented

throughout the analysis. The descriptive analysis provides an overview of central tendency, the dispersion of data, a discussion of the outliers eliminated and any preliminary inferences that impact the development of models.

*a. Improvised Explosive Device*

Upon completion of the research methodology covering 2008–2017, a total of 221 incidents were included for analysis when an IED was the attack method. This terrorism attack type yielded the largest dataset of the five studied. The analysis of this group also includes 15 incidents involving a VBIED.

(1) Central Tendency and Data Dispersion

The overview discusses central tendency as represented by the mean ( $\mu$ ). The dispersion of data is discussed in terms of the maximum range ( $x_{max}$ ) since the minimum ( $x_{min}$ ) for this study will always be zero or one. The standard deviation ( $\sigma$ ) is then used to identify outliers. This delineation of outliers is noted by listing the initial findings, as well as the adjusted findings. The histograms for each attack type and supplemental data are available in Appendix B for a more detailed review of the data distribution and standard deviation of the norm.

Two hundred twenty-three IED incidents were initially included in the study when at least one person other than the assailant(s) was either killed or wounded and a crowd size was estimated. Notably, some incidents included in the study had a count for injured but no fatalities and vice versa. These incidents are still included to incorporate instances where victims are killed but none is wounded, or individuals are wounded but no fatalities. As shown in Tables 6, 7, and 8, 58.7% (131/223) of IED incidents reported at least one victim killed, and 90.1% (201/223) of incidents yield at least one injured.

The mean is another essential factor for this study since the central tendency of the data can be used in modeling as a baseline for expected consequences. Here, the mean killed per IED incident dropped by 34.8% (from 6.93 initial to 4.52 adjusted), while those wounded by IEDs fell 30.8% (18.71 initial to 12.95 adjusted). The average crowd size

estimated at the time of the IED attacks examined amounted to 183 and then 168 after outliers were removed (an 8.2% decrease).

Table 6. Data Summary: Killed by IED

| <b>Data Summary—Killed by IED</b>                                           | <b>Initial</b> | <b>Adjusted</b> | <b>% Change</b> |
|-----------------------------------------------------------------------------|----------------|-----------------|-----------------|
| Total Instances Included in Sample Size ( $n$ )                             | 223            | 214             | ↓ 4.04%         |
| Total Instances Where at Least One Innocent Person Is Killed ( $n_{kill}$ ) | 131            | 131             | ...             |
| Average Number of Persons Killed Per Attack ( $\mu$ )                       | 6.93           | 4.52            | ↓ 34.75%        |
| Maximum Persons Killed at a Single Attack ( $x_{max}$ )                     | 158            | 57              | ↓ 63.92%        |
| Standard Deviation for Persons Killed ( $\sigma$ )                          | 17.21          | 9.59            | ↓ 44.25%        |
| Ratio of Average Killed within the Average Crowd Size                       | 1:27           | 1:34            | ↑ 25.93%        |

Table 7. Data Summary: Wounded by IED

| <b>Data Summary—Wounded by IED</b>                                            | <b>Initial</b> | <b>Adjusted</b> | <b>% Change</b> |
|-------------------------------------------------------------------------------|----------------|-----------------|-----------------|
| Total Instances Included in Sample Size ( $n$ )                               | 223            | 211             | ↓ 5.38%         |
| Total Instances Where at Least One Innocent Person Is Wounded ( $n_{wound}$ ) | 201            | 201             | ...             |
| Average Number of Persons Wounded Per Attack ( $\mu$ )                        | 18.71          | 12.95           | ↓ 30.79%        |
| Maximum Persons Wounded at a Single Attack ( $x_{max}$ )                      | 351            | 125             | ↓ 64.39%        |
| Standard Deviation for Persons Wounded ( $\sigma$ )                           | 37.59          | 20.83           | ↓ 44.57%        |
| Ratio of Average Wounded within the Average Crowd Size                        | 1:10           | 1:13            | ↑ 30%           |

Table 8. Data Summary: IED Crowd Size

| <b>Data Summary—IED Crowd Size</b>                           | <b>Initial</b> | <b>Adjusted</b> | <b>% Change</b> |
|--------------------------------------------------------------|----------------|-----------------|-----------------|
| Total Instances Where a Crowd Size Is Estimated ( $n$ )      | 223            | 214             | ↓ 4.04%         |
| Average Crowd Size Observed ( $\mu$ )                        | 183.42         | 168.37          | ↓ 8.20%         |
| Maximum Crowd Size Observed at a Single Attack ( $x_{max}$ ) | 5,000          | 5,000           | ...             |
| Standard Deviation for Crowd Size ( $\sigma$ )               | 565.51         | 570.24          | ↑ 0.84%         |

Appendix B also provides insight into the data distribution. The maximum range is significantly lowered (63.9% decrease for killed and 64.3% reduction for wounded) once outliers are removed, which is the desired effect. The standard deviation is also narrowed by 44.2% for fatalities and 44.6% for wounded.

## (2) Outliers

Outliers were defined as those beyond the 97.5% quantile shown in the initial results for both killed and wounded. In the case of IED fatalities, a total of five incidents resulting in 58 killed or more were removed from the study since they met this study's threshold as an outlier. Four separate incidents and one incident already labeled as an outlier for fatalities were identified as outliers for wounded by IEDs. In total, nine incidents are considered IED outliers, which mean they exceed 2.5 standard deviations from the norm. These outliers can be thought of as statistically improbable yet still plausible outcomes. Once adjusted for outliers, the dataset suggests that most IED attacks will result in a range of 1–10 killed (86% probability) and 1–20 wounded (77% probability).

## (3) Ratio and Effective Target Impact Area

Of the 223 IED incidents in which a pre-attack population was estimated, the average crowd size per attack was 183 persons with an average of nearly one killed and 19 wounded per attack. These results equate to one fatality per 27 participants ( $183/7 =$  ratio of 1:27) and one wounded per 10 participants ( $183/19 =$  ratio of 1:10). When adjusted to remove outliers, the ratios broaden to one fatality per 34 participants (1:34) and one wounded per 13 participants (1:13).

## (4) Discussion

Although this data is useful in making rough generalizations, the breakdown provided here does not encompass complex factors, such as type of explosives, fragmentary materials added to the IED, and placement at the time of the explosion (i.e., unidirectional blast vs. omnidirectional blast). Other modeling tools and calculations specific to explosives can aid in accounting for these variables. The intent of this research is to purposefully paint with a broad brush and accepts that variance in the sample size determines the final averages of the killed and wounded.

### ***b. Firearms***

The summary of research spanning 2008–2017 revealed a total of 104 incidents in which a firearm was the chosen method of attack and a pre-attack crowd size was estimated.

The same analysis of central tendency, standard deviation and outliers, and effective target impact area measured for IEDs will also be applied to attacks involving firearms.

(1) Central Tendency and Data Dispersion

Tables 9, 10, and 11 indicate that 77.2% (77/101) of active shooter incidents reported at least one victim killed and 79.2% (80/101) of incidents yield at least one injured. The average killed and wounded per incident is relatively equal: 4.32 killed and 4.93 wounded when adjusted for outliers. The removal of outliers significantly reduced the average of wounded individuals per each firearms attack (14.48 initial to 4.93 adjusted, or a decrease of 65.95%). The fatality average per attack also dropped but not nearly as significantly. The average crowd size observed during an active shooter attack also fell by a similar proportion as the average wounded when removing outliers (333.5 initial to 112.15 adjusted, or a decrease of 66.37%). The removal of only three outliers also reduced the standard deviation of those killed by firearms by 26.32% and an 89.99% reduction of wounded by firearms. The decrease in standard deviation again lends weight to the importance of isolating outliers when developing a model of the most probable consequences. The data summary of this portion of the analysis is documented in Tables 9, 10, and 11.

Table 9. Data Summary: Killed by Firearms

| <b>Data Summary—Killed by Firearms</b>                                      | <b>Initial</b> | <b>Adjusted</b> | <b>% Change</b> |
|-----------------------------------------------------------------------------|----------------|-----------------|-----------------|
| Total Instances Included in Sample Size ( $n$ )                             | 104            | 101             | ↓ 2.88%         |
| Total Instances Where at Least One Innocent Person Is Killed ( $n_{kill}$ ) | 77             | 77              | ...             |
| Average Number of Persons Killed Per Attack ( $\mu$ )                       | 5.42           | 4.32            | ↓ 20.4%         |
| Maximum Persons Killed at a Single Attack ( $x_{max}$ )                     | 59             | 40              | ↓ 32.2%         |
| Standard Deviation for Persons Killed ( $\sigma$ )                          | 10.30          | 7.59            | ↓ 26.32%        |
| Ratio of Average Killed within the Average Crowd Size                       | 1:67           | 1:25            | ↓ 62.7%         |

Table 10. Data Summary: Wounded by Firearms

| <b>Data Summary—Wounded by Firearms</b>                                       | <b>Initial</b> | <b>Adjusted</b> | <b>% Change</b> |
|-------------------------------------------------------------------------------|----------------|-----------------|-----------------|
| Total Instances Included in Sample Size ( $n$ )                               | 104            | 101             | ↓ 2.88%         |
| Total Instances Where at Least One Innocent Person Is Wounded ( $n_{wound}$ ) | 80             | 80              | ...             |
| Average Number of Persons Wounded Per Attack ( $\mu$ )                        | 14.48          | 4.93            | ↓ 65.95%        |
| Maximum Persons Wounded at a Single Attack ( $x_{max}$ )                      | 851            | 69              | ↓ 91.89%        |
| Standard Deviation for Persons Wounded ( $\sigma$ )                           | 84.90          | 8.50            | ↓ 89.99%        |
| Ratio of Average Wounded within the Average Crowd Size                        | 1:23           | 1:22            | ↓ 4.35%         |

Table 11. Data Summary: Active Shooter Crowd Size

| <b>Data Summary—Active Shooter Crowd Size</b>                | <b>Initial</b> | <b>Adjusted</b> | <b>% Change</b> |
|--------------------------------------------------------------|----------------|-----------------|-----------------|
| Total Instances Where a Crowd Size Is Estimated ( $n$ )      | 104            | 101             | ↓ 2.88%         |
| Average Crowd Size Observed ( $\mu$ )                        | 333.5          | 112.15          | ↓ 66.37%        |
| Maximum Crowd Size Observed at a Single Attack ( $x_{max}$ ) | 22,000         | 3,000           | ↓ 86.36%        |
| Standard Deviation for Crowd Size ( $\sigma$ )               | 2,164.89       | 353.68          | ↓ 83.66%        |

## (2) Outliers

Three incidents were identified as outliers since their killed or wounded rates were greater than the 97.5% quantile. As the distribution shown in Appendix C indicates, the threshold for removing active shooter attacks are incidents where more than 43 individuals are killed or more than 71 wounded. Unlike IEDs, the three outliers removed for active shooter attacks exceeded the threshold in both killed and wounded outcomes. The primary incident that greatly skewed the initial findings was the 2017 Las Vegas shooting (59 killed, 851 wounded, and 22,000 in attendance). Once adjusted for outliers, the data indicates that 89% of the time, an active shooter incident will produce a range of 1–10 killed and 1–10 wounded.

## (3) Ratios and Effective Target Impact Area

When adjusted to remove outliers, the proportion of a crowd size likely to be killed by firearms is about 1:25. The removal of outliers reduced this killed by firearms ratio from 1:67, mainly due to removing the 2017 Las Vegas shooting. The ratio of wounded by firearms, on the other hand, fell from 1:23 to 1:22 once the outliers had been eliminated.

#### (4) Discussion

The use of firearms against mass gatherings indicates a nearly equal ratio of killed and wounded. Although types of firearms (rate of fire, caliber, amount of ammunition on hand, etc.) vary, a fundamental difference in this attack type compared to an IED is the length of time available to conduct the shooting. The nearly equal ratios of killed and wounded by firearms perhaps contributed to the indiscriminate nature of the attack as the crowd is engaged. However, the higher killed and injured rates are likely attributed to the length of time the attacker uses to fire the weapon before the crowd disperses or the attacker stops shooting. An additional factor that can likely increase the overall casualty rate is the shooter's position in relation to the masses. An elevated position allows for a broader field of fire against the crowd. The 2017 Las Vegas shooting included an attack against a large and exposed group from an elevated position for an extended period, which allowed for higher casualty rates. Thankfully, these are uncommon characteristics of incidents reviewed in this study yet underscore the importance of accounting for outliers when developing a model for most likely outcomes.

### 2. Regression Analysis

The correlation ( $r$ ) between attack type and casualty rate given a known or estimated crowd size are analyzed for the IED and firearm attack types. As explained in the research design, regression analysis is used to answer the primary research question by determining whether a relationship exists between these variables. Assuming an  $r$  value greater than zero exists, the secondary research question may be examined to determine the degree of relationship and fitness of data in support of a predictive consequence model.

#### *a. Improvised Explosive Devices*

Analyses of IEDs, casualty rates, and crowd sizes uncover a weak positive correlation throughout. Once outliers are removed for IED fatalities, the study shows the estimated crowd size holds almost no correlation between the independent and dependent variables. Table 12 summarizes the findings across all IED categories, while Appendix B provides a more detailed look at the regression analysis.

