2020-09

USING BEHAVIOR MODELING TO ENABLE EMERGENCY RESPONDER DECISION-MAKING

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THESIS

USING BEHAVIOR MODELING TO ENABLE EMERGENCY RESPONDER DECISION-MAKING

by

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September 2020

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2020	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE USING BEHAVIOR MODELING TO ENABLE EMERGENCY RESPONDER DECISION-MAKING	**5. FUNDING NUMBERS**
6. AUTHOR(S) Amanda A. Rowton	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Mistakes during training are expected and usually welcomed for their teaching potential, but when realistic training subjects emergency responders to dangerous scenarios then there is still a high level of risk. Training is crucial for reducing risks associated with real-life operations, but how can real-life scenarios be practiced where it can be safe to learn from mistakes? This research will investigate the question, "to what extent can Monterey Phoenix (MP) behavior modeling be used to support low-risk training for emergency responders?" We use MP to first generate a baseline "typical-case" model of an active shooter scenario from FBI and FEMA procedures. We next develop alternative models by adding SME-provided variables to generate all possible scenarios within a scope limit with MP. Multiple scenarios allow emergency responders to practice making good decisions and gain a better understanding of the scenario, creating opportunities to decrease injuries and fatalities. This research found that both of the MP models, the typical-case model and the alternative events model, provide trainees with deeper insights into the roles and their actions during an active shooter scenario. In the alternative events model, we also see the variables that can occur within the scenario and identify where critical decisions are made by the corresponding roles. Both models are useful tools for improving training programs or understanding critical decision points.

14. SUBJECT TERMS emergency responder, training, injuries, fatalities, Monterey Pheonix, MP, variables, behavior modeling, alternative scenarios, emergent behavior	**15. NUMBER OF PAGES** 75
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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USING BEHAVIOR MODELING TO ENABLE EMERGENCY RESPONDER DECISION-MAKING

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Mistakes during training are expected and usually welcomed for their teaching potential, but when realistic training subjects emergency responders to dangerous scenarios then there is still a high level of risk. Training is crucial for reducing risks associated with real-life operations, but how can real-life scenarios be practiced where it can be safe to learn from mistakes? This research will investigate the question, “to what extent can Monterey Phoenix (MP) behavior modeling be used to support low-risk training for emergency responders?” We use MP to first generate a baseline “typical-case” model of an active shooter scenario from FBI and FEMA procedures. We next develop alternative models by adding SME-provided variables to generate all possible scenarios within a scope limit with MP. Multiple scenarios allow emergency responders to practice making good decisions and gain a better understanding of the scenario, creating opportunities to decrease injuries and fatalities. This research found that both of the MP models, the typical-case model and the alternative events model, provide trainees with deeper insights into the roles and their actions during an active shooter scenario. In the alternative events model, we also see the variables that can occur within the scenario and identify where critical decisions are made by the corresponding roles. Both models are useful tools for improving training programs or understanding critical decision points.

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LIST OF ACRONYMS AND ABBREVIATIONS

CBT	computer-based training
CPR	Cardiopulmonary Resuscitation
DOD	Department of Defense
EMS	Emergency Medical Services
FEMA	Federal Emergency Management Agency
FBI	Federal Bureau of Investigations
IACP	International Association of Chiefs of Police
MP	Monterey Phoenix
OJT	on-the-job training
OPSIT	operational situation
SME	subject matter expert

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EXECUTIVE SUMMARY

Training realism can also lead to similar injuries and fatalities experienced in mission execution. Thus, it is important for emergency responders to have accurate and necessary training that is effective, as well as economically feasible and safe. This thesis investigates the use of Monterey Phoenix (MP) as a behavior modeling tool as a potential safe and cost-effective training platform augmenting current training methods.

In order to identify beneficial changes within emergency responder training that will reduce risk of injuries and fatalities, trainers must first fully understand the subject of training. The process of behavior modeling using automated tools examines information collected as part of a system or process, such as its actors, decision points, constraints, and actions or activities. By using MP behavior modeling, maximum possible choice traces can be determined. Applying behavior modeling within a training program for emergency responders allows detailed composition of each role, actions to be completed, possible connections between actors and variations within their actions. Behavior modeling can potentially allow the user to more fully understand the response process and the varying scenario outcomes with the information incorporated in the model.

First, we constructed the baseline "typical-case" model from the mission narrative, developed from FBI and FEMA procedures and then edited through two separate interactions with a local law enforcement SME. The typical-case model also considered constraints, limitations, and assumptions during the build. Initial constraints consisted of information from outside agency reference data and SME support. The baseline MP model represented a typical case, which means that alternative events were excluded.

The typical-case model served as the foundation for the alternative scenario models with the inclusion of the variables. We added decision variables as alternative events into the MP baseline model, which increased the number of possible scenario variants significantly. The addition of the decision variables offered multiple scenario instances on which responders could practice decision making. Since our focus was on the First Responding Officer, Secondary Units, and Suspect, all added decision variables

corresponded to these roles. The added decision variables corresponded to inserted alternative events that result in 160 alternative scenarios. Upon examining those scenarios, we identified four major points on the timeline at which decisions being made have a large impact on following events: (1) First Officer's actions upon arrival on scene, (2) Suspect encounter, (3) end to violent actions and (4) clearing the scene. Although there are three main decision-making roles within the scenario, the interactions among them produce four major points within the model where significant changes could result based on a specific role's actions and the corresponding reaction.

Emergent behaviors occur within the models and are brought to light by MP. These behaviors can be unexpected or expected. The first unexpected emergent behavior discovered, the First Officer was the only role to encounter and respond to the Suspect's actions. Although we wanted to keep this option within the possible scenarios to account for the First Officer encountering a Suspect alone, we also needed to include the possibility of an encounter within the Secondary Unit's role.

We also discovered an unexpected emergent behavior that involved officers engaging with deadly force without the Suspect first attacking. We expected to see officers only engage with deadly force when the Suspect attacks an officer. Officers could respond with deadly force if the Suspect attempted to withdraw a weapon and fire upon the officers. Another possibility for this scenario involves the Suspect firing upon victims, which would result in the officers engaging in deadly force.

Next, we discovered an emergent behavior when the Suspect could surrender to the officers and is disarmed but then commits suicide. We did not expect this scenario since we believed that if a Suspect was disarmed, then there would be no weapon to cause harm. Possibilities for this event occurring included if the Suspect decides to attack or flee and the officers respond with deadly force or the Suspect flees into a dangerous situation such as oncoming traffic. Another possibility is that the Suspect has concealed another weapon such as a knife or substance that they are able to use to commit suicide after being disarmed.

Lastly, an emergent behavior was found with the "Clear scene" event and the discovery of an additional Suspect. Previously we believed that additional Suspects would

require an increase in the scope since the “Encounter Suspect” action was on a loop in order to see more than one Suspect. However, after looking through the models, we discovered that it could be possible that a new Suspect could emerge during the officers’ actions of clearing the scene and escorting the medics. We expected the officer to encounter and eliminate all Suspects before clearing the scene and escorting the medics. We unexpectedly discovered that the officers could encounter another Suspect but continue the path of actions by clearing the scene and escorting the medics without eliminating the threat. After some thought, this scenario could occur if an officer encounters a Suspect but does not know it. Encountering a Suspect without knowing it is possible if the Suspect blended in with the surroundings, changed their appearance to hide in the crowd, or posed from the beginning as one of the crowd. The First Officer had a “search” action following the unknown encounter. The search action could occur because they were aware of a second Suspect after the missed encounter. The officers could become aware when informed by the public or discovered evidence while assisting victims, such as another weapon. This scenario ending with a “search” action is an example of a Suspect that successfully evaded capture.

In order to answer the question of to what extent Monterey Phoenix behavior modeling could be used to support low-risk training for emergency responders, we looked at the developed models. The MP models, both the typical-case model and the alternative events model, provide deeper insights into the roles and their actions during an active shooter scenario. In the alternative events model, we also see the variables that can occur within the scenario and identify where decisions are made by the corresponding roles. Both models are useful tools for improving training programs or understanding levels of decision making. These models also have applicability to other emergency responders, and future work might show how other emergency responders should be equipped for scenario variances.

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ACKNOWLEDGMENTS

First, I would like to thank my advisor, Dr. Kristin Giammarco, for her incredible patience and assistance during this research. Her knowledge on MP was essential to help get through modeling roadblocks and help the vision of the model come to fruition. I also want to thank my second reader, Professor John Dillard, and Michael Thomas at the Graduate Writing Center for all the time they took to understand what I was trying to say and help me convey it with the proper word usage and structure. I would also like to thank Heather Hahn for her dedication and persistence to get me to the finish line; procrastination never had a chance! Last, but certainly not least, I would like to thank my husband, Alex, and kids, Mara and Marvin, for dealing with me on very little sleep and missing out on many fun family activities. Their love and understanding helped keep me going when times were tough.

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I. INTRODUCTION

Emergency responders in the field of medical, fire and police inherently face unanticipated dangers daily. Even their potentially hazardous preparatory, qualification and refresher training can present challenges. Training environments for emergency responders can include high levels of risk to provide representative operational scenarios. Training realism can also lead to similar injuries and fatalities experienced in mission execution. Thus, it is important for emergency responders to have accurate and necessary training that is effective, as well as economically feasible and safe. This thesis investigates the use of Monterey Phoenix (MP) as a behavior modeling tool as a potential safe and cost-effective training platform augmenting current training methods. For the purpose of this thesis, emergency responders are limited to three types: law enforcement, firefighters, and emergency medical services (EMS).

This chapter provides the research question, background, and methodology used to construct a training model, and the significance of this research by looking at potential second order effects. Chapter II provides a literature review to discuss current training programs, injury and fatality statistics, and training costs, and a review of MP behavior modeling. Chapter III describes the selected high-risk training scenario chosen for this research, the MP behavior model, and corresponding scenarios that result from the MP model. We analyze the resulting scenario variants in Chapter IV with discussion on assumptions made during the process. Chapter V provides conclusions and recommendations on how the MP behavior modeling can be used for other applications as well as future research opportunities.

A. RESEARCH QUESTION

To what extent can Monterey Phoenix (MP) behavior modeling be used to support low-risk training for emergency responders?

B. BACKGROUND

Training is expected to increase proficiency and reduce some areas of risk. Thorough training is extremely important when it comes to high risk and unpredictable occupations in the emergency response fields. Unfortunately, even proper training and preparation for an emergency event does not completely eliminate emergency responder injuries or fatalities during real-life events. As training opportunities seek to replicate real-life scenarios, injuries and fatalities can also occur. Modification of training scenarios to reduce risk is often either impractical or denies the realism needed for maximum training effectiveness.

The optimal training environment for emergency responders allows for the employment of a variety of scenarios that will increase the responder's ability to make good decisions when under stress, while reducing risk of injuries and fatalities. The first step in solving this difficult task is to thoroughly understand various scenarios and all possible variables, which is where behavior modeling comes in.

In order to identify beneficial changes within emergency responder training that will reduce risk of injuries and fatalities, trainers must first fully understand the training. The process of behavior modeling using automated tools examines information collected as part of a system or process, such as its actors, decision points, constraints, and actions or activities. By using behavior modeling, maximum possible choices can be discovered from generated traces. Applying behavior modeling within a training program for emergency responders allows detailed composition of each role, actions to be completed, possible connections between actors and variations within their actions. Behavior modeling can potentially allow the user to more fully understand the response process and the varying scenario outcomes with the information incorporated in the model.

C. RESEARCH METHODOLOGY

For this thesis, we first collect information from statistical databases and prior research on injuries, fatalities, and their types of associated emergencies and training. Limited information is available in terms of broad-scale training requirements for each of the three selected emergency responders. Missing information is supplemented from local

inquiries. By using the collected information, we selected a single, high-risk training scenario and used the experience of a subject matter expert (SME) to develop a training narrative for the "best-case" scenario that ends with success for the trainees (favorable scenario outcomes).

We then modeled the "best-case" scenario in MP, verifying it matches SME expectations consistent with the written narrative. Then, we inserted alternative events that lead to high-risk scenarios (events either in the environment, such as gunfire, or in the trainee behavior, such as a poor decision) that lead to scenarios that do not end well for the trainees (i.e., injuries, deaths). We validated all scenario outcomes (good and bad) with the SME, and refined the models as needed to approximate possible real events and decisions.

Finally, we analyzed the aspects of MP modeling that could be used to reduce training risk, along with limitations of MP. We provide herein conclusions and recommendations for incorporation of MP behavior modeling into training exercises.

D. PRACTICAL SIGNIFICANCE OF RESEARCH

This research uses behavior modeling to identify opportunities to better train emergency responders, using multiple sources, including civilian subject-matter expertise. Similarly to the general public sector, the DOD also has emergency responders who conduct hands-on training resembling such operational environments. While training may vary slightly in terms of protocols or information given before entering a training environment, overall concepts and possible responses to particular scenarios are essentially the same. Regardless of agency, no emergency responders are excluded from risk of injuries or fatalities during training. Whether government or civilian in nature, this effort sought to demonstrate that behavior modeling can be a valuable tool to shape response training. More thorough analysis evoked from its use might provide a variety of alternative decision points, choices and mission outcomes for responders while keeping them safe.

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II. LITERATURE REVIEW

This chapter details emergency responder training programs, injury and fatality statistics, costs associated with training, injuries and fatalities, prior strategies applied to reduce injuries and fatalities in training and supporting previous research of Monterey Phoenix (MP) as it pertains to exhaustive scenario generation.

A. EMERGENCY RESPONDER TRAINING

a. Training Programs

Training comes in many forms and most professions utilize multiple platforms to improve proficiency of a specific skillset. Different training types include hands-on training, utilizing an outside training program, computer-based training (CBT), and on-the-job (OJT) training developed internally.

Hands-on training is learning "the how" while doing it. An example of this type of training is CPR training wherein a manikin is used for emergency responders to practice chest compressions or inserting a nasal cannula. An outside training program can be a purchased training program from a certification entity or a training that is hosted by an outside agency. CBT is training that can be done virtually on the emergency responder's own time, while OJT training is often completed with a supervisor or another emergency responder who has a higher level of expertise.

Exercises can incorporate different forms of teaching and training that supplement the training types to maximize proficiency. Exercises can include orientation seminars, workshops, walkthroughs, table-top exercises, full-scale exercises, or functional exercises (Ready 2016). Orientation seminars, workshops and walk-throughs are a basic level of training for focus on familiarization (Ready 2016). Table-top exercises are scenario-based discussions that take place in a classroom environment with a facilitator (Ready 2016). Full-scale exercises are scenarios that are completed in a similar operational environment with potentially local businesses participating and using the same equipment (Ready 2016). Functional exercises are also scenario-based but within a simulated environment (Ready 2016).

Other platforms may be utilized to ensure training is ongoing and frequent, allowing requirements to be met within a specific budget, all the while, mastering proficiency while keeping emergency responders safe. Training is crucial for emergency responders not only for their safety but also for the safety of those in the community. Eliminating training to reduce risk is not an option since the lack of proficiency gained through training increases the risk in the operational environment.

b. Injury and Fatality Statistics

Injuries and fatalities occur within all career fields, but emergency responders are even more at risk. Both law enforcement and firefighters are three times greater than the average of all professions to experience a fatal occupational injury, while EMS personnel are two and a half times the average (Houser et al. 2004).

A RAND study compiled data from the NFIRS 1998 Firefighter Casualty Module to construct a matrix providing details of injuries and general details of the activity at the time of the injury, which is seen in Figure 1 (Houser et al. 2004).

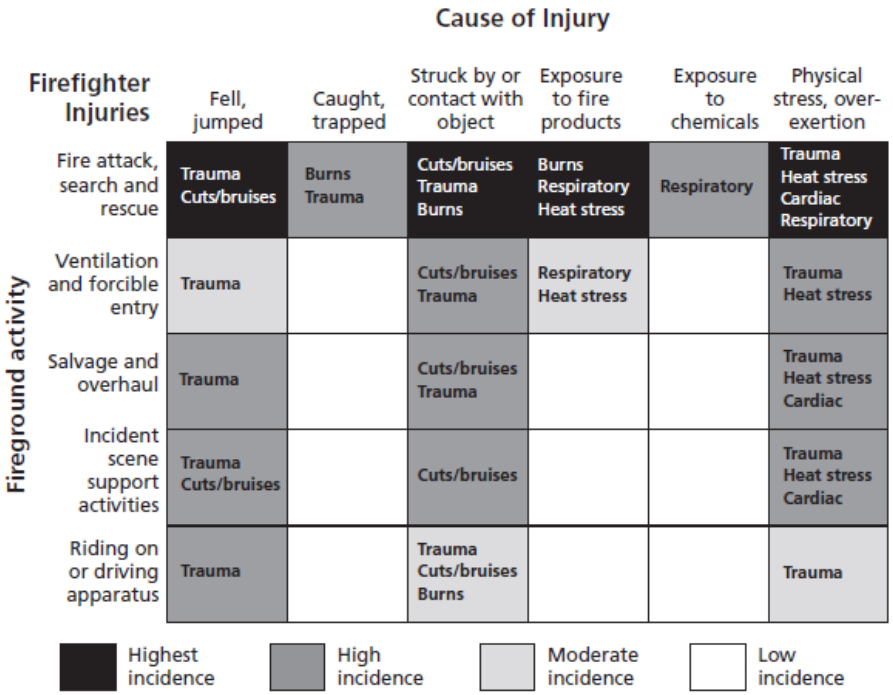

Figure 1. Firefighter injury matrix for causes of injuries and activity during which the injury occurred (Houser et al. 2004, xvii). Data source: NFIRS 1998 Firefighter Casualty Module.

The figure shows that the highest incidence of injury occurred during the most common event a firefighter is exposed to, a fire attack and search and rescue operations (Houser et al. 2004). The nature of the injury included trauma, cuts/bruises, struck by or contact with object, exposure to fire products, and physical stress, over-exertion (Houser et al. 2004). The study also mentions that the most common causes of death for firefighters are physical stress, being lost or trapped in a fire situation, and vehicle accidents, with almost 50% of fatalities from physical stress (Houser et al. 2004).

The RAND study estimates that the highest incidence correlates to approximately 150 firefighter injuries or 10%, high incidence correlates to a range between 33 and 66 firefighter injuries or 2 to 4%, and medium incidence correlates to 15 to 28 firefighter injuries or 1 to 2% (Houser et al. 2004).

A RAND study completed a similar exercise for law enforcement compiled from data from the Survey of Occupational Injuries and Illnesses, Bureau of Labor Statistics as seen in Figure 2 (Houser et al. 2004).

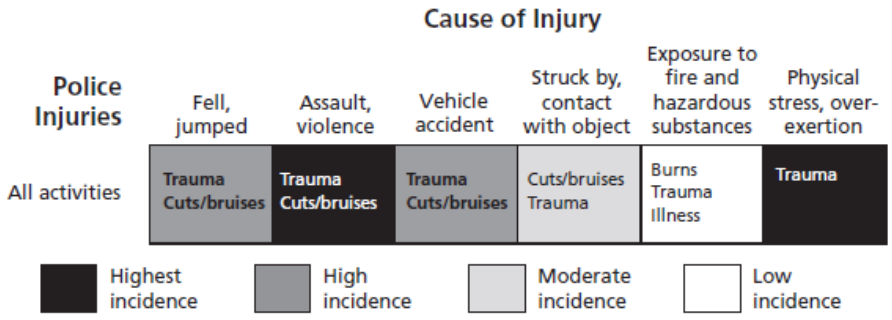

Figure 2. Law enforcement injury matrix for causes of injuries and activity during which the injury occurred (Houser et al. 2004, xviii). Data source: Survey of Occupational Injuries and Illnesses, Bureau of Labor Statistics (2003b).

For law enforcement, the highest incidence of injury occurred during all activities with the most common injury being caused by assault or violence and physical stress or over-exertion (Houser et al. 2004). The specific injuries that occurred from assault or violence included trauma and cuts/bruises (Houser et al. 2004). The injury from physical

stress or over-exertion is trauma (Houser et al. 2004). The study also mentions that the most common causes of death for law enforcement are from vehicle accidents and assaults, with an astounding nine out of ten fatalities (Houser et al. 2004).