Table 12. Regression Analysis: Improvised Explosive Devices

|                          | Killed—Initial | Killed—Adjusted | Wounded—Initial | Wounded—Adjusted |
|--------------------------|----------------|-----------------|-----------------|------------------|
| Correlation ( <i>r</i> ) | 0.15           | 0.06            | 0.16            | 0.13             |
| Relationship             | Weak Positive  | Weak Positive   | Weak Positive   | Weak Positive    |

**b. Firearms and Active Shooter**

Initially, crowd size and the total killed and wounded rates from an active shooter show a notably higher correlation when compared to IEDs. When adjusted to eliminate the outliers, the relationship between active shooter fatalities and the estimated crowd size falls to a weak positive correlation. The relationship for wounded by an active shooter and the estimated crowd size drops from almost a direct relationship to just barely a moderate, positive relationship. As with IEDs, Table 13 summarizes the findings across all categories, whereas Appendix C offers additional details of the regression analysis.

Table 13. Regression Analysis: Firearms

|                          | Killed—Initial    | Killed—Adjusted | Wounded—Initial | Wounded—Adjusted  |
|--------------------------|-------------------|-----------------|-----------------|-------------------|
| Correlation ( <i>r</i> ) | 0.54              | 0.24            | 0.98            | 0.35              |
| Relationship             | Moderate Positive | Weak Positive   | Strong Positive | Moderate Positive |

**3. Evaluation of Research Questions**

With the descriptive and regression analyses complete, the research questions are now reexamined. Since a large enough sample size is not available to assess the incendiary device, edged weapon, and ramming vehicle attack types, the research questions will only be assessed with the results of active shooter incidents and IEDs.

**a. Primary Question**

*What relationship exists between the known or estimated crowd size and the killed and wounded rates of common terrorism attack types?*

The research design required a correlation coefficient (*r*) greater than or equal to 0.3 to reject the null hypothesis. In all instances except for the relationship between those

wounded by an active shooter, the adjusted  $r$  values indicate a weak, positive correlation overall (where  $r > 0$  and  $< 0.3$ ). A weak positive correlation demonstrates significant ambiguity between the relationship of the attack type (where a crowd size is known or estimated) and the number of killed or wounded from the attack. For these variables (killed by IED, wounded by IED, and killed by active shooter), the null hypothesis ( $H_o$ ) cannot be rejected outright. Sufficient evidence supports a conclusion that even though crowd size and attack type ( $X$ ) is a factor in overall casualty outputs of a given attack type, the influence of the crowd size variable is unclear. However, the crowd size is likely not statistically significant in estimating casualty rates ( $Y$ ).

The moderate, positive correlation between those wounded by active shooters allows the null hypothesis ( $H_o$ ) to be rejected and supports the alternative hypothesis ( $H_a$ ). The adjusted  $r$  value of 0.35 clears the threshold of  $\geq 0.3$  required to accept the alternative hypothesis. Stated differently, a demonstrable correlation exists between the crowd size at the time of an active shooter terror attack and its corresponding casualty rates. Given that this correlation barely clears the threshold with a small margin, the relationship should still be viewed with a fair degree of skepticism.

In summary, the data used for this analysis yields little evidence that the overall crowd size plays a significant role in predicting total casualty rates for an IED or active shooter attack. Logically, a crowd or small group must be present for an attack against mass gatherings to have any level of impact. Most attacks included in this study in which a crowd size was available using PAI typically fell below 500 attendees at the time of the attack. Closer research may reveal that crowds under 500 attendees represent the majority of terror attacks and should be used as a baseline for developing consequence models. Alternatively, a deeper study into the lethality of attacks against larger populations of 500+ attendees may provide a valuable comparison of consequences between large and small groups.

***b. Secondary Question***

*How can the results be used to develop a consequence model that predicts future lethality rates of terror attacks against mass gatherings?*

Although the overall crowd size plays far less of a role in predicting casualty outcomes of IED and active shooter terror attacks than suspected, this research identified other factors as more important considerations. These factors include the maximum effective range of the attack type, crowd density, ease of egress (i.e., a crowd's ability to disperse quickly), and the winnowing of data to determine bounds for realistic outcomes. A large enough dataset that incorporates these variables will likely produce a more accurate consequence model for predicting domestic terrorism casualty rates. Each of these variables is explained in more detail.

The maximum effective range helps determine the scope of impact for the chosen attack type. For example, even though the overall crowd size at an event may total 5,000, a single attacker will likely only have access to a fraction of the total crowd size. This access, or "spot-light," combined with the attack lethality (i.e., rate of fire, blast area, size, power, and velocity of a vehicle, etc.) is a more accurate casualty prediction method.

Crowd density is inherently difficult to measure but an important factor nonetheless. The density of a crowd often changes throughout a single event. Larger mass gatherings with multiple performance areas and attractions can have changing densities throughout the event footprint at any given moment. The ease of egress is important since the crowd itself is the terrorist's target. Limiting the exposure of a crowd to an active assailant lessens overall casualty rates. Therefore, the quicker a crowd can disperse after an active shooter, edged weapon, or ramming vehicle attack begins, the survivability odds increase. It follows that less dense and smaller groups have lower casualty rates. It might also explain why some outliers, like the 2017 Las Vegas shooting, saw significantly higher killed and wounded rates. Although crowd density would play a factor in an IED, VBIED, and perhaps incendiary device attacks, the casualty rate of these attack types was nearly instantaneous, which made the attacker's length of exposure to the target a non-factor.

Finally, the development of a consequence model must determine whether the outcomes represent the maximum of maximums (i.e., worst-case scenario) or the likely range of most realistic outcomes. Considering both factors within the same model is possible; however, the key question is how to identify and evaluate outliers. The bounds placed by this study are just one example of how big data can be filtered to identify a

sample size that yields more realistic outcomes. The outliers are certainly worth additional research to identify similarities between these “black swan” events more clearly.

Although the findings of this study indicate a lack of correlation between crowd size and casualty rates within the IED and active shooter attack vectors, the results still have merit. The descriptive analysis provides helpful markers that can be used to set parameters for Monte Carlo simulations. Monte Carlo simulations are computer-generated random samplings within a predefined set of boundaries. The historical data and analysis completed by this research can be used to establish those boundaries as fenceposts for the Monte Carlo simulations. Those simulations can then generate a large enough sample size for all five attack types within realistic, data-driven limits. Although this method may not be as accurate as creating a consequence model solely based on historical events, the use of Monte Carlo simulation is a good compromise and a common alternative when sample sizes are small. Dr. Thomas Mackin, co-advisor for this thesis, developed a prototype consequence model using a Monte Carlo mathematical simulation. This model employs the tenets and findings of this research to establish a proof of concept. A summary of this approach is provided by Dr. Mackin in Appendix D.

## **V. SUMMARY**

This thesis used a statistical analysis approach to assess whether the human consequences of common terror attack methods against crowds and mass gatherings could be predicted within realistic parameters. The GTD yielded enough historical data for the analysis of IED and firearm attack types. The analysis results demonstrate a generally weak correlation between crowd size at the time of the attack and the ensuing casualty rates. Although more research and analysis are necessary to build a complete model, this study still has value. The implications, recommendations, and a pathway to implementation based on this research are detailed in the following sections.

### **A. IMPLICATIONS AND RECOMMENDATIONS**

The work completed through this study can be considered a basic proof of concept that encourages future inquiry and strongly advocates for continued research in the development of public safety risk assessments for mass gatherings. The implications of this thesis relate to the potential, continued study, and advancement of this topic that is only possible with a more rigorous application of academic research and statistical analysis. Although this project stopped short of a fully developed consequence model for all attack types considered, the findings revealed some powerful benefits of thoroughly researched, tested, and vetted predictive analysis tools. Four key implications were identified during this research. These implications serve as recommended topics for further study.

#### **1. Shifting the Focus Away from Crowd Size**

The regression analysis showed that only the active shooter attack type had a moderate-positive correlation ( $r = 0.35$ ) to those wounded by firearms once outliers were removed. Those killed by firearms had the second-highest correlation coefficient of  $r = 0.24$ , which was near a moderate-positive correlation. These results signify that the active shooter attack type is better suited for more investigation over the four other attack types, given this initial correlation and higher frequency of occurrence available to study.

Yet, the low correlation between the overall crowd size and casualty rates among IED and firearm attacks cannot be ignored. Although this initial assessment reveals low statistical significance between the independent and dependent variables, knowing that the total crowd size influences casualty rates less than initially hypothesized is important to acknowledge.

Instead, the future pursuit of a probabilistic consequence model would benefit from research into other crowd dynamics. Specifically, this project's research team observed the variables of the maximum effective range of the attack type, crowd density, and ease of egress as key variables that contributed to overall killed and wounded totals. An assessment into each of these components' impact on the attack type's outcomes can be incorporated into a more holistic model that factors in more than just the crowd size. The correlation coefficient for each variable (crowd size, crowd density, maximum effective range, and ease of egress) can then be used to determine the weight or influence each variable holds over the model's predictive analysis output.

## **2. Considering Pockets of Risk vs. Overall Risk**

The current DHS special event assessment rating and the Philadelphia OEM's risk and vulnerability ratings for special events each provide a risk calculation that assesses an event in its totality. This approach is helpful at a macro level yet lacks the flexibility to evaluate known vulnerabilities within a single event. A tool that incorporates this level of granularity holds practical value to public safety planners.

Large races, parades, or other mobile events are an excellent example of this concept. When the Philadelphia Marathon takes place each November, the DHS SEAR assessment rates the event at a SEAR 3 or below.<sup>63</sup> No additional information is available to the local jurisdiction. Philadelphia's risk and vulnerability assessment expands with more detail but still assesses the event holistically. Neither product specifically addresses or accounts for heightened vulnerabilities at the start of the race when runners are corralled.

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<sup>63</sup> SEAR 3: An event of national and/or international importance that requires only limited federal support.

An IED or active shooter attack at this point would have the highest consequences given the crowd size and density. Once the race starts, the vulnerability at the starting line quickly lessens as runners embark and the adversarial attractiveness decreases. While runners and spectators are dispersed across the 26.2-mile course, their exposure is also spread across that same route. The consequences of any single attack along the route will impact far fewer individuals than at the starting line. As logically follows, the finish line increases in its vulnerability and adversarial attractiveness as the area becomes crowded with race finishers and local media. In this way, the risk is not a static value that can be fully represented as an overall calculation. The vulnerabilities and consequences at most large gatherings will naturally ebb and flow to various locations within the designated area of a single event.

A model that can assess individual pockets of risk (to include variables like crowd size, crowd density, and ease of egress at those pockets) within a single event is worth pursuing since most attacks observed in this study only affected a fraction of the overall crowd. Therefore, all attendees within a major concert arena, large festival, or along a parade route are unlikely to all be exposed to harm (i.e., the maximum effective range) at the time of a terrorist attack. In these larger venues or events, some attendees may not even be aware of an attack when it first unfolds. In these cases, a more sensible approach includes identifying key areas or pockets within the event or venue that are most vulnerable and susceptible to an attack. Local public safety officials, event planners, and venue owners know these vulnerabilities best. Providing these professionals with an easily accessible, predictive analysis tool that identifies the most probable outcomes of an attack within those individual pockets of risk supports better preparedness through data-driven prevention and mitigation strategies.

### **3. Accounting for Outlier Events**

A clear implication of this study is the influence of outlier events. This research defined an outlier as a terrorist incident that exceeded 2.5 standard deviations ( $2.5\sigma$ ) from the norm. The findings indicate the value of appropriately accounting for outliers as evidenced in the differences between initial and adjusted results.

Failure to account for the outliers skews the results by setting unrealistic parameters if applied to a mathematical model or simulation. The technique and threshold for identifying these statistically improbable events in this study were straightforward and relatively basic when compared to other mathematical approaches. Regardless of the method and threshold chosen, future study in this topic should also account for outliers in the research design to identify and remove these “black swan” incidents.

However, outliers should be set aside and not discarded altogether. Another vein of potential research is a deeper inquiry into how these statistically improbable outcomes materialized. Analyzing the variables and tactics that create casualties at such a high rate can be incorporated into a consequence model as a maximum of maximums. The result is a simulation that sets realistic ranges of the most likely casualty rates while still noting potential worst-case scenarios based on historical data.

#### **4. Rethinking Datamining and Publicly Available Information**

Admittedly, the chosen research design that incorporated several small teams of interns was inefficient and not sustainable in the long term. The research group spent approximately 1,500 collective hours researching terror attacks against mass gatherings ultimately to find 755 incidents that fit the profile for statistical analysis. The START Consortium at the University of Maryland uses a similar internship framework to update and maintain the GTD.

Furthermore, the research teams found that many of the older news articles cited by the GTD are archived and no longer available online. The team also reported that the ability to use social media as an alternate source of crowd size and dynamics became increasingly limited in the more formative years of social media’s existence.<sup>64</sup> Eventually, the amount of open-source information available for this study became sparse and dwindled as the team investigated older incidents. The entire group’s diligent and admirable work was also incredibly tedious, tiresome, and mentally taxing. Yet, an attractive alternative could address this inefficiency.

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<sup>64</sup> Twitter launched in 2006, YouTube launched in 2005, and Facebook launched in 2004.

The role and value of artificial intelligence (AI) in the future of public safety research—specifically where big data is involved—cannot be understated. A properly written algorithm implemented as an AI function could scour the same open-source information to pair crowd sizes with GTD casualty rates in a fraction of the time it took this research team. In this way, AI can supplement this type of qualitative research, which reduces the overall burden on staff members. Such an AI program can also be modified to search for multiple characteristics of crowds or terrorism attacks in a way that is constantly learning and improving. Incorporating AI into public sector research is undoubtedly a priority implication. Well-resourced organizations that host and maintain extensive databases, such as the GTD, are ideal laboratories to experiment and refine AI’s potential use in public safety research.

## **B. IMPLEMENTATION**

The primary, overarching recommendation is to advance this research to lead possibly to a widely accepted and easily accessible casualty prediction tool for public safety practitioners. Just as the U.S. military developed and maintains a set of risk assessment calculations and products, the same set of resources should be created and implemented to help mitigate domestic threats against special events and mass gatherings. This section details specific actions and practical strategies that can make these tools a reality for civilian planners.

### **1. Project Ownership and Collaboration**

Before all else, future success of this project requires more detailed research and subject matter expertise. Although the research team’s efforts produced beneficial outcomes, a local emergency management office is not the ideal champion to advance the project beyond this point. Additional individual research or support from organizations with subject matter expertise in developing mathematical models is now necessary.

Each of the four areas previously identified as implications and recommendations are excellent areas for more targeted research or perhaps, as future thesis topics. Additionally, the individual work by Dr. Mackin, as outlined in Appendix D, illustrates the interest in this topic among those with the specific skillsets and knowledge required to

develop a mathematical model. In this way, any individual research contributes to the body of knowledge in an ad hoc or less organized fashion.

Alternatively, the project can be adopted by a research institution or even as a collaborative effort between several organizations. As an example, the DHS Science and Technology (S&T) Directorate oversees the aforementioned COE network. The DHS description of the COE network aligns closely with the current needs of this project:

The COE network is an extended consortium of hundreds of universities conducting groundbreaking research to address homeland security challenges. Sponsored by the Office of University Programs, the COEs work closely with the homeland security community to develop customer-driven, innovative tools and technologies to solve real-world challenges.<sup>65</sup>

The START Consortium, hosted at the University of Maryland, is already an emeritus member of the COE. Since START (and the GTD database maintained there) is part of this broader network, perhaps START is the ideal candidate to incorporate a consequence model into its GTD portfolio. Even the incorporation of new variables related to crowd size or dynamics would be a valuable addition to its yearly updates. If these variables are collocated in the GTD, other individuals or research institutions can more easily contribute with their areas of expertise by means of in-depth statistical analysis, application of AI, and the development of mathematical models. For example, Johns Hopkins University's EMCAPS tool already laid a clear foundation for modeling the impacts of explosives. Combining the resources of EMCAPS and the GTD to develop a predictive analysis model for other attack types seems like a natural starting point of collaboration between two existing COE members. Of course, the COE is only one network among many. Undoubtedly, a plethora of individual universities, think tanks, research initiatives, or government agencies can leverage the necessary expertise to expedite this project.

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<sup>65</sup> "Centers of Excellence," Department of Homeland Security, July 6, 2009, <https://www.dhs.gov/science-and-technology/centers-excellence>.

## **2. Improved Department of Homeland Security Risk Assessments for Local and State Partners**

In the interim, the DHS-SEWG can investigate options for providing more of an assessment to local and state jurisdictions beyond the current numerical SEAR score. Local jurisdictions across the United States gather a large amount of data for each special event submitted for a DHS-SEWG assessment. Since the full DHS assessment of any submitted event is classified and off-limits to local contributors, a reasonable compromise is for the DHS to offer a shorter, sanitized risk report. The sensitive but unclassified assessment may be of particular use to more rural counties that lack the resources to build their own risk assessment products or may not have access to a regional fusion center for intelligence support.

## **3. Increased Accessibility**

For either of the suggested implementation strategies, each still requires a means of placing those tools and risk assessments within easy reach of local planners. Of course, an abridged and sanitized risk assessment from the DHS can be emailed to the requester. A consequence model or more comprehensive risk and vulnerability assessment tool can be hosted on a website like the EMCAPS tool. However, consolidating resources at a common collaboration point would be beneficial. The DHS created the Homeland Security Information Network (HSIN) for precisely this purpose.

The HSIN is a natural fit for this need. The HSIN is available nationwide to all public safety members at all levels of government. Members can access and share information through communities of interest (COIs). Access to the HSIN and appropriate COIs within the network is provided on a need-to-know basis. The DHS-SEWG already uses a COI to receive special event data from local jurisdictions. The data shared on the SEWG COI is used to generate the SEAR ratings and warehouse special event data. In its current form, the SEWG COI is a unidirectional communication path to the SEWG.

The proposal, then, is to build on this existing framework and create a new COI on the HSIN specific to special event preparedness. Even better, incorporate more features into the current SEWG COI so that the SEWG is the main repository for approved special

event resources as they become available. The SEWG COI can then be used as the nationwide collaboration point for public safety practitioners and planners to access a suite of approved risk management tools, vetted consequence models, risk assessments, and other resources related to protecting soft targets like mass gatherings. In this way, the SEWG COI becomes an even more effective and accessible resource to their partners at the state and local levels.

## **C. CONCLUSION**

Regardless of whether the approach used in this thesis is followed or another methodology is chosen, the continued focus on developing easily accessible and realistic consequence models is greatly needed in the homeland security community. Violent extremists continually choose mass gatherings, special events, and other soft targets in public spaces because of their adversarial attractiveness. I strongly advocate following the example set by the Department of Defense (DOD) in its prediction of U.S. troop casualties as an element of pre-battle risk assessment. Redesigned and repurposed to anticipate civilian casualties caused by domestic terrorism, an authoritative consequence model can be of tremendous benefit in determining the overall risk of special events and mass gatherings. The ability to uniformly and accurately measure consequences (and therefore risk) is an important, necessary, yet absent tool. A clear understanding of the potential consequences is required for risk to be appropriately managed, mitigated, transferred, or accepted. Focusing the efforts of researchers, statisticians, and policymakers to develop and maintain a domestic terrorism consequence model is sorely needed but well within reach.

This research endeavor ultimately answered the primary research question by discovering the overall crowd size only minimally impacts casualty rates among the two attack methods analyzed, IEDs and active shooters. Little to no relationship exists between these variables. However, the project highlighted the need for continued research into other key variables that likely hold a higher degree of influence over casualty outcomes. Those areas warranting further study include crowd density, the maximum effective range of the chosen attack type, and the ease of egress. Furthermore, this thesis demonstrated how the

consequences of terrorist attacks could be predicted or modeled if enough historical data were available to set realistic parameters for mathematical models, such as Monte Carlo simulations. The study then provides an achievable and actionable implementation strategy using preexisting networks and resources should future interest arise in developing this concept further.

The threats against soft targets are unlikely to lessen. However, their consequences can be more effectively mitigated with properly researched, tested, and implemented risk analysis products. With any intensive statistical analysis, it can be easy for researchers to lose sight of the significance behind data, numbers, and endless spreadsheets. In this case, the numbers most often represented lives lost in previous terror attacks. Yet, energetic collaboration and active investment around this risk assessment and consequence management topic provides hope for lives saved, trauma minimized, and fears eroded; thereby, finding safety in numbers.

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## APPENDIX A. EXAMPLE OF PHILADELPHIA'S PROTOTYPE CONSEQUENCE MODEL



Figure 2. Example of a Prototype Consequence Model Developed by the Philadelphia OEM for Use in Risk and Vulnerability Assessments