The RAND study estimates that the highest incidence correlates to approximately 5,000 law enforcement injuries, high incidence correlates to 4,000 law enforcement injuries, and medium incidence correlates to 2,400 law enforcement injuries (Houser et al. 2004). The total estimation for law enforcement injuries is 25,000 between 1998 and 2000 (Houser et al. 2004).

Minimal data exists for EMS personnel injuries and fatalities, but according to the RAND study, high incidences occur for sprains and strains, particularly back-related (Houser et al. 2004). Another risk to EMS personnel is exposure to infectious diseases, such as percutaneous injuries or needle (Houser et al. 2004). Regarding EMS personnel fatalities, the most common relates to vehicle accidents and medical aircraft fatalities (Houser et al. 2004).

c. Training, Injury and Fatality Costs

Everything has a cost; training costs departments money to ensure that responders stay proficient in their training regularly, and there are costs associated with an injury or death of a responder. There are many costs associated with training to include costs for instructors, facilities, materials, travel if necessary, and examinations and certifications (Stoy et al. n.d.). The specific cost varies considerably since every training differs in the number and expertise of the attendees, the type of trainings required, and available budget. Costs are even more difficult to project since costs relate to the type of training, which then determines the type of facilities needed, which can vary from a classroom to a field environment (Stoy et al. n.d.). Additionally, if training materials are needed, they can include specialized equipment, educational aids and/or documents such as reference books, course guides or lesson plans (Stoy et al. n.d.). Training for emergency responders varies based on location, due to regulatory guidance and environmental factors. Since training comes with a price and each department manages their training program differently, the operating budget can affect the training offered to responders. Tailoring the training to the

available budget could leave responders without the proper proficiency needed to protect themselves and others.

Injuries and fatalities can be just as costly to the community because they reduce the number of emergency responders available should a real-world event occur. According to NIST, the cost of firefighter injuries in the U.S. is estimated between $1.6 to $5.9 billion annually (Butry et al. 2019). For further understanding, NIST breaks the overall cost out to annual cost per fire department at an estimated $50,000 to $200,000 (Butry et al. 2019). For injuries, the average number of days that a firefighter is out of work for an injury is 15 days (Butry et al. 2019). An injury that required over 31 days off duty was 31%, while injuries only requiring one day off was 10%. According to Pessemier, firefighter fatalities cost 12.85% or $622 million of the average cost of injuries annually (2018). In the last 20 years, less than six percent of fire departments experienced a fatality of a firefighter (Pessemier 2018).

For law enforcement injuries, the average number of days that an officer is out of work for an injury is 10 days (U.S. Bureau of Labor Statistics 2018). In 2018, the International Association of Chiefs of Police (IACP) reported 1,295 injuries that correlated to 5,938 days out of work (IACP 2018). The IACP estimates each injury results in an average four and a half days missed (IACP 2018). Using the average salary of law enforcement, this would put the cost of injuries in 2018 at $1.2 million (IACP 2018). Since injuries and fatalities also reduce the manpower within units, an injured responder could put more stress on other emergency responders, which can lead to more injuries or fatalities. The IACP estimates that the cost of the injury itself can be combined with the cost of overtime for the other officers to bring that total up to $3 million for 2018 (IACP 2018).

B. PRIOR STRATEGIES APPLIED TO REDUCE INJURIES AND FATALITIES IN TRAINING

Training is expected to be the strategy to reduce injuries and fatalities, but when injuries and fatalities occur during training, the strategies need to be reassessed. According to Rhoades, there were 135 firefighter fatalities from training between 2001 and 2010 and

7,935 injuries during training in 2009 alone (2012). The IACP reported 175 law enforcement training injuries in 2018 (IACP 2018).

Injuries and fatalities during training is not only an issue with emergency responders. For example, a certain level of physical fitness is necessary for an Army career, but physical fitness can be the issue and cause injuries (Holl 2019). In 2003, the Army found from civilian data that overtraining was seen in the current fitness program because fitness levels were not improving but injury rates were increasing (Holl 2019). Through the investigation of the fitness program utilized, the Army determined that fitness program modifications were necessary to reduce injuries (Holl 2019). Two focus groups were used, with one group completing the current program and the second with a modified fitness program (Holl 2019). The changes made to the program included reducing the number of miles that trainees had to run, completed distance runs in separate groups where runners had similar speeds, added speed drills, completed warm-up exercises, and provided more variety in exercises (Holl 2019). Also, the amount of training was constantly assessed as well as the intensity to ensure a gradual increase was performed and overtraining avoided (Holl 2019). Within a year the program was integrated Army-wide and after nine years the injury rate decreased by 46% (Holl 2019).

C. MONTEREY PHOENIX

Monterey Phoenix (MP) is "an NPS-developed approach and language for modeling behaviors and interactions for systems, software, hardware, people, organizations, operational and business processes" (Giammarco and Auguston 2019). MP-Firebird uses information from analysis questions and source data from SMEs to provide documentation and results to informed decisions (Giammarco and Auguston 2019). For this thesis, MP-Firebird is used to model a training process.

MP is a suitable tool for exploring the research question since its design is based upon good behavior to clarify and fix ambiguities (Giammarco and Auguston 2019). There are other types of behavior modeling tools, such as manually produced, but can miss behavior variations or be extremely time consuming for the user (Mosher n.d.). This tool is also unique with event trace generation, automatically exhausting all possibilities within

the scope defined (Mosher n.d.). A previous thesis by Ruppel states, “of the publications reviewed, no other formal, executable approach claims to exhaustively search for all possible scenarios (within a given scope) while also supporting event attributes, assertion checking, and different viewpoints” (2016, 45). Finally, MP assists with identifying emergent behaviors with ease by displaying all possible event scenarios, including interactions that were expected and unexpected. For this thesis, the tool will help create example training scenarios by allowing critical decision points pertinent to training be incorporated. This thesis will fully detail a training scenario and allow integration of the three types of emergency responders.

Previous research utilizing MP is related to business processes, systems, software, and search and rescue operations. Although the research on search and rescue operations included MP, the author investigated multiple model-based systems engineering techniques to determine how search and rescue operations are conducted (Hunt 2015). The author developed a baseline model which enables future improvements to be discovered and potentially allows more lives to be saved (Hunt 2015).

Revill researched swarming behavior of UAVs, which are large groups of UAVs organized to assist with multifaceted operations (2016). He used MP to gain a better understanding of the organization of the swarms and identify if potential failure scenarios exist (Revill 2016). In Revill’s research, MP identified an unexpected emergent behavior within a bingo fuel scenario which resulted in the establishment of an improvement (2016).

A similar effort can also be seen in an example of simulated environment where acquisition leaders can learn through experiences before ever having a role of a manager of a weapons system (Pickar 2019). Dr. Pickar demonstrates the benefits of experimental learning while connecting to acquisition leaders (2019). Pickar’s work can be applied to emergency responders in a similar approach to determine whether particular actions or decisions lead to potential scenarios.

Currently, no research exists for utilizing MP for training programs. This thesis is like Hunt’s work in the sense that the intended outcome is to display the modeling process in MP and Pickar’s work that focuses on acquisition professional training, both with the

purpose of improvement. Lastly, we hope that by identifying the process, it will provide a greater understanding and identify emergent behaviors similar to Revill's research.

III. BEHAVIOR MODELING

This chapter will detail the methodology used to create the model in Monterey Phoenix (MP) through which the event traces (scenario variants) are generated and explored. For this thesis, we have modeled an active shooter scenario. The scenario was chosen for two reasons: (1) it is the leading cause of death to officers during operations over the last decade, which makes it particularly dangerous and (2) it includes many potential scenario variants (National 2019). Section A helps clarify use of terminology and provides background information on the overall situation leading up to the active shooter scenario, referred to as an Operational Situation (OPSIT). Section B provides the mission narrative for the scenario, while the initial constraints and assumptions about the scenario are found in Section C. Section D shows the baseline MP model for the "typical-case" scenario and Section E shows a variety of alternatives to the baseline model.

A. ACTIVE SHOOTER OPERATIONAL SITUATION

On a Friday of a holiday weekend in a local beach town, conditions are clear and sunny with a temperature of approximately 87°F. A local plaza consists of a bank, restaurant, coffee shop, clothing store, and souvenir shop and is heavily populated with tourists and locals. At 1215, a business plaza employee exits the store and enters her car, which is parked in front of the restaurant. The employee sees a man exit his SUV, leave the door open, and pace back and forth for five minutes frantically. He then walks directly toward the restaurant while leaving the vehicle running and door still ajar. The employee, feeling uneasy about the odd behavior, decides to call 9-1-1. While describing her concern, the employee sees the suspect enter the restaurant and begins yelling. Moments later, the employee sees the man withdraw a handgun from his waistband, and discharge it twice in the direction of a seated individual.

B. ACTIVE SHOOTER MISSION NARRATIVE

The OPSIT sets the stage for the ensuing active shooter mission narrative. We develop a mission narrative by utilizing information from outside agencies' procedures and supplementing local responder procedures through SME support. The mission narrative in

below will set the foundation for the baseline "typical-case" scenario through which variables will be added to generate alternative scenarios.

1. Dispatch receives a call notifying law enforcement of an active shooter scenario and gathers all available information.
2. Dispatch relays the complete available information to include the last location of the suspect to all units.
3. All officers communicate and coordinate with one another to understand location and arrival time.
4. First officer arrives on scene with body armor, weapons and ammunition.
5. First officer enters the facility/building and moves toward the sound of gunfire, if available, otherwise use people within the facility as an indicator (Healthcare & Public Health Sector Coordinating Council 2017).
6. First officer broadcasts on-scene information to secondary units.
7. Secondary units arrive on scene and park their vehicles where they do not block other emergency vehicles entering or exiting the location (Healthcare & Public Health Sector Coordinating Council 2017).
8. First officer and secondary units communicate/coordinate with each other.
9. Secondary units enter the facility/building and move toward the sound of gunfire, if available, otherwise use people within the facility as an indicator (Healthcare & Public Health Sector Coordinating Council 2017).
10. Secondary units secure a perimeter to ensure suspect does not evade or enter depending on location (Federal 2013).
11. Secondary units evacuate surrounding facilities/buildings depending on location (Federal 2013).
12. First officer and secondary units direct people to safety while maneuvering through facility/building (Healthcare & Public Health Sector Coordinating Council 2017).