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## APPENDIX B: SUPPORTING ANALYSIS FOR IMPROVISED EXPLOSIVE DEVICES

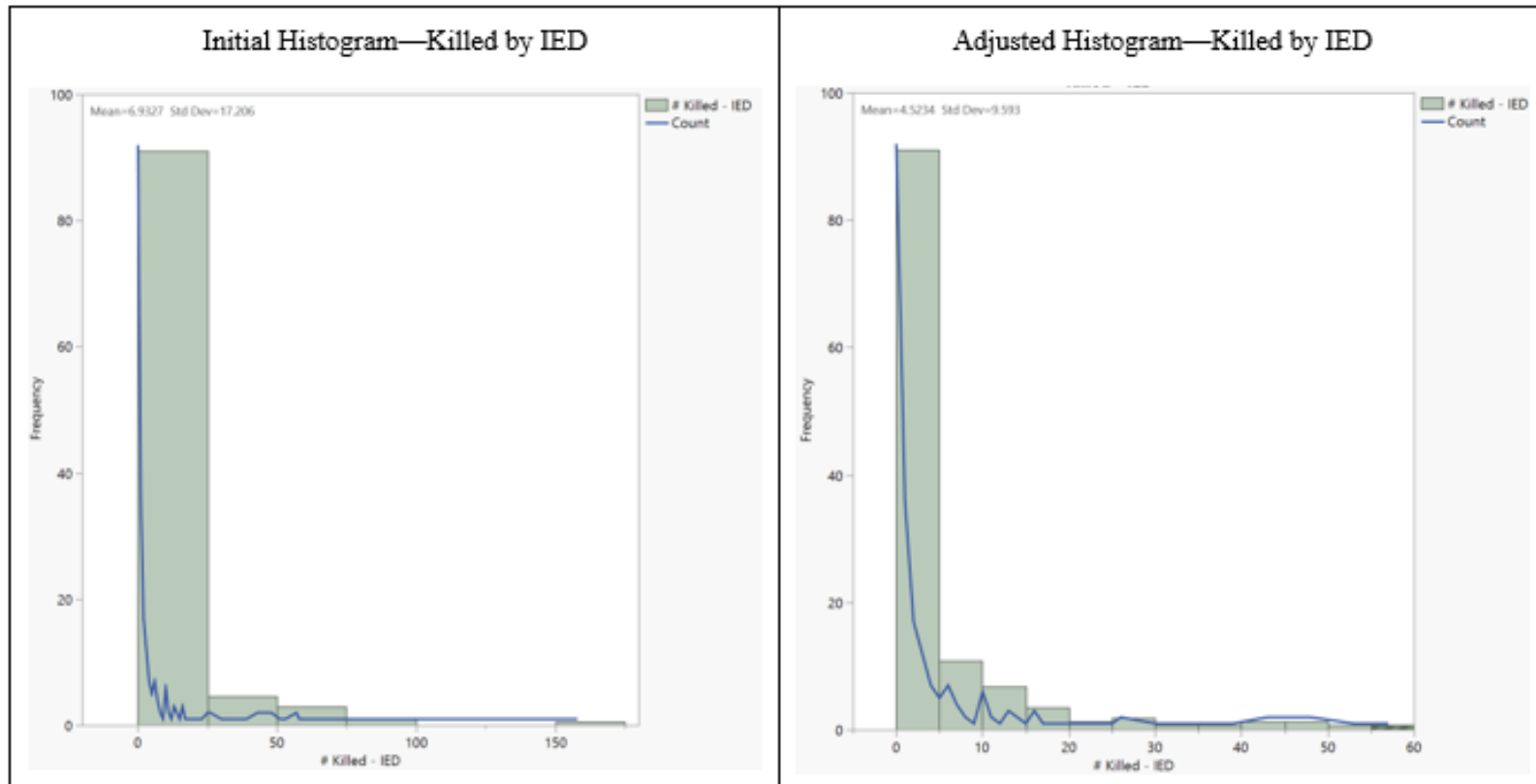


Figure 3. Initial and Adjusted Histograms: Killed by IED

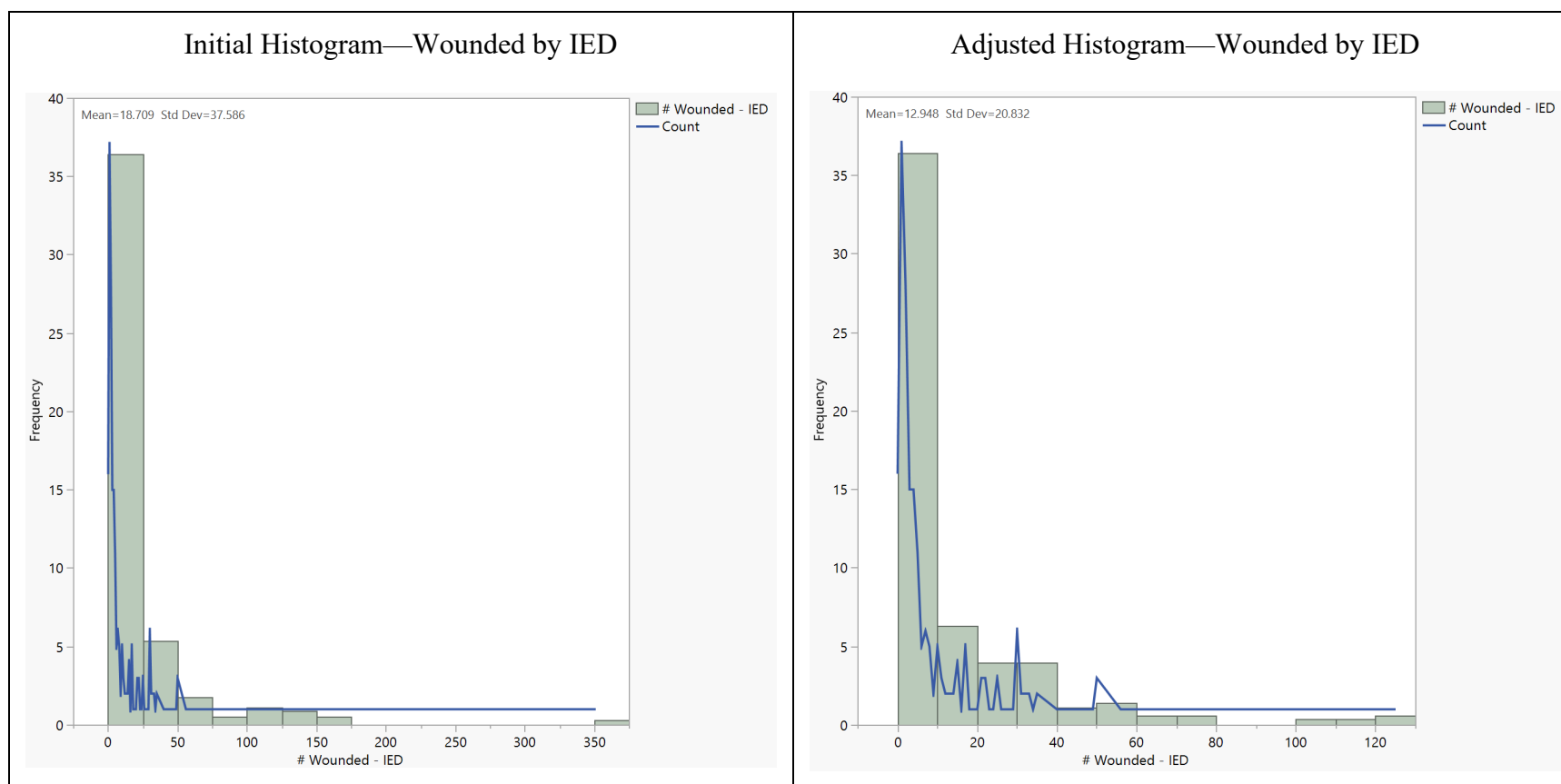


Figure 4. Initial and Adjusted Histograms: Wounded by IED

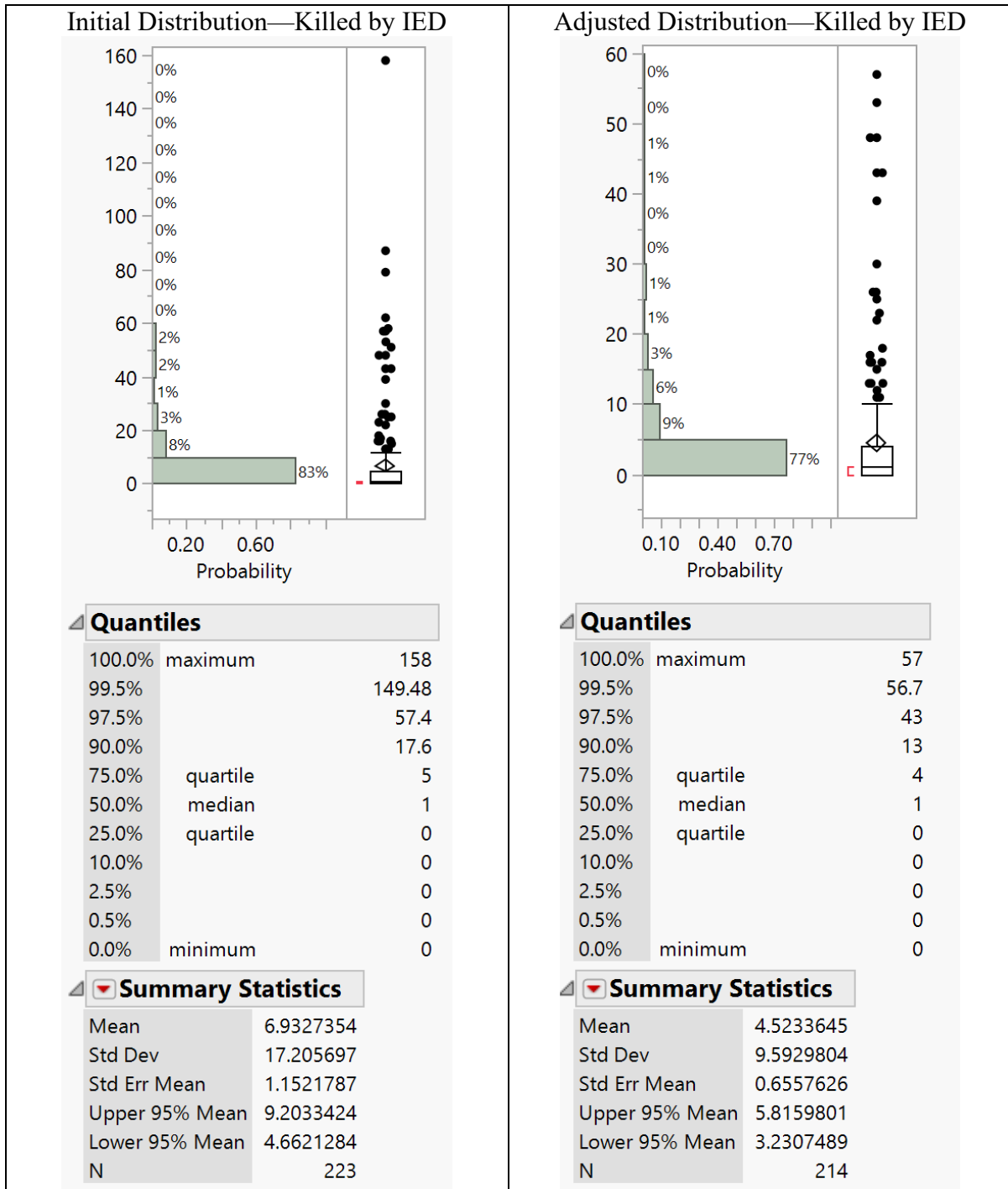


Figure 5. Initial and Adjusted Data Distribution: Killed by IED

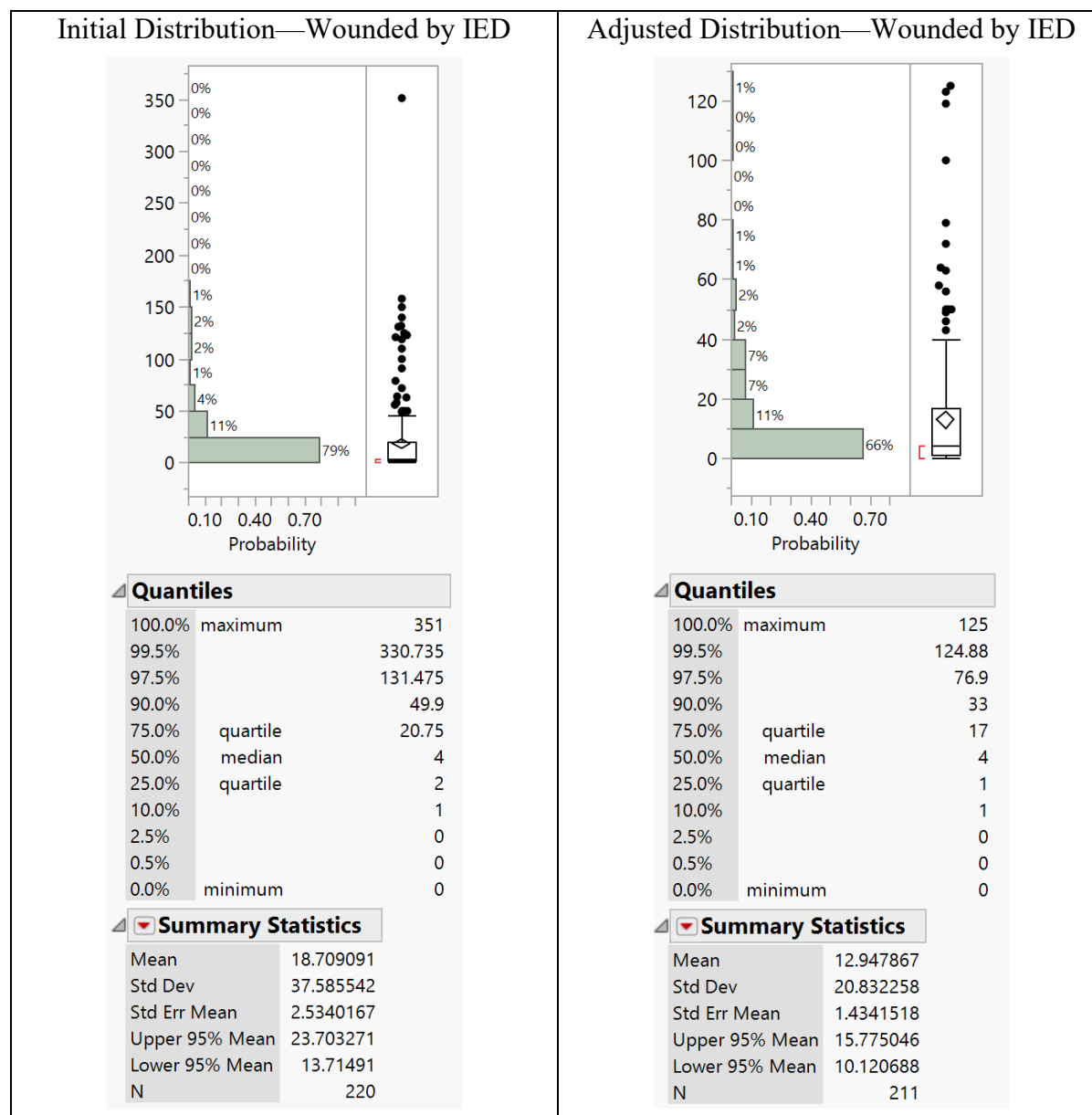


Figure 6. Initial and Adjusted Data Distribution: Wounded by IED

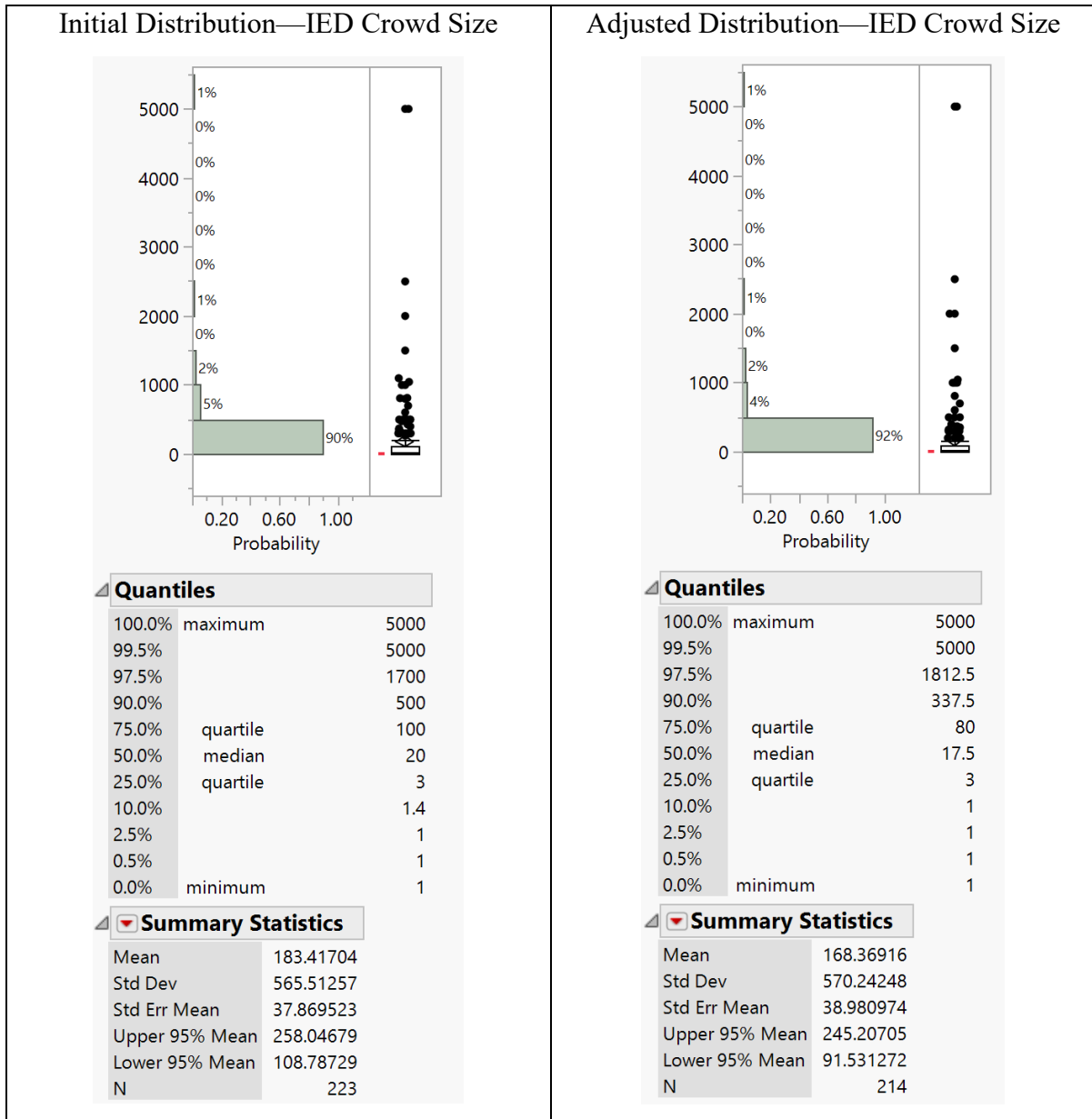
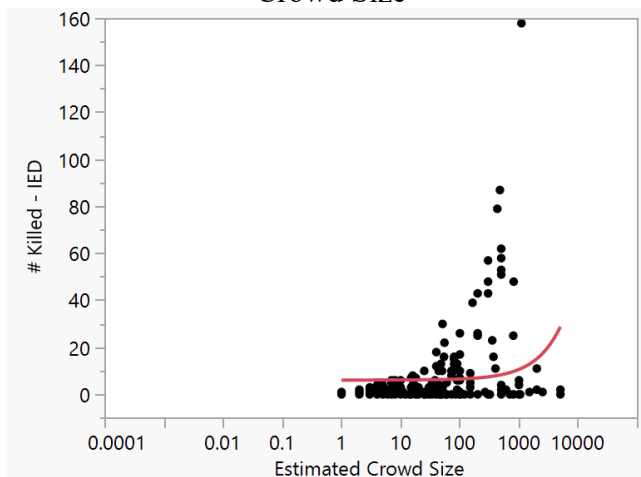


Figure 7. Initial and Adjusted Data Distribution: IED Crowd Size

### Regression Analysis of Initial $n$ Killed by IED with an Estimated Crowd Size



Linear Fit

#### Summary Statistics

|             | Value    | Lower 95% | Upper 95% | Signif. Prob |
|-------------|----------|-----------|-----------|--------------|
| Correlation | 0.149278 | 0.018259  | 0.275257  | 0.0258*      |
| Covariance  | 1452.479 |           |           |              |
| Count       | 223      |           |           |              |

| Variable             | Mean     | Std Dev  |
|----------------------|----------|----------|
| Estimated Crowd Size | 183.417  | 565.5126 |
| # Killed - IED       | 6.932735 | 17.2057  |

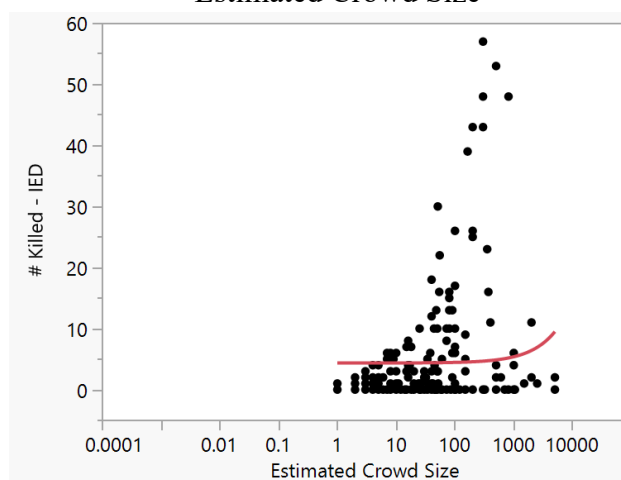
#### Linear Fit

# Killed - IED = 6.0996973 + 0.0045418\*Estimated Crowd Size

#### Summary of Fit

|                            |          |
|----------------------------|----------|
| RSquare                    | 0.022284 |
| RSquare Adj                | 0.01786  |
| Root Mean Square Error     | 17.05136 |
| Mean of Response           | 6.932735 |
| Observations (or Sum Wgts) | 223      |

### Regression Analysis of Adjusted $n$ Killed by IED with an Estimated Crowd Size



Linear Fit

#### Summary Statistics

|             | Value    | Lower 95% | Upper 95% | Signif. Prob |
|-------------|----------|-----------|-----------|--------------|
| Correlation | 0.06113  | -0.07359  | 0.193659  | 0.3735       |
| Covariance  | 334.4021 |           |           |              |
| Count       | 214      |           |           |              |

| Variable             | Mean     | Std Dev  |
|----------------------|----------|----------|
| Estimated Crowd Size | 168.3692 | 570.2425 |
| # Killed - IED       | 4.523364 | 9.59298  |

#### Linear Fit

# Killed - IED = 4.3502185 + 0.0010284\*Estimated Crowd Size

#### Summary of Fit

|                            |          |
|----------------------------|----------|
| RSquare                    | 0.003737 |
| RSquare Adj                | -0.00096 |
| Root Mean Square Error     | 9.597596 |
| Mean of Response           | 4.523364 |
| Observations (or Sum Wgts) | 214      |