13. First officer and secondary units develop a tactical plan if the first officer is unable to locate the suspect.

14. First officer and secondary units maintain communication to relay information if the suspect is located.

15. First officer or secondary units eliminate threat.

16. First officer and secondary units clear scene to ensure threat was eliminated and no additional threat exists.

17. Secondary units escort medics to provide treatment of injuries.

Identified in the 17 steps above, all actions are carried out by three roles: Dispatch, First Officer and Secondary Units. In addition to these roles, the role of the Caller must be considered as it is initiating the scenario. These roles with their significant responsibilities and functions form the framework of the MP baseline model.

C. INITIAL CONSTRAINTS AND ASSUMPTIONS

Now that we have a protocol on which to build the MP baseline model, we document constraints and limitations we initially assume for the scenario. Initial constraints consist of information from outside agency reference data and SME support. The call must be made by the Caller and received by Dispatch. Dispatch is the only entity that has the ability to communicate with the Caller and the only entity that relays the information to the First Officer and the Secondary Units simultaneously. Further communication during the scenario takes place between the First Officer and the Secondary Units.

The model assumptions include:

- The 9-1-1 call is legitimate.
- All officers arrive to the scene with all necessary resources and proper training.
- There are no communication issues, that all methods are fully functioning and that there is no break in service or issue with passing of misinformation.
- The First Officer is also the most qualified, either by rank or experience, in order to develop a plan and task the Secondary Units.

- This scenario takes place within a single city (does not span city limits).
- Local enforcement is able to handle the situation without additional support.
- The Suspect does not take any hostages.

D. BASELINE MP MODEL STRUCTURE

While the mission narrative suggests numerous roles and actions such as Dispatch, First Responding Officer and Secondary Units, the roles and responsibilities we chose for the MP baseline model, as noted above are Suspect, Caller, Dispatch, First Responding Officer (abbreviated to First Officer), and Secondary Units, the last of which can be subdivided into the Initial Responding Officers and Secondary Units 2. We made this division since there were actions within Secondary Units that are completed by separate individuals and unable to complete in a linear sequence within the same role. Three of the roles were identified as extractions from the mission narrative, and the role of the Caller was added to provide the source of the call explicitly in the model. We did not think to include the role of the Suspect in the baseline "typical-case" model due to the limited inclusion of the Suspect's actions within the original narration. We will include the Suspect's role in the model of alternative events. The information from the mission narrative, the identification of the Caller, and the understanding of the assumptions and constraints are incorporated into MP to provide the baseline model, seen in Figure 3.

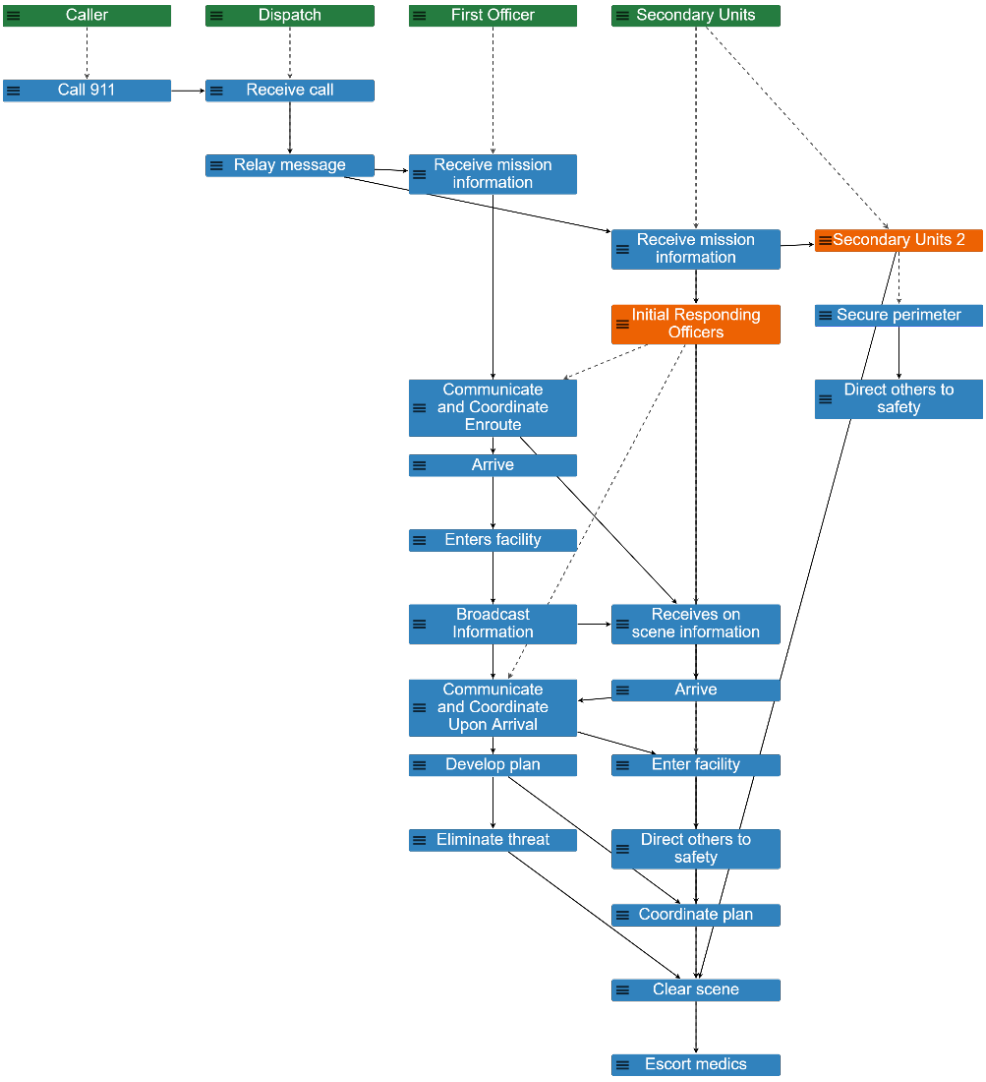

Figure 3. Baseline MP model for a "typical-case" response to an active shooter

The baseline MP model represents a typical case, which means that alternative events are excluded. The typical case is the simplest scenario baseline to which decision variables will be added to develop alternative scenarios in Section E.

E. ALTERNATIVE SCENARIOS INVOLVING DECISION-MAKING

By adding decision variables as alternative events into the MP baseline model, the number of possible scenario variants increases significantly. The addition of the decision variables offers multiple scenario instances on which responders could practice decision

making. Since our focus is on the First Responding Officer, Secondary Units, and Suspect, all added decision variables correspond to these roles. The added decision variables correspond to inserted alternative events that result in 160 alternative scenarios. Upon examining those scenarios, we identified four major points on the timeline at which decisions being made have a large impact on following events: (1) First Officer's actions upon arrival on scene, (2) Suspect encounter, (3) end to violent actions and (4) clearing the scene. Although there are three main decision-making roles within the scenario, the interactions among them produce four major points within the model where significant changes could result based on a specific role's actions and the corresponding reaction.

With the First Officer's actions upon arrival on the scene, the following alternative scenarios may occur depending on the choice made by the First Officer. The officer may enter the facility immediately, which is the preferred response, but the response is also dependent on timing of the arrival of the Secondary Units. If the officers are seconds away, the First Officer may wait, but a longer wait time may compel the First Officer to enter without backup. Additionally, the First Officer may remain outside for other reasons, such as a change of location of the Suspect. The Suspect may be outside or may have relocated to another facility when the First Officer arrives, which would cause the officer to not enter the facility initially identified. Another possibility that could result in the First Officer's decision to not enter the facility is a reasonable suspicion that he or she would not survive long enough to apprehend the Suspect should they enter. Figure 4 shows an example where the First Officer remains outside to wait for backup, rather than immediately entering the facility.

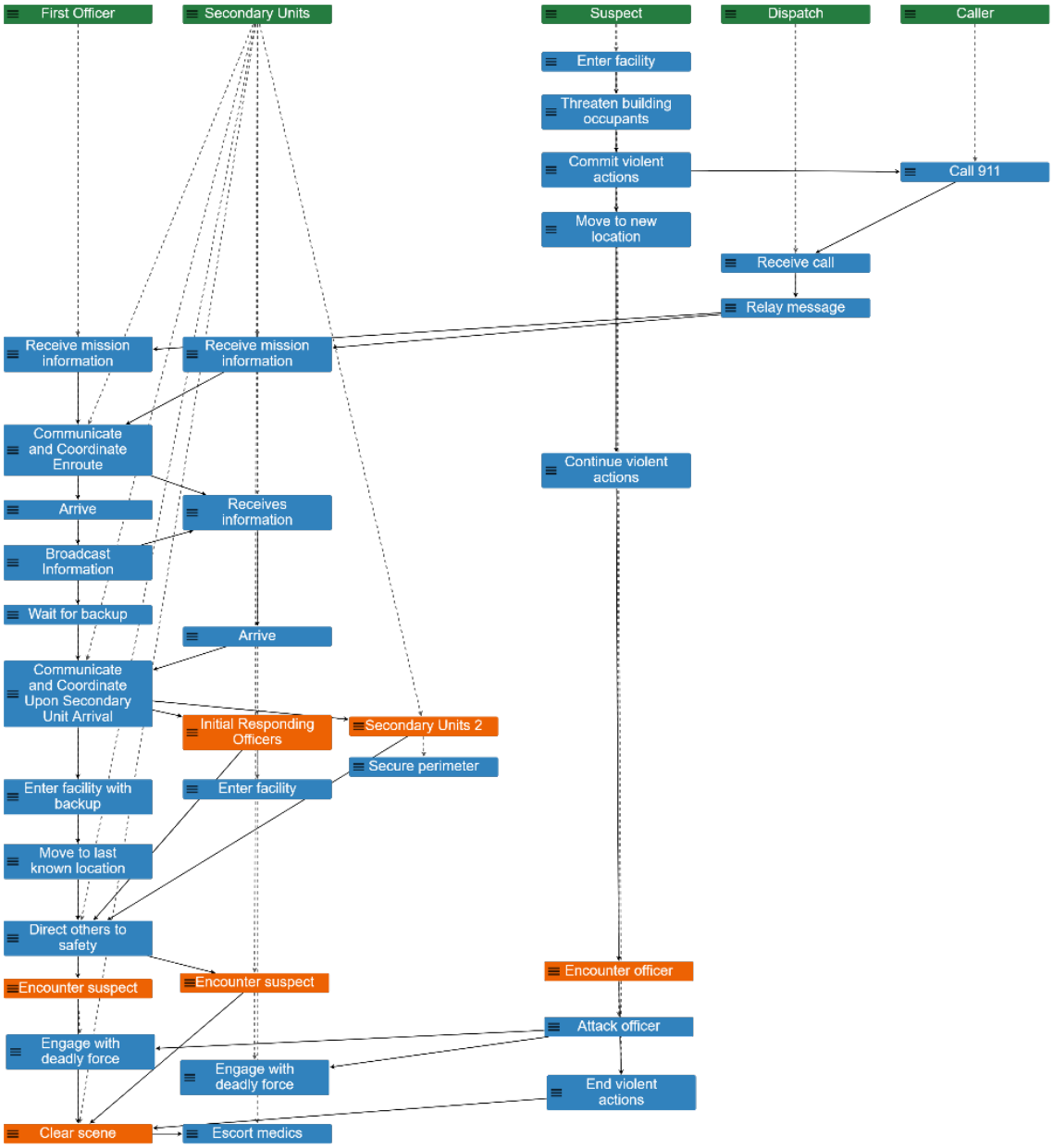

Figure 4. Example of variable within the First Officer's actions upon arrival on scene

At the next major decision point in the model, the encounter with the Suspect leads to multiple possibilities not only because of the officer's potential responses, but also because of the Suspect's potential actions. The Suspect has the possibility of exhibiting a fight or flight response when encountering the officer. Taking a more aggressive role, the Suspect may alternatively threaten or attack the officer, while a more hesitant Suspect

could surrender, flee or try to hide from officers. Figure 5 shows an example of a scenario variant containing the Suspect's action of encountering the officers and then attacking the officers, with the officers responding by engaging with deadly force.

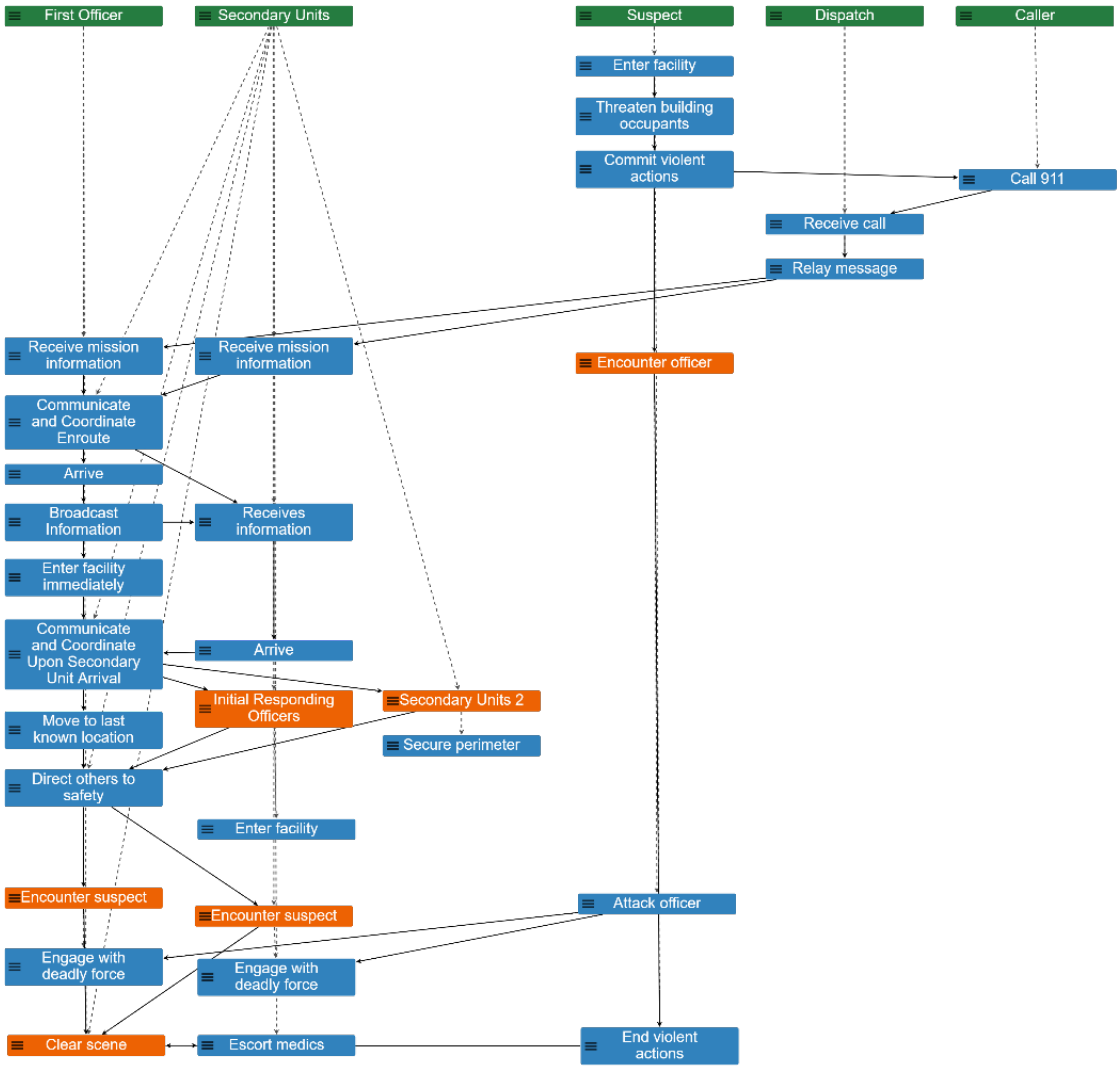

Figure 5. Example of a variable within the Suspect encounter

A third major decision point in the model relates the end of violent actions to the officer's response to the Suspect's actions. A scenario variant includes the Suspect committing suicide, which results in the officers clearing the scene in response. The officer could alternatively disarm the Suspect, which would end violent actions since the Suspect

would be taken into custody. Another alternative scenario occurs when the Suspect responds in an aggressive manner which results in the officer engaging with deadly force. Similar to the previous figure, Figure 6 shows the Suspect attacking the officers and the officers responding by engaging in deadly force, but the variable in this alternative scenario is when the Suspect commits suicide, resulting in the end of the violent actions.

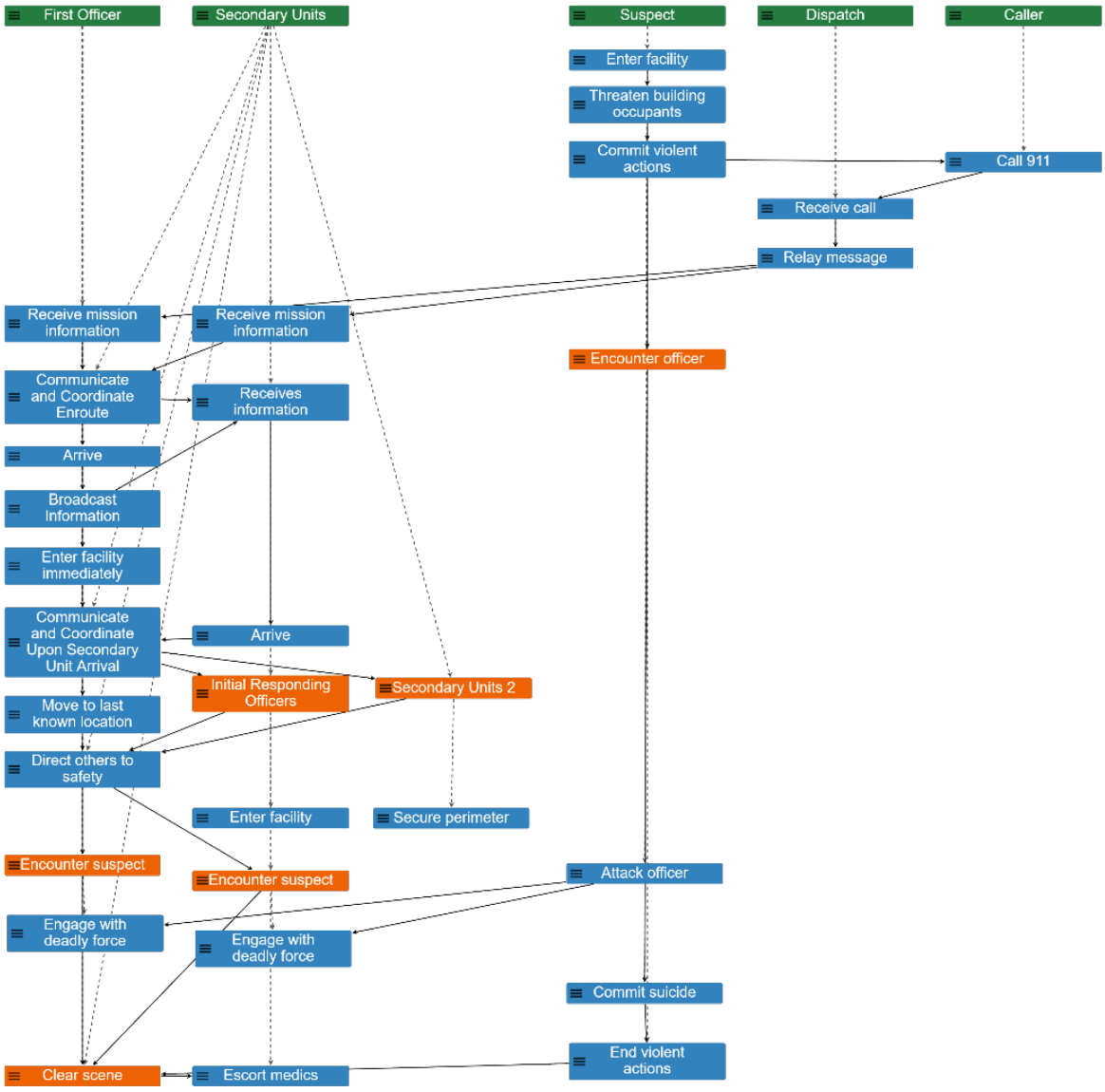

Figure 6. Example of a variable within the end of violent actions

The final major decision point in the model concerns clearing the scene. If the known Suspect is eliminated, then clearing of the scene is initiated. Here, the model incorporates a loop to take into account other possible Suspects that may not have been encountered. During the scene clearing operation, the First Responder and/or the Secondary Units could encounter another Suspect, which would prompt the repetition of previous actions until all Suspects are eliminated.