Figure 8. Initial and Adjusted Regression Analysis: Killed by IED

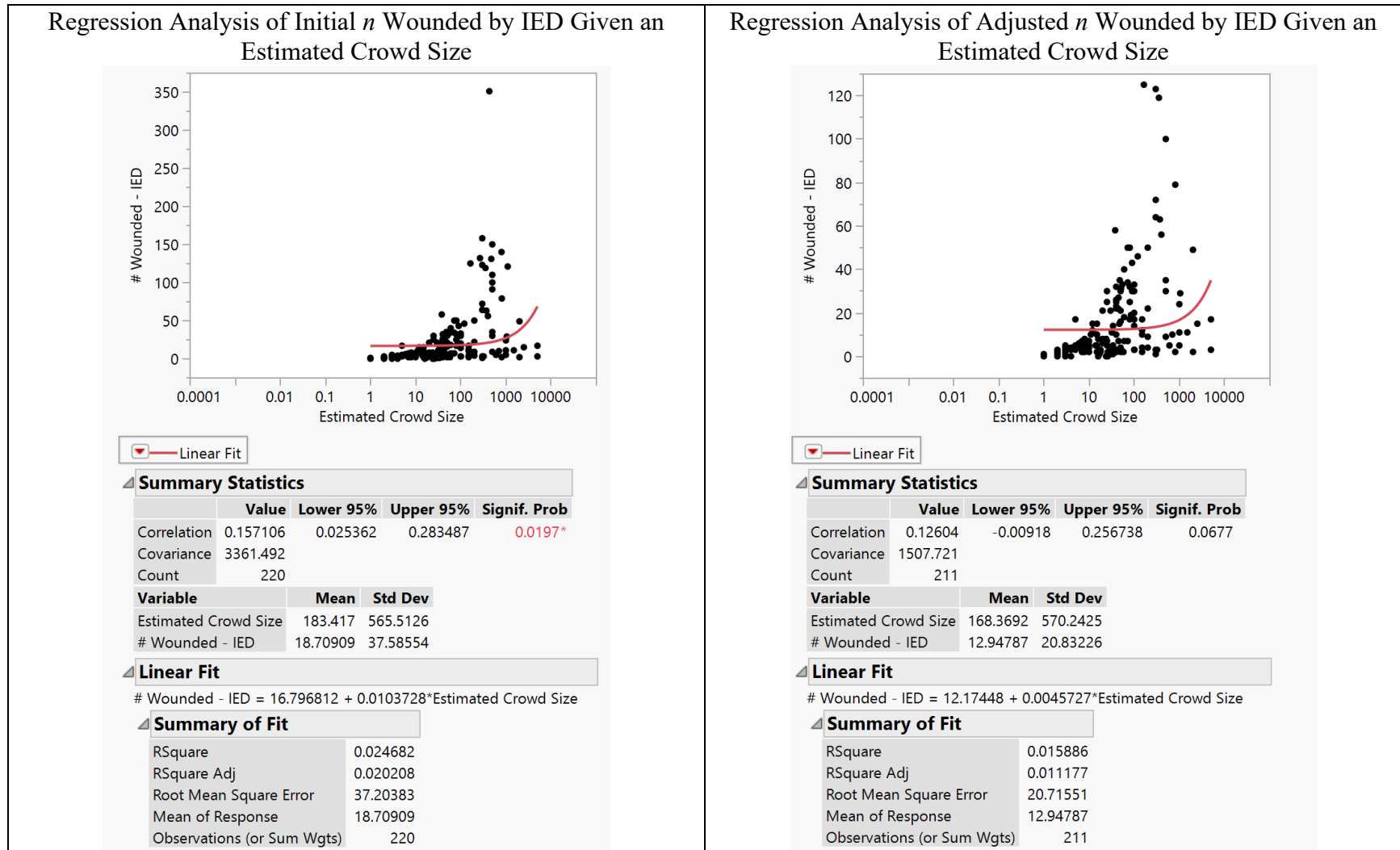


Figure 9. Initial and Adjusted Regression Analysis: Wounded by IED

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## APPENDIX C: SUPPORTING ANALYSIS FOR FIREARMS AND ACTIVE SHOOTERS

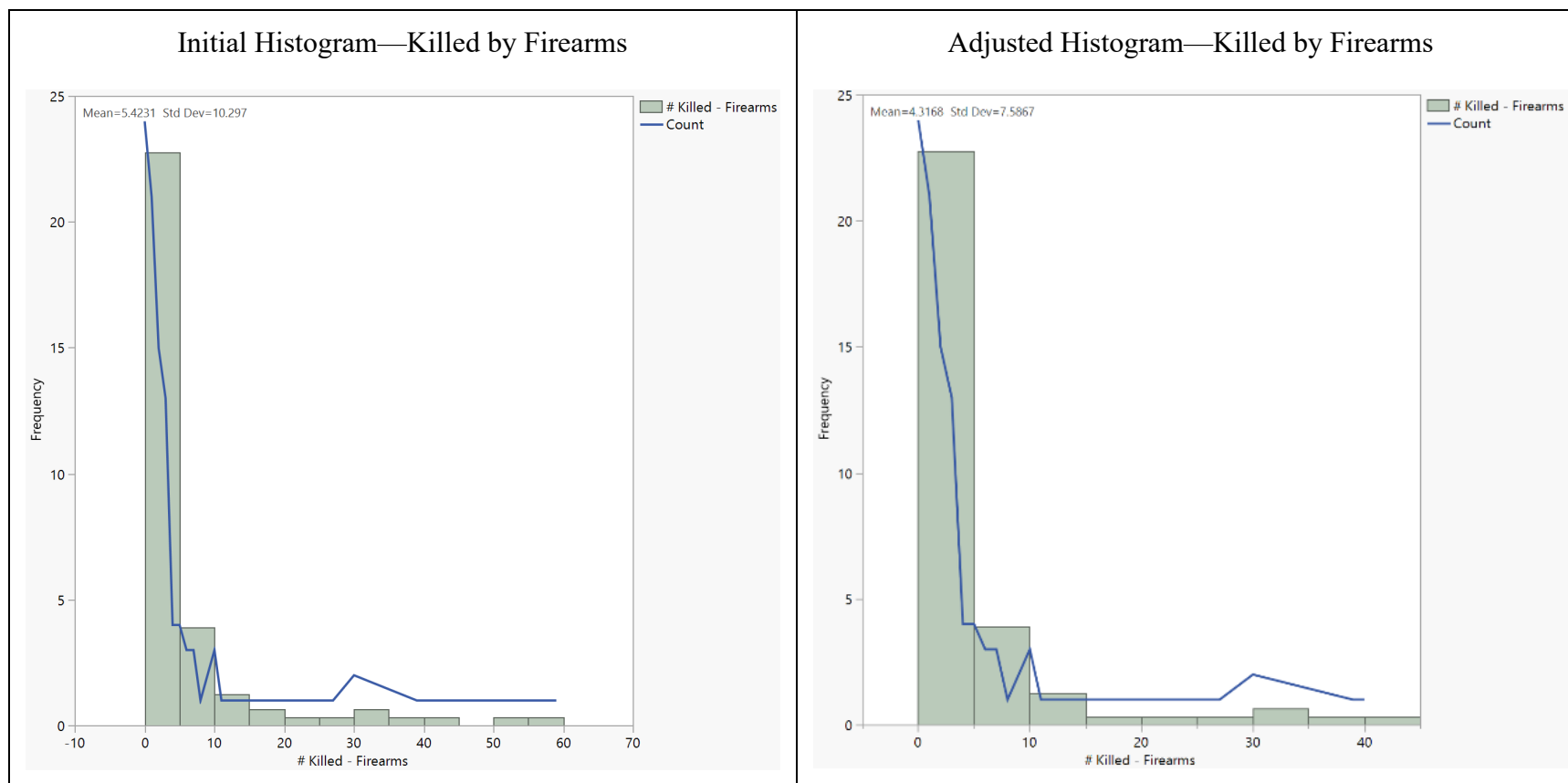


Figure 10. Initial and Adjusted Histograms: Killed by Firearms

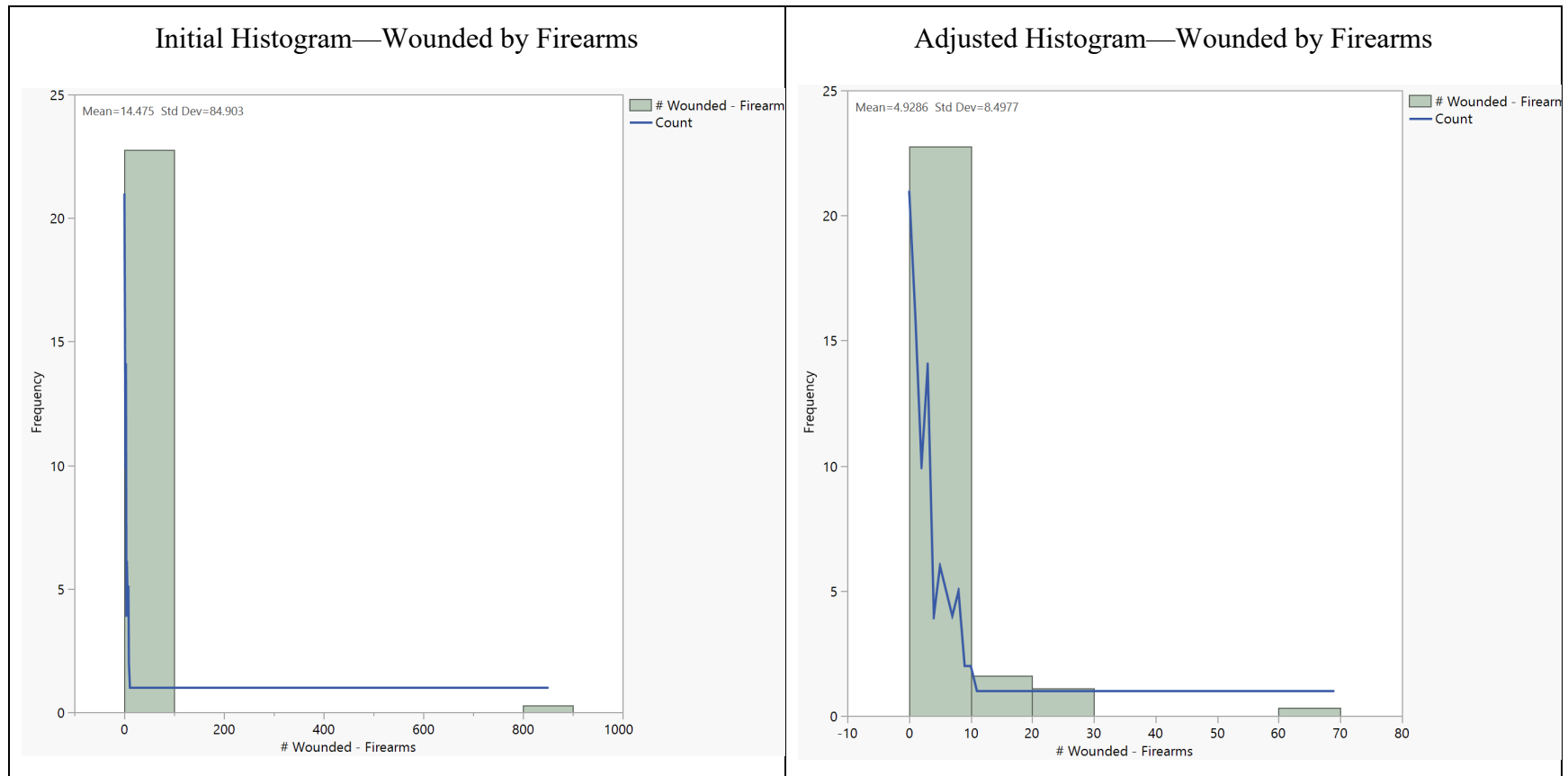


Figure 11. Initial and Adjusted Histograms: Wounded by Firearms

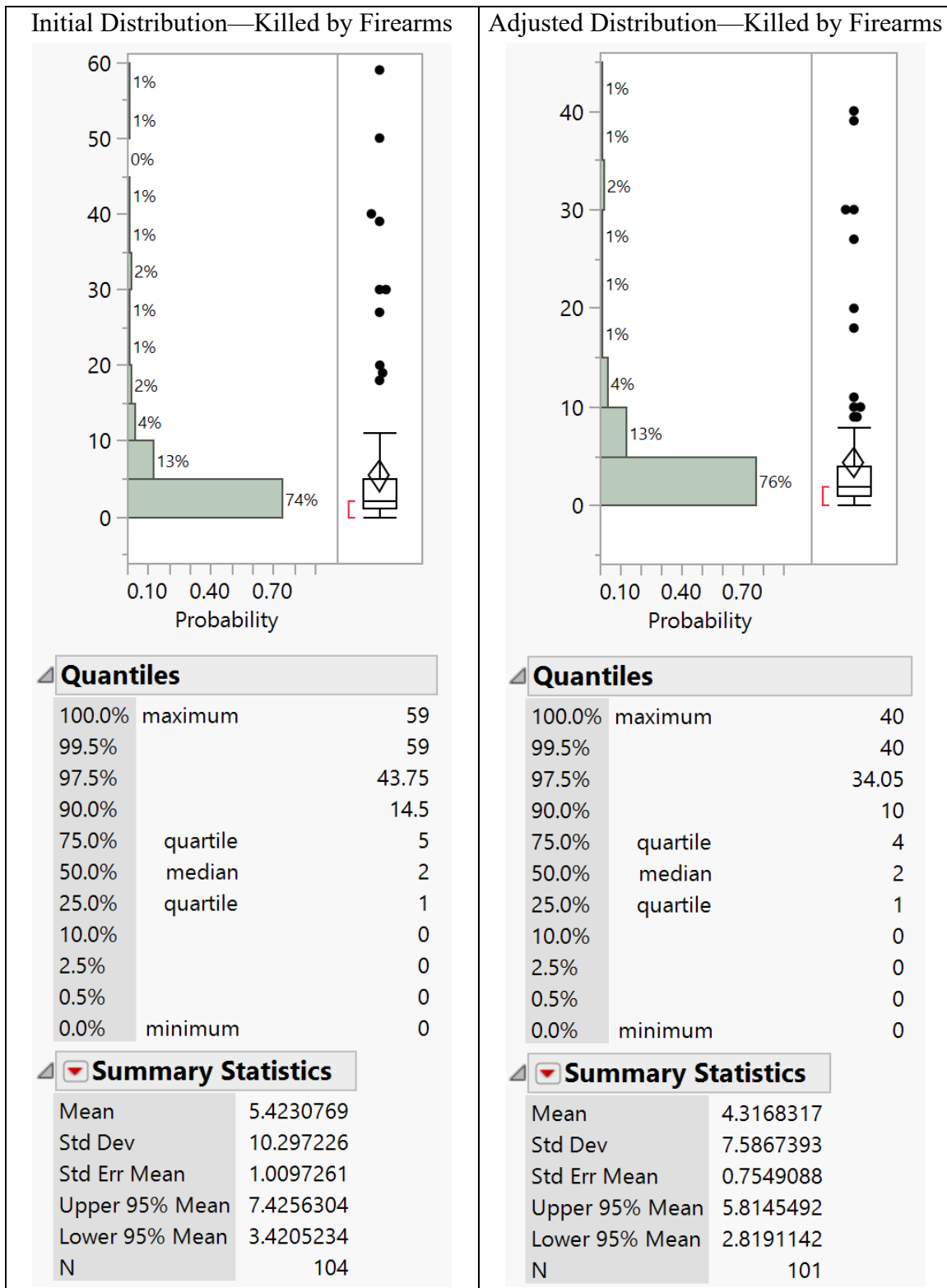


Figure 12. Initial and Adjusted Data Distribution: Killed by Firearms

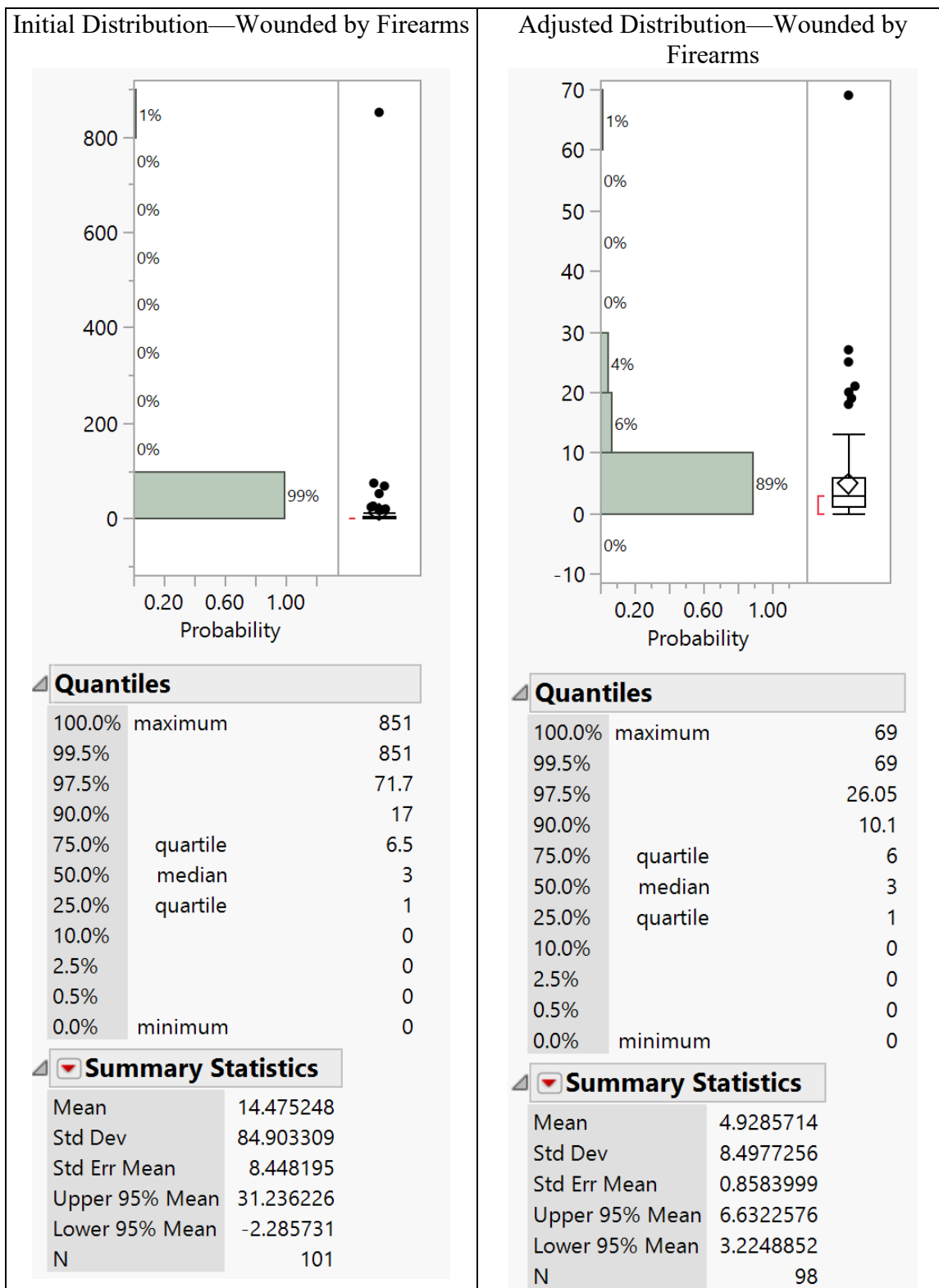


Figure 13. Initial and Adjusted Data Distribution: Wounded by Firearms

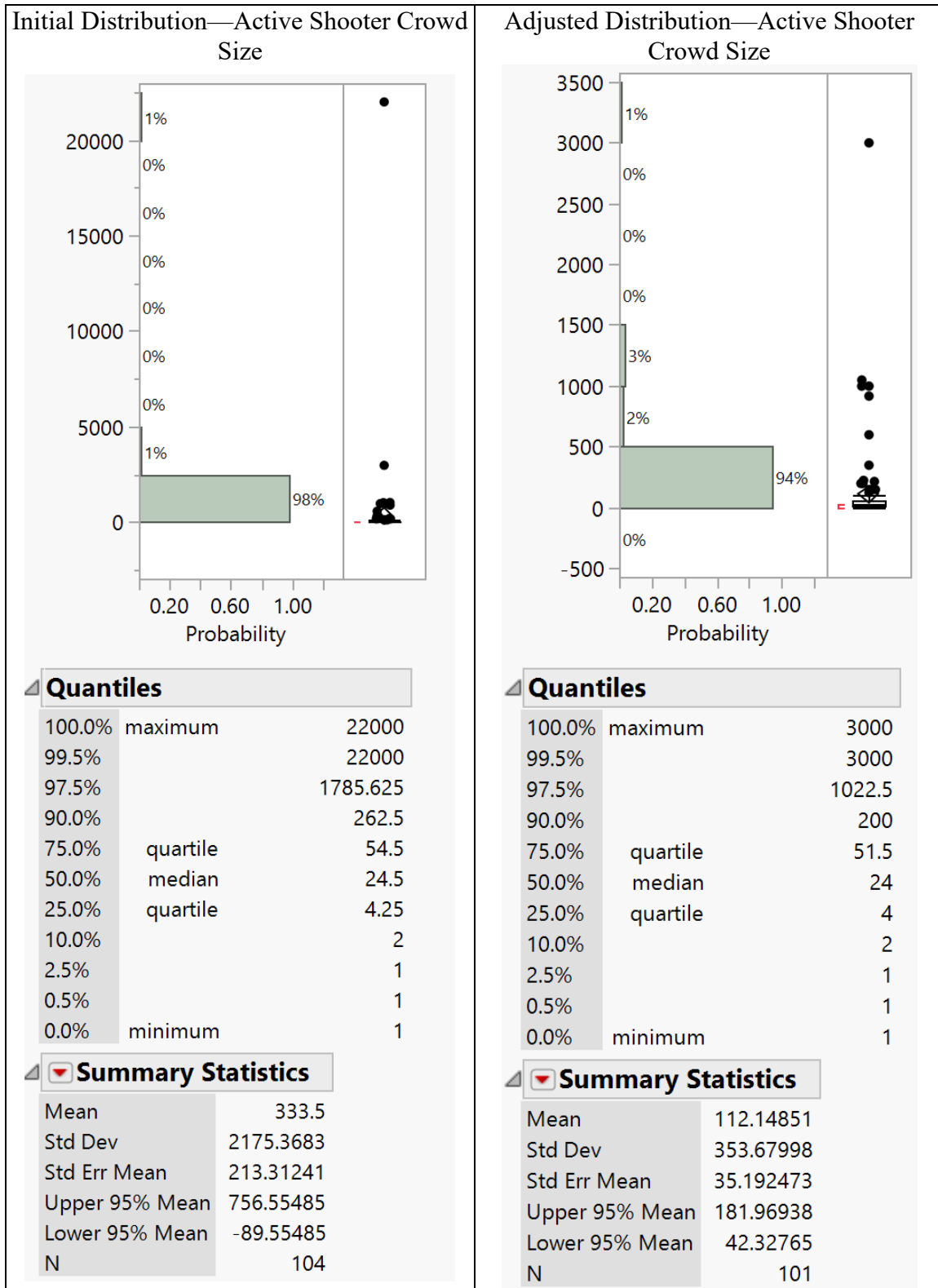
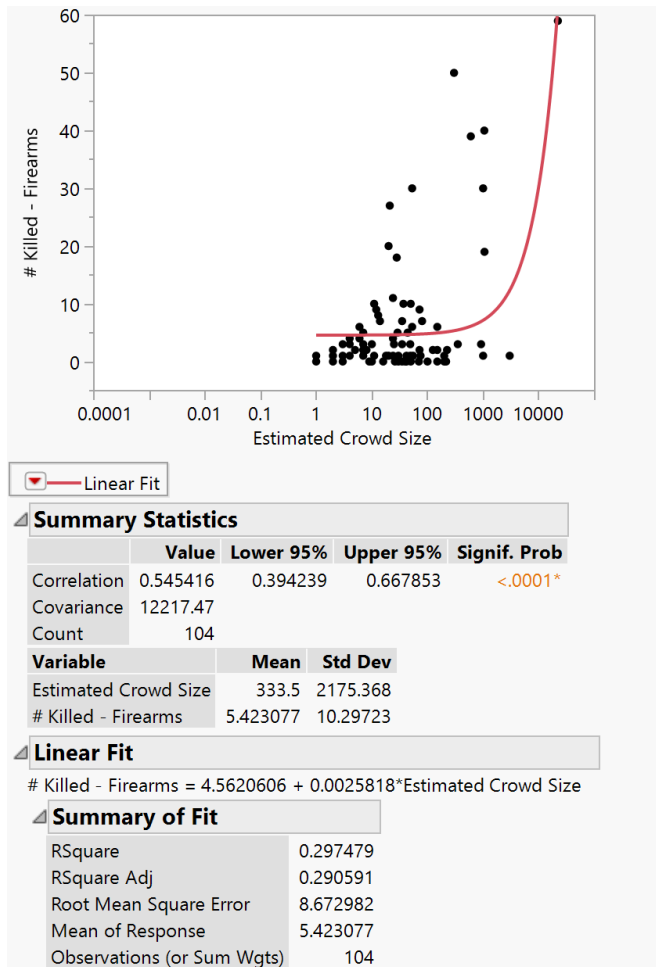


Figure 14. Initial and Adjusted Data Distribution: Active Shooter Crowd Size

### Regression Analysis of Initial $n$ Killed by Firearms Given an Estimated Crowd Size



### Regression Analysis of Adjusted $n$ Killed by Firearms Given an Estimated Crowd Size

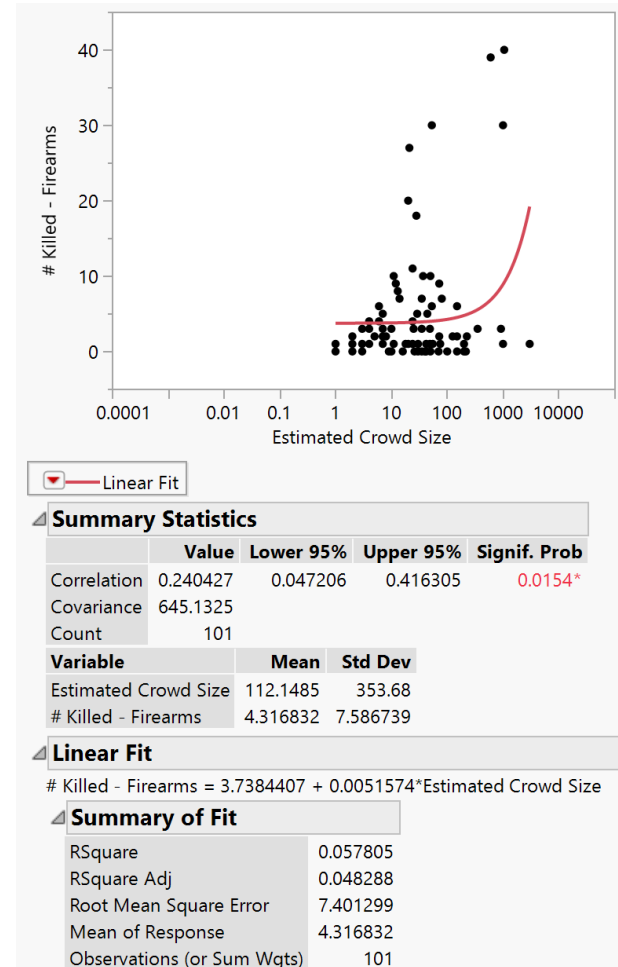
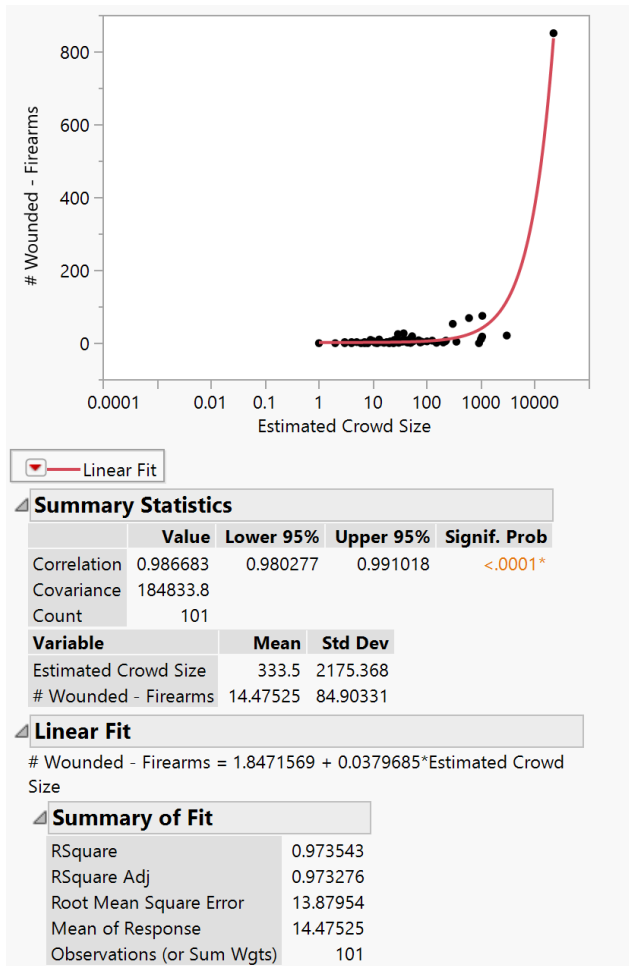


Figure 15. Initial and Adjusted Regression Analysis: Killed by Firearms

### Regression Analysis of Initial $n$ Wounded by Firearms Given an Estimated Crowd Size



### Regression Analysis of Adjusted $n$ Wounded by Firearms Given an Estimated Crowd Size

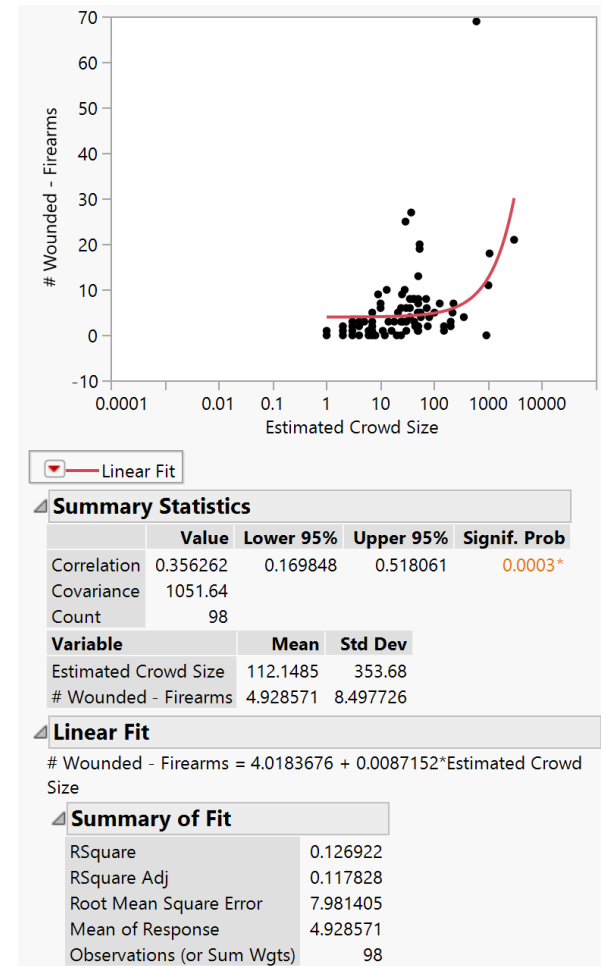


Figure 16. Initial and Adjusted Regression Analysis: Wounded by Firearms

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## **APPENDIX D: EXAMPLE CONSEQUENCE MODEL**

Example Consequence Model for Active Shooter Attacks at Mass Gatherings by  
Dr. Thomas J. Mackin.

### **A. OVERVIEW OF THE APPROACH**

To estimate the potential consequences of an attack on a crowded venue, we present models that can be used to run Monte Carlo simulations. These models incorporate the basic physics of several attack modes, including: (1) IEDs, (2) active shooter with an assault weapon, (3) melee or edged weapon, (4) ramming vehicle or a vehicle driven through a crowd, and (5) incendiary device. To construct the lethality models, we also need knowledge of the area of the venue and the density of people. The basic construct of lethality overlays an effective “spot-light” area for the given weapon onto the crowded venue. This “spot-light” is a target area for the given attack method. Clearly, an active shooter armed with an assault weapon at an elevation above the crowd (e.g., 2017 Las Vegas shooting) has an exceptionally large target area that may well include the entire venue. The same attack, at ground level, has a cross section identical to the view space of the attacker. These basic sorts of basic physics must be incorporated into each attack method. They are fundamental to a calculation of the “lethality” of any given attack method. Once a mathematical model is developed for each attack method, it can be implemented into an Excel spreadsheet for Monte Carlo simulations to determine the statistics of the attack methods for a given venue. To do so, we need to know a rate function for the attack (how many potential victims per second), an attack duration, which we will set as an input to the model but is also directly related to response time, a fatality probability for any given wound delivered, and a hit probability. Furthermore, the model inputs will have parameters influenced by interdiction or prevention methods to result in a lower fatality count. For instance, changing the range of possible elevations of the shooter will decrease the “spot-light” area for the shooter and reduce the lethality of the attack. The same can be said for limitations on vehicle size in that the smaller the frontal area of the

vehicle, the smaller the overall probe volume for a given attack, and the slower the speed of the vehicle, the fewer victims for a given time span.

## B. MODELING THE VENUE

Any venue is comprised of a footprint area, crowd capacity, venue shape, access, and egress. As a first step in developing a model, we simply consider a circular footprint and a completely unsecured perimeter. This simplification allows us to develop models and run simulations in the most open scenario, which makes evident the key properties of the models. The area of the venue is denoted as:

$A_v$  and the number of people attending is given by  $N_v$ . The areal crowd density, then, is simply:  $\rho = \frac{N_v}{A_v}$

Though the shape of the venue will have an impact on the lethality of any given attack, we defer consideration of such until after initial model development. We also need to develop rational numbers of crowd packing that also provide a range of acceptable densities. Clearly, if no people are present, the density is 0. At the other extreme, the Civil Engineers Reference Book states that for a tightly packed space, each person occupies 2.5 square feet. Therefore, the footprint area of a person, in a tightly packed space is  $A_{p-max} = 2.5ft^2$ . In effect, it is an estimate of the area occupied by a given person. Additionally, it also tells us the maximum density of people, packed shoulder to shoulder, which is the inverse of  $A_{p-max}$ . Thus, the maximum density is  $\rho_{max} = 0.4$  people per square foot. For a given venue attendance, we determine the total area occupied by people as  $A_{people} = \frac{2.5ft^2}{person} \times N_v$ . The area fraction of people,  $f_a$ , is the ratio of the area occupied by people to the total venue area, which is:

$$f_a = (2.5 \times N_v) / A_v$$

This ratio serves as an input into each lethality equation by allowing us to calculate the percent of the venue area occupied.

### C. MODELING AN ACTIVE SHOOTER

To model an active shooter, we need to know the weapon in use to determine the firing rate, the magazine size to determine the duration of fire for a given magazine, the number of targets available given the shooter's line of sight, and the probability of death for a given hit.

To illustrate the method, we choose a commercially available AR-15 manufactured by Colt. This weapon is a semi-automatic, which means that each round requires a trigger pull. The manufacturer claims a firing rate of 45 rounds/minute. Though large capacity magazines are available, the AR-15 comes standard with a 32-round magazine, and a search of online forums reveals a 2-second delay for magazine changes. We shall model the firing rate, conservatively, as 32 rounds per minute.

To determine the probability of a hit, we imagine bullets fired randomly into the viewable area, and estimate the hit probability using the area fraction of people in the venue:

$$P_{hit} = f_a \quad (1)$$

We determine the probability of a lethal hit by calculating the area of head and torso to the total cross-sectional area of a person. We find these areas from standard anthropometric tables of human dimensions, illustrated in Figure 17. Anthropometric data are from HE Design data tabulated by the DOD for use in human-machine interface design. These dimensions result in a total frontal area by adding the head, neck, torso, and arms and legs to provide a total area of a single male, in the 50th percentile, as:

$$A_{person} = 7.315 ft^2. \quad (2)$$

The lethal hit area is the sum of the head, neck, and torso:

$$A_{lethal} = 1.906 ft^2. \quad (3)$$

As such, the probability of a lethal hit, for equal chance of hitting any area is given by:

$$P_{lethal} = \frac{1.906}{7.315} = 0.26. \quad (4)$$

This relatively low probability accounts for the fact that hits below the waist and in the arms are not likely to be fatal. We can now combine Equations (1) and (4) to provide the probability of a lethal hit for a single shot at the entire area of the venue:

$$P_{lethal-hit} = 0.26 \times f_a. \quad (5)$$

This equation provides the probability of a lethal bullet strike for one random firing at the entire area of the venue. However, these probabilities will increase as the skill of the shooter increases. These numbers are simple calculations to illustrate the key input parameters that enable a model. To illustrate, we imagine that a bullet is fired randomly into the venue area and use equation (5) to calculate the probability of a lethal hit on an attendee. A plot of that probability, as a function of attendance, for a 2,000 sq. ft. venue, is shown in Figure 17. The maximum attendance, assuming people are packed shoulder-to-shoulder, chest to back, is 800. Figure 18 shows how the probability of a lethal hit goes up with the number of attendees. That is, the richer the target space, the more likely a person is to be killed.