IV. MODEL DISCOVERY, VERIFICATION, AND VALIDATION

This chapter will discuss how the models were developed through the research process and analyze each iteration to determine if they properly align to the information provided from both the FEMA and FBI procedures and SME recommendations. Section A will cover the model discovery process for both the baseline "typical-case" scenario and the alternative scenario models and determine changes needed to improve the layout of the information, while maintaining validity. Section B will outline constraints or assumptions that were made during the modeling process.

A. MODEL DISCOVERY PROCESS

We developed the model in two iterations, the first being the typical-case model, followed by the alternative scenario models. We constructed the typical-case model from FBI and FEMA procedures, then further refined through assistance from a local law enforcement SME. After we developed the typical-case model, the SME assisted with the discovery of variables that resulted in alternative scenario models.

1. Typical-Case Model—First Draft

The first interview with the SME assessed the mission narrative, developed from established procedures of a typical-case. A typical-case is the most representative sequence of events during an active shooter scenario. The draft mission narrative included the Caller calling 9-1-1 and Dispatch receiving the call. Following the call, Dispatch relays the information to the First Officer and Secondary Units. The First Officer arrives first on scene and communicates on-scene information to the Secondary Units. When Secondary Units arrive, a plan is developed, and the Secondary Units secure a perimeter and evacuate surrounding facilities. After they secure the perimeter and evacuate facilities, the First Officer and Secondary Units enter the facility, direct others to safety and eliminate the threat before assisting victims. The draft mission narrative, developed initially through information acquired from FEMA and FBI procedures only, is modeled in Figure 7.

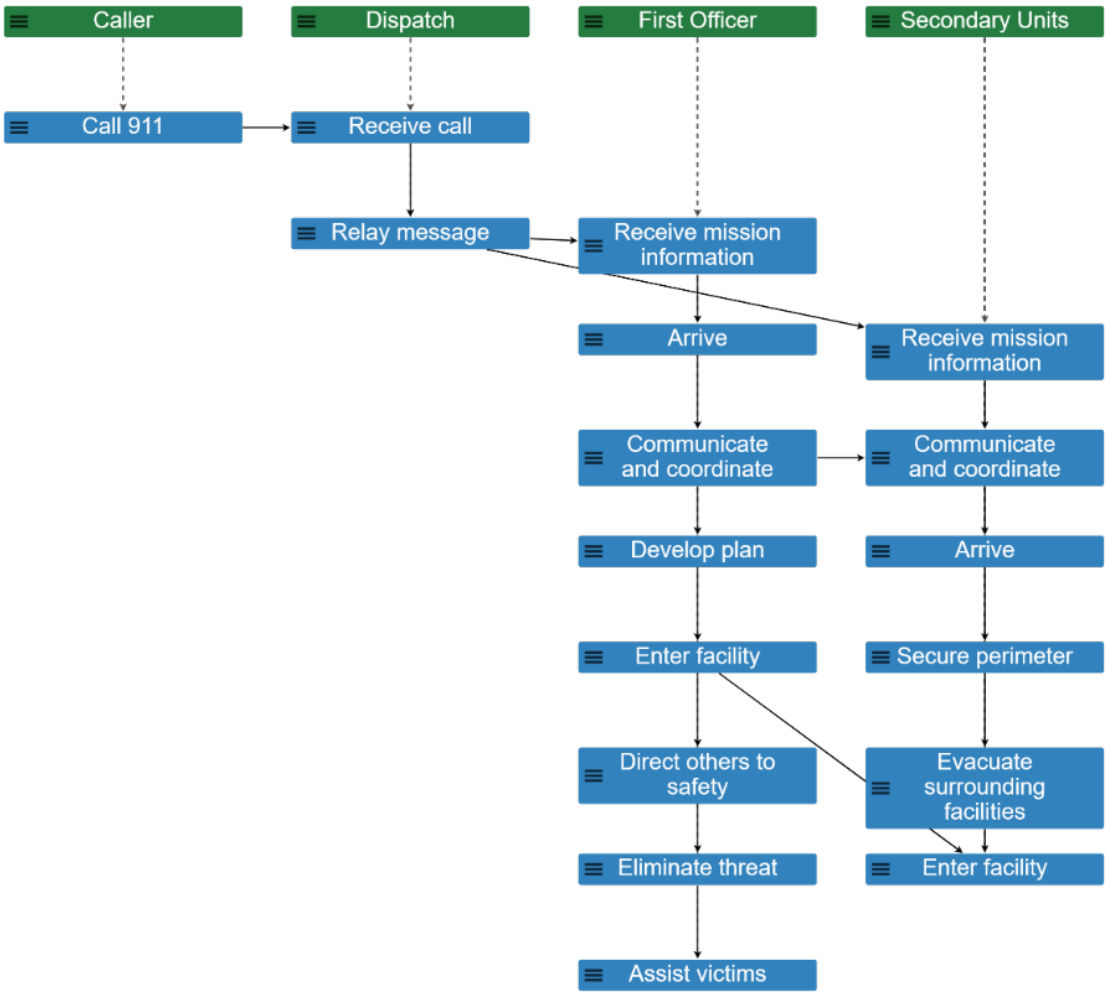

Figure 7. First draft typical-case model based on mission narrative developed from FEMA and FBI procedures only

We discussed the draft mission narrative with a local SME to determine the validity of the information. Upon verification with a SME, we adjusted the following aspects: timing of entry for the First Officer and Secondary Units, and coordination between First Officer and Secondary Units and associated responsibilities, including identification of missing events.

The first key change identified by the SME revolved around the issue with timing of entry—first, regarding the First Officer, then with Secondary Units. In the above draft mission narrative, the First Officer did not enter the facility until the Secondary Units arrived. Initially, this approach enabled the First Officer to develop a plan to cover the

necessary actions such as securing the perimeter and evacuating surrounding facilities. However, the SME determined that the timing for officers entering the facility was not indicative of a typical case. The SME identified that, for a typical case, the First Officer immediately enters the facility, rather than waiting for backup from Secondary Units. There are two reasons that this is most representative for a typical case. First, since a Suspect could commit violent actions and end those violent actions before an officer arrives, the First Officer will want to enter as soon as possible to prevent such an outcome. Second, in the case of the Suspect whose violent actions are ongoing when the First Officer arrives, then the First Officer may be able to end those violent actions before there are additional victims.

Similarly, the SME identified timing for entry with Secondary Units as requiring adjustment. In the first draft baseline typical-case model, Secondary Units did not enter the facility until a perimeter was secured and surrounding facilities were evacuated. However, the SME indicated that the Secondary Units are expected to have a similar response to the First Officer upon arrival. This means that Secondary Units enter the facility and then secure a perimeter and evacuate surrounding buildings. The evacuation of surrounding buildings occurs following the establishment of a perimeter. Establishing a perimeter outlines the areas of concern and facilities within that perimeter are also at risk. If officers identify facilities that are at risk, they can safely evacuate any bystanders within those facilities. Whereas in the draft mission narrative, the First Officer developed a plan before entering the facility, we made necessary adjustments so that the planning occurred after both the First Officer and Secondary Units could create a plan after entering the facility. The reasoning for developing the plan following the action of entering the facility was to allow all officers to fully understand their surroundings and be able to react to the plan immediately.

The SME also identified missing information regarding how much communication and coordination occurs during the scenario. With the draft mission narrative, communication and coordination only occurred when the First Officer arrived on scene. We reasoned that the First Officer would have the best information when on scene and could provide additional information about the situation that may have changed since the

Caller dialed 9-1-1. However, according to the SME, communication and coordination between the First Officer and Secondary Units should happen at multiple points throughout the scenario. Therefore, within the typical case scenario, officers communicate and coordinate multiple times, with the first occurrence immediately following the Dispatch's relay of information. During the first occurrence, all officers communicate and coordinate among one another for details on their expected arrival time. Next, when the First Officer arrives to the scene, information is broadcasted to all units. Again, the purpose of the broadcast is for responding units to achieve a greater understanding of the location and the current situation. Secondary Units also communicate to the First Officer and other Secondary Units in order to provide status updates en route and upon arrival. When other units arrive, they communicate and coordinate with the First Officer to get information on the whereabouts of both the Suspect and the First Officer. This communication assists the development of a plan between the First Officer and Secondary Units in determining where assistance is needed and how the situation has developed since the initial call.

2. Typical-Case Model—Second Draft

After receiving the SME's input, we edited the model to reflect the changes to the timing of entry for the First Officer and Secondary Units, and coordination between First Officer and Secondary Units and associated responsibilities, including identification of events that were missing from previous drafts to develop the second draft model shown in Figure 8.

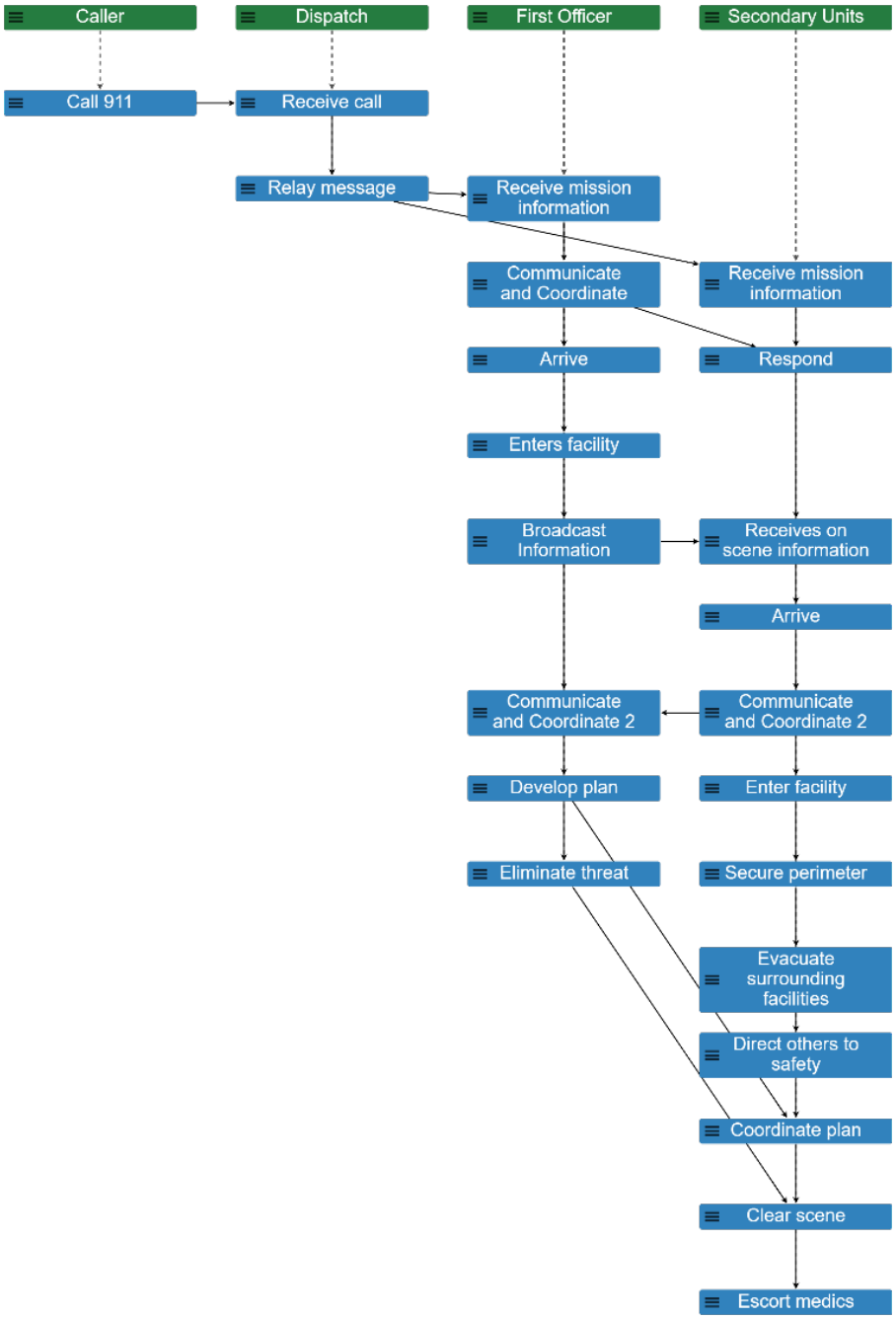

Figure 8. Second draft typical-case model with edits to entry timing, increased coordination between officers, and inclusion of previously omitted events

We reviewed the second draft typical-case model during an additional SME discussion. A model adjustment was required within Secondary Units, which occurred when assessing the establishment of a perimeter. In the second draft typical-case model, the Secondary Units enter the facility, followed by their securing a perimeter and then evacuating surrounding facilities before directing others to safety. If Secondary Units enter the facility, then the same officers are not available to secure a perimeter or evacuate surrounding facilities. Similarly, a split within Secondary Units was necessary since those securing the perimeter will not enter the facility with the other units. The split into Initial Responding Officers and Secondary Units 2 was done to allow two paths for the scenario. Within Secondary Units, the Initial Responding Officers are those who enter the facility, while Secondary Units 2 are those who remain outside to assist with the perimeter. The split was also modeled to distinguish that there were officers completing different tasks but that the officers and their reactions to each other's actions are still linked. The First Officer and Initial Responding Officers are in search of the Suspect within the facility, and Secondary Units 2 ensure that the Suspect does not relocate to another facility. Secondary Units 2 also assist with directing bystanders to safety should they escape the facility and prevent others from entering a hazardous area. Lastly, Secondary Units 2 assist with clearing the scene after the threat is eliminated by ensuring that there are no other Suspects in the surrounding area, either outside or in surrounding facilities.

3. Typical-Case Model—Finalized

The finalized typical-case model was constructed through reviews of previous draft models and incorporating SME recommendations and can be seen in Figure 9.

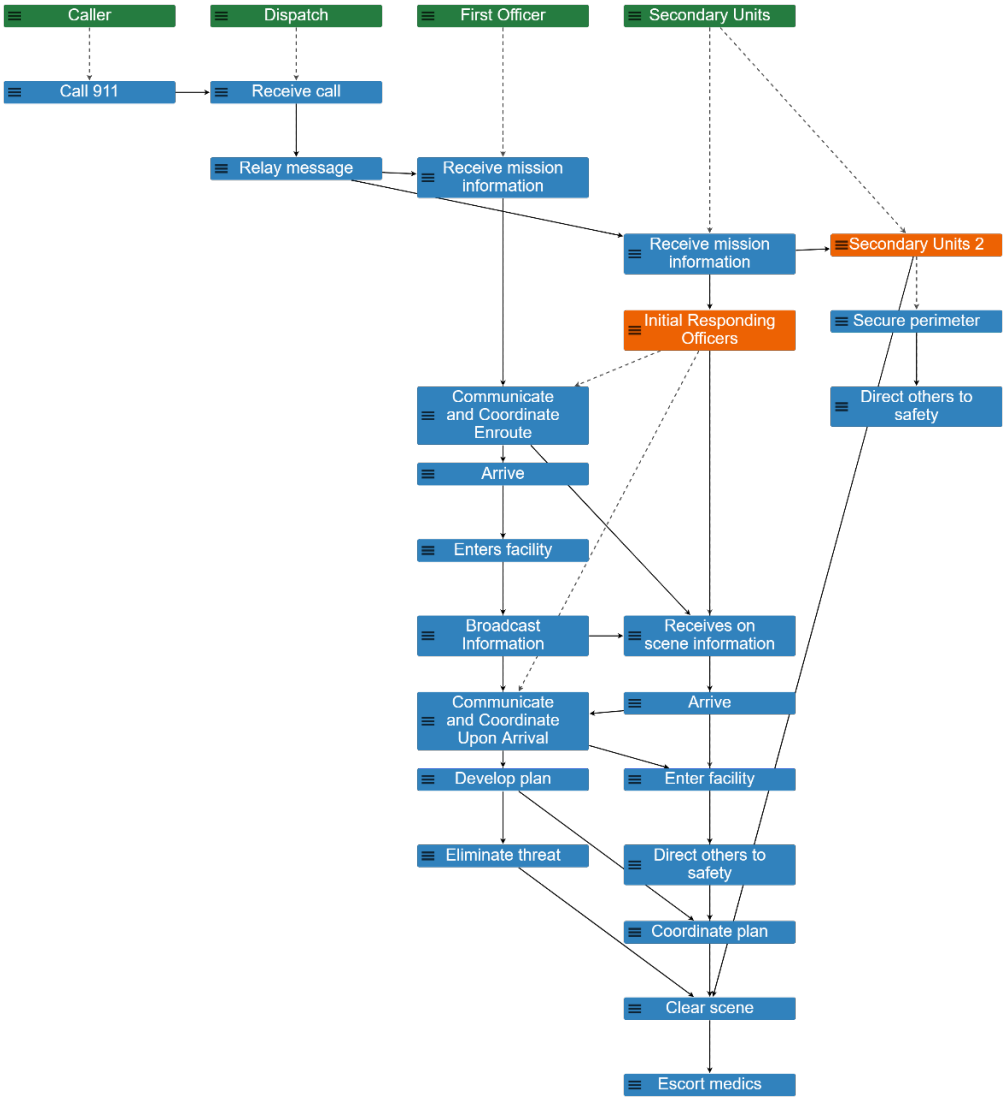

Figure 9. Final typical-case scenario

In the final typical-case scenario, the Caller places the 9-1-1 call, followed by Dispatch receiving the call and relaying the message to all officers. The officers communicate and coordinate en route. Upon arrival, the First Officer enters the facility and broadcasts information to the Secondary Units. When Secondary Units arrive, they communicate and coordinate with the First Officer again, then enter the facility. The First Officer develops a plan and coordinates with Secondary Units. Secondary Units 2 secure a perimeter and direct others to safety. The First Officer eliminates the threat, which initiates clearing the scene and escorting medics to assist with any victims.

4. Alternative Scenarios—First Draft

Following the creation of the typical-case model, we started adding variables to create alternative scenarios. Variables were first gathered through SME interviews to identify the points at which most variations could occur within an active shooter scenario. Discussions typically began with one variable, then further investigation revealed other varying possibilities within the same action category.

We added the variables for the First Officer role within four groupings within the first draft of the alternative scenarios. The first variable identified, as previously mentioned, was the decision of the First Officer on whether to enter the facility or not. This began with two possibilities for the First Officer upon arrival: enter facility or remain outside. The First Officer should enter the facility upon arrival and only remain outside if there are extenuating circumstances that lead the First Officer to believe that he or she is unable to eliminate the Suspect alone.

Following the variable grouping for the First Officer to enter the facility or remain outside, there is another variable grouping within the role of the First Officer to make the decision to move to the last known location or follow indications from building occupants. The First Officer selects the action upon entering the facility and contributed by the conditions of the environment. The First Officer may choose to move to last known location since there is also sounds of gunfire in the same direction. If the First Officer sees building occupants running from another area of the building, the First Officer may decide to change course thinking that the Suspect move to another area.

The third variable grouping that we added to the First Officer role included locating the Suspect, searching, or waiting for backup. We grouped these actions together following the development of a plan since the First Officer could immediately locate the Suspect before having assistance from the Secondary Units. However, during the development of a plan, the best course of action decided by the First Officer or Secondary Units may be to wait for backup before proceeding. Alternatively, the First Officer may not locate the Suspect and be required to search for the Suspect.

The actions of the Suspect, which were not incorporated into the initial baseline model, and the corresponding variations of the First Officer and the Secondary Units, were now all incorporated into model. These various actions were incorporated following the initial action of committing violent actions with expected reactions of the First Officer and Secondary Units. To account for multiple possibilities, optional events were utilized within the First Officer, Secondary Units, and Suspect roles.