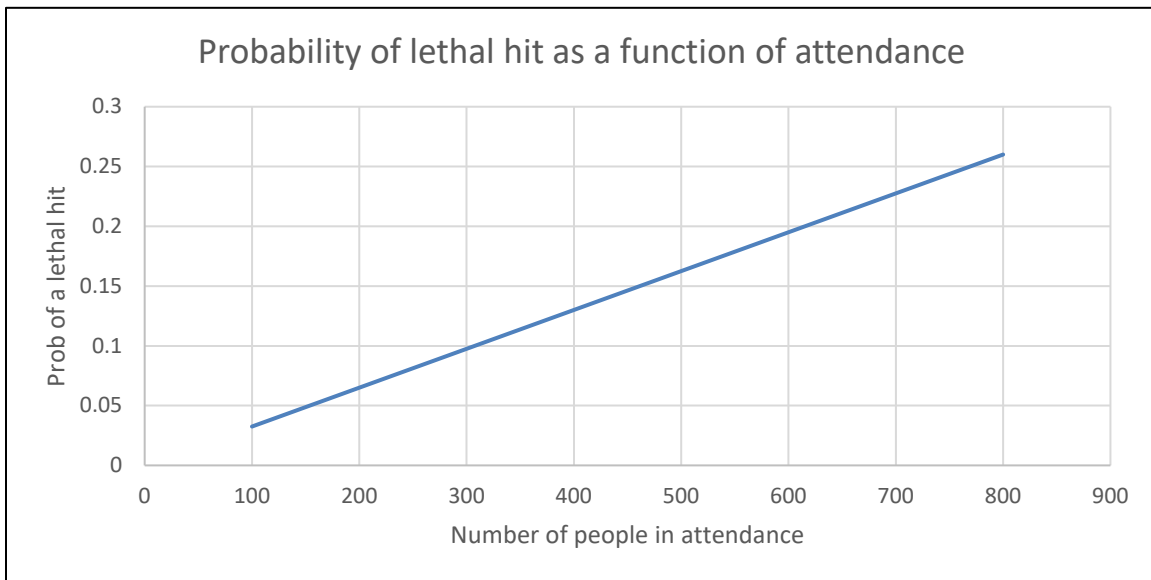


Figure 17. Probability of a Lethal Hit as a Function of Attendance

The shooter's elevation above the venue changes the line of fire to the targets. An adversary directly above a venue has access to the entire target area, while a ground-based adversary has initial access only to a line of targets. Of course, that line can be a circle if the shooter is situated in the middle of the crowd. To address this possibility, we must develop a model that incorporates the elevation angle into the shooter's viewable area, or "spot-light."

We simplify this problem by estimating the number of people in the viewer's target space,  $N_s$ , using:

$$N_s = (N_s - N_g) \sin \theta + N_g \quad (6)$$

where  $N_g$  is the number of targets viewable at ground level ( $\theta = 0$ ). This equation has the appropriate functional form, since when  $\theta = 90$ , the entire attendance,  $N_s$ , is viewable. Now,  $N_g$  is the number of targets viewable at ground level. This number, we assume, can be found by multiplying the target density by the ground-level viewable target area. We shall estimate it as the diameter of the venue multiplied by the average height of people,  $h_{avg}$ . We find the diameter of the venue using:

$$d = \sqrt{\frac{4A_v}{\pi}}. \quad (7)$$

Then, the ground observable number of targets is:

$$N_g = N_v \frac{2h_{avg}}{\sqrt{\pi A_v}}. \quad (8)$$

Using (8) in (6) provides us with:

$$N_s = N_v \left( \sin \theta + \frac{2h_{avg}}{\sqrt{\pi A_v}} (1 - \sin \theta) \right). \quad (9)$$

We can normalize the number of targets observable by the shooter by the total number of people:

$$\frac{N_s}{N_v} = \left( \sin \theta + \frac{2h_{avg}}{\sqrt{\pi A_v}} (1 - \sin \theta) \right). \quad (10)$$

As  $\theta = 90$ , the entire crowd is visible to the shooter.

We can use equation (9) in (5) to develop the probability of a single fatal shot fired from an active shooter at any elevation angle,  $q$ , by replacing  $N_v$  in (5) with  $N_s$  from (9). This equation gives the probability of a fatal hit for a single bullet fired under the given conditions as:

$$P_{lethal} = (0.26) * \left(\frac{2.5}{A_v}\right) N_v \left( \sin \theta + \frac{2h_{avg}}{\sqrt{\pi A_v}} (1 - \sin \theta) \right). \quad (11)$$

A plot of equation (11) is shown in Figure 18. To construct this plot, we created a virtual venue of 10,000 sq. ft., and then placed different numbers of people into the venue. This plot shows that the probability of a lethal strike goes up with increasing elevation angle and reaches a maximum for a perfect full-field view at 90 degrees above the venue. It also shows how the probability of a lethal strike, for a random directional fire into the venue, increases as the number of people increases.

This simple model allows us now to measure the effect of firing rate on the anticipated number of casualties. As mentioned earlier, the firing rate of an AR-15, as reported by Colt, is 45 rounds per minute. We can combine this firing rate with the probabilities detailed in (11) to estimate the number of fatalities as a function of time.

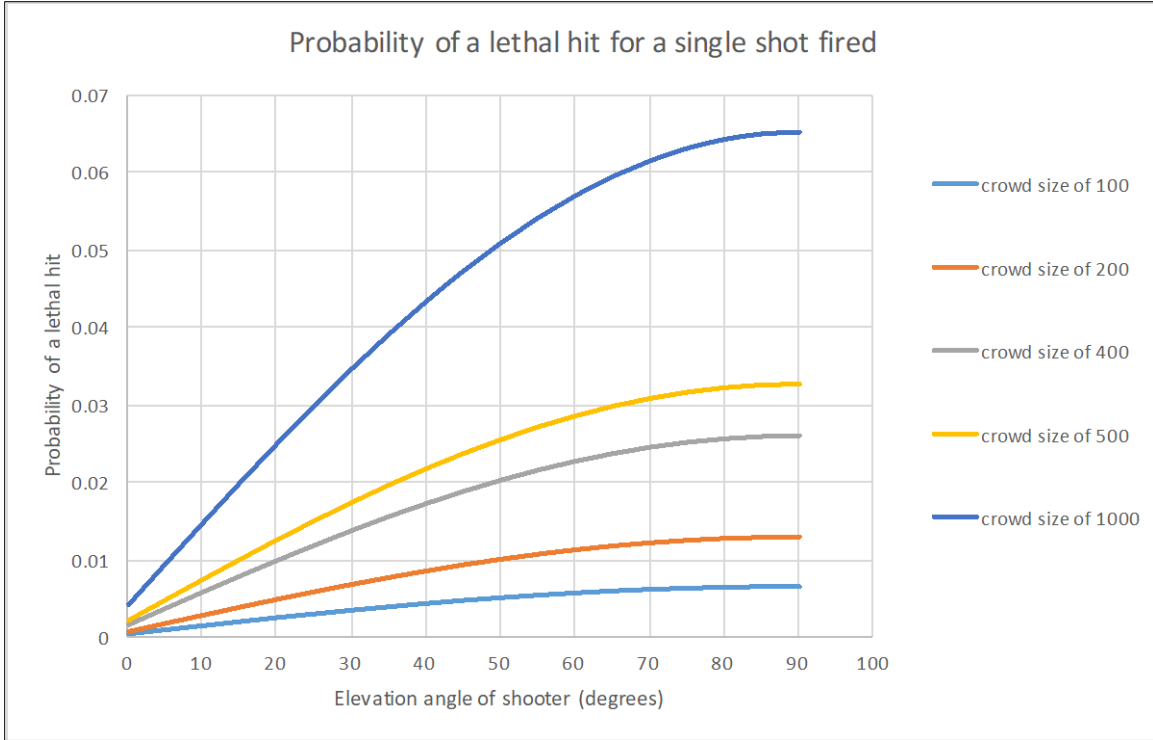


Figure 18. Probability of a Lethal Hit as a Function of Elevation Angle of the Viewer

These equations allow a simple approach to estimating the fatalities in a given venue of a known area and known attendance for an active shooter using a weapon with a specified firing rate. To illustrate the approach, let us consider the 10,000 sq. ft. venue discussed to create Figure 18. Further, we shall imagine the shooter is using an AR-15 with a firing rate of 45 rounds per minute and elevated at 30 degrees above the venue. We can combine equation (11) with the firing rate and time to estimate the number of fatalities, providing:

$$N_f = P_{lethal} * R * t \quad (12)$$

where:  $N_f$  is the number of projected fatalities

$R$  is the firing rate of the weapon

and  $t$  is the elapsed time.

Using the aforementioned inputs, we use (12) to generate the bar chart shown in Figure 19.

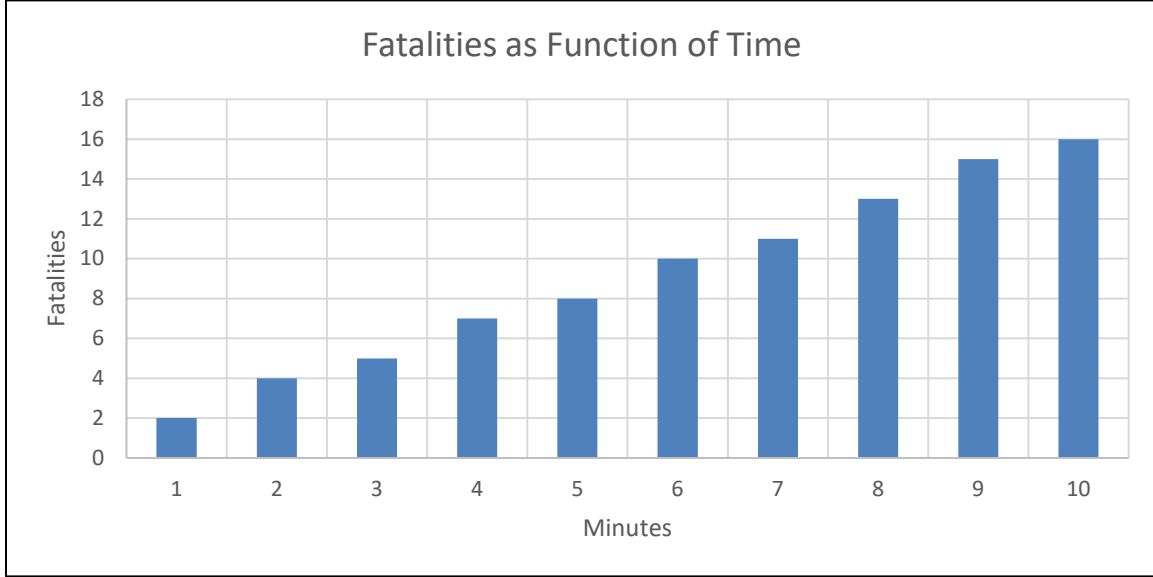


Figure 19. Fatalities as a Function of Time for a Crowd of 1,000 in a 10,000 sq. ft. Venue and a Shooter at an Elevation Angle of 30 Degrees

#### D. COMPARING THE MODEL PREDICTIONS WITH LAS VEGAS

We can assess the predictive capabilities of such a simple model using the Las Vegas shooter. To do so, we use what we know about attendance (22,000 people), venue size (15 acres), number of rounds fired (1,100), and the angle of inclination of the shooter. We know that the perpetrator was on the 37th floor of the Mandalay Bay hotel who was firing NE into the venue. Using Google maps, we can measure the distance from the hotel to the venue. Using a straight-line measurement from the Mandalay Bay complex to the center of the venue, we find the distance to be 1,104 ft. There are 43,560 sq-ft/acre, so the venue occupied 653,400 sq-ft, roughly 1/5 of which is immediately adjacent to the stage and occupied by the concert attendees, giving an effective venue area of 130,680 sq-ft. We find the angle of inclination by taking the inverse tangent of the height divided by the distance from the hotel to the venue, as follows:

$$\theta = \tan^{-1} \frac{370}{1104} = 19^\circ. \quad (13)$$

Using this information in (11), we estimate the probability of a fatality per shot as:

$$P_{lethal} = (0.26) * \left( \frac{2.5}{130680} \right) (22,000) \left( \sin(19) + \frac{2 * 5.85}{\sqrt{\pi(130680)}} (1 - \sin(19)) \right)$$

$$P_{lethal} = 0.039.$$

If we multiply this by the number of rounds fired, 1,100, we obtain a prediction of the number of dead:

$$\#deaths = 43. \tag{14}$$

In this case, we have underpredicted the fatalities. In the Las Vegas incident, a total of 58 deaths were reported. Even so, this prediction is reasonable. However, the output number is strongly dependent upon the input variables. As such, the model must be compared with a number of incidents to assess the general validity of the approach.

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