We added three variables within the First Officer to account for how the threat was eliminated. The variables included within the role of the First Officer were: engage with deadly force, disarm the Suspect, and negotiate with the Suspect. In response, the Suspect's actions could include threatening the officer, attacking the officer, surrendering, or fleeing the officer.

Other variations within the model for alternative events include the Secondary Units identifying a second Suspect while clearing the scene. According to the SME, there is a "+1 rule" which is taught to officers, which simply means that when a Suspect is eliminated, the officers treat the scene as if there is another Suspect who poses a threat. It is not until the possibility of a second Suspect is eliminated that the scene is cleared.

Lastly, we incorporated two variations to the Suspect's role. This include an optional event of committing a violent action after threatening building occupants and committing suicide following encountering the officer. These actions stand alone, rather than are incorporated into a variation group since they can take place without another previous event occurring. We incorporated the variations and changes to the final typical-case model to create the first draft of the model of alternative scenarios, seen in Figure 10.

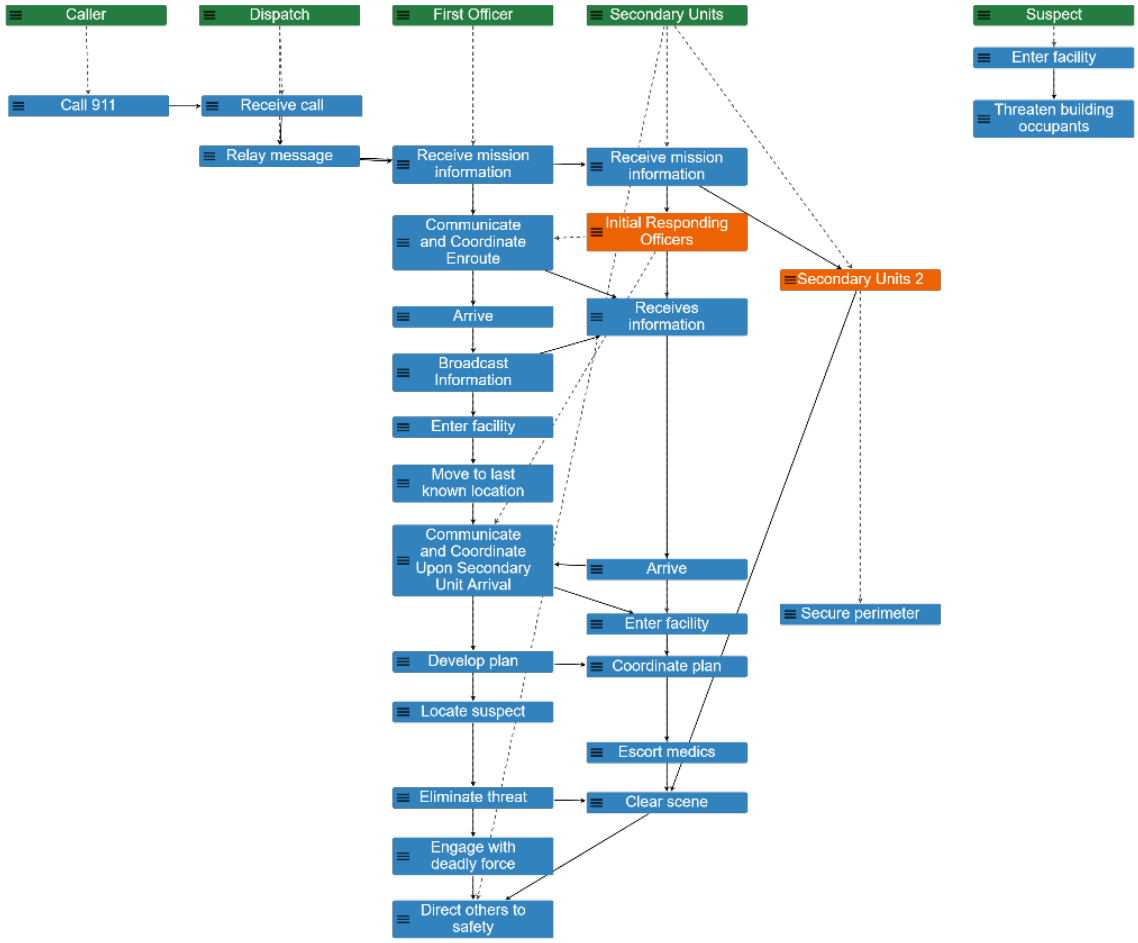

Figure 10. First draft of the alternative scenario model where the First Officer enters the facility, moves to last known location, locates the Suspect, then engages with deadly force to eliminate the threat

5. Alternative Scenarios—Second Draft

After reviewing some alternative event models, we determined that adjustments would help the flow in the initial stages of the scenarios and reduce the number of alternative scenarios since 1440 event traces existed. All changes took place within the First Officer and Suspect roles, while the Secondary Units, Caller and Dispatch remained unchanged.

We identified the first necessary change of incorporating the “Wait for backup” action within the similar action grouping. This means that the First Officer arrives on scene, then can either enter the facility immediately, wait for backup or remain outside. On the previous version of the model, the First Officer technically does not have the option to wait for backup upon arriving on the scene. Since the First Officer may elect to wait for backup when outside the facility, we incorporated the action into a more similar action category.

Next, we renamed the action “Eliminate threat” to “Encounter Suspect.” The renaming takes a less aggressive stance since it could be misinterpreted to be the First Officer engaging with deadly force. The actions within the group remained the same but added “Search” and a loop was added to the grouping. This allows the First Officer to encounter the Suspect multiple times but take different actions upon each encounter.

Commit suicide was moved within the “Encounter officer” action grouping. Technically the action does not need to take place during the encounter, but the Suspect would be located by the First Officer who would recognize that the threat no longer exists and can initiate clearing the scene. We incorporated the edits to the first draft of the alternative scenario model and created the second draft of the model of alternative scenarios, seen in Figure 11.

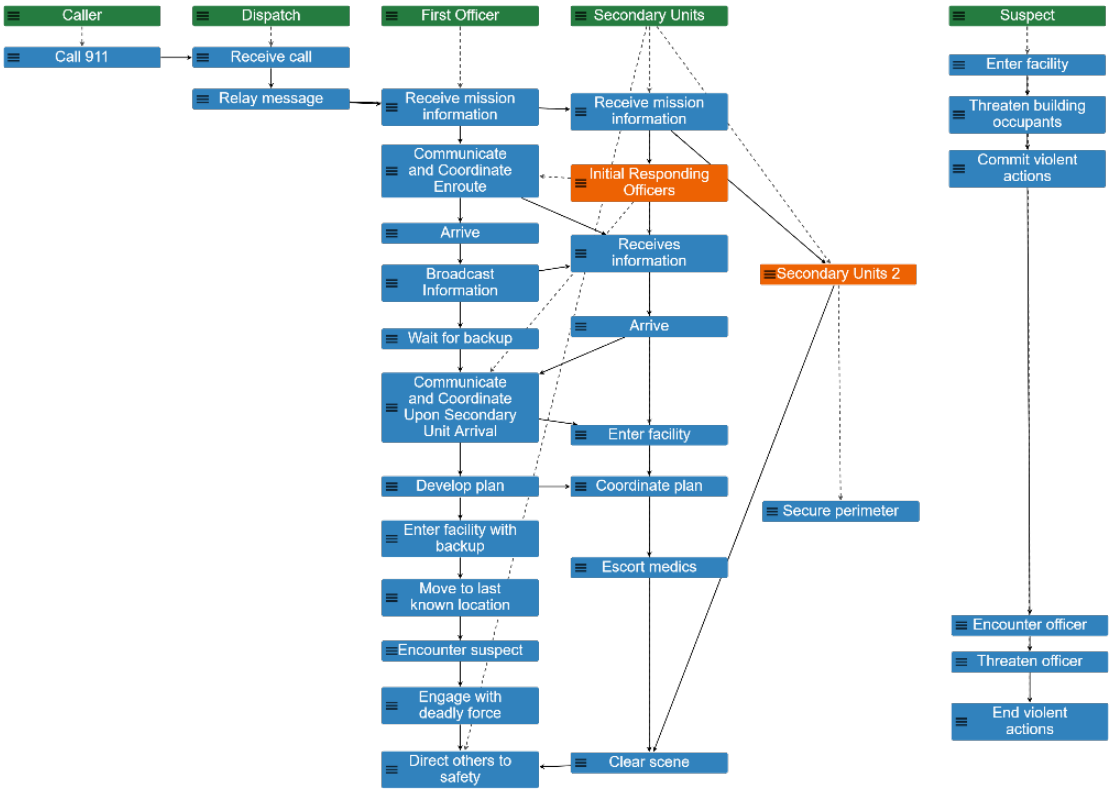

Figure 11. Second draft of the alternative scenario model where the First Officer waits for backup, enters the facility after Secondary Units arrive, and encounters the Suspect who threatens the officer

6. Alternative Scenarios—Third Draft

The second draft provided 256 event traces, which we determined could be reduced further by making some minor edits to the model. First, we added a loop within the Suspect's role where the Suspect moved locations and continued violent actions within that facility. We utilized a separate loop for the "Encounter officer" action grouping and added the action "Hide from officers" since the Suspect can evade capture, but not leave the facility, such as the action "Flee officer" implies. The back-to-back loops allows either, neither or both groupings to happen multiple times. The back-to-back loops are more realistic as the Suspect could move to several different locations without encountering the officer. Since the encounter officer grouping is on a loop, we had to remove the Suspect's action to commit suicide from the grouping, since it cannot happen multiple times.

The First Officer is the only role that encounters the Suspect which was not intended. We incorporated the action within the Secondary Units for both the Initial Responding Officers and the Secondary Units 2. Also, to account for the loops within the Suspect's role, we added a loop on the action of securing a perimeter within the Secondary Units 2 role. This allows the perimeter to expand should the Suspect move to a new location that puts another facility that was previously outside of the danger, within harm's way.

We adjusted the items mentioned above and moved the Suspect's role for the ease of reading to develop the third draft of the alternative scenario model in Figure 12.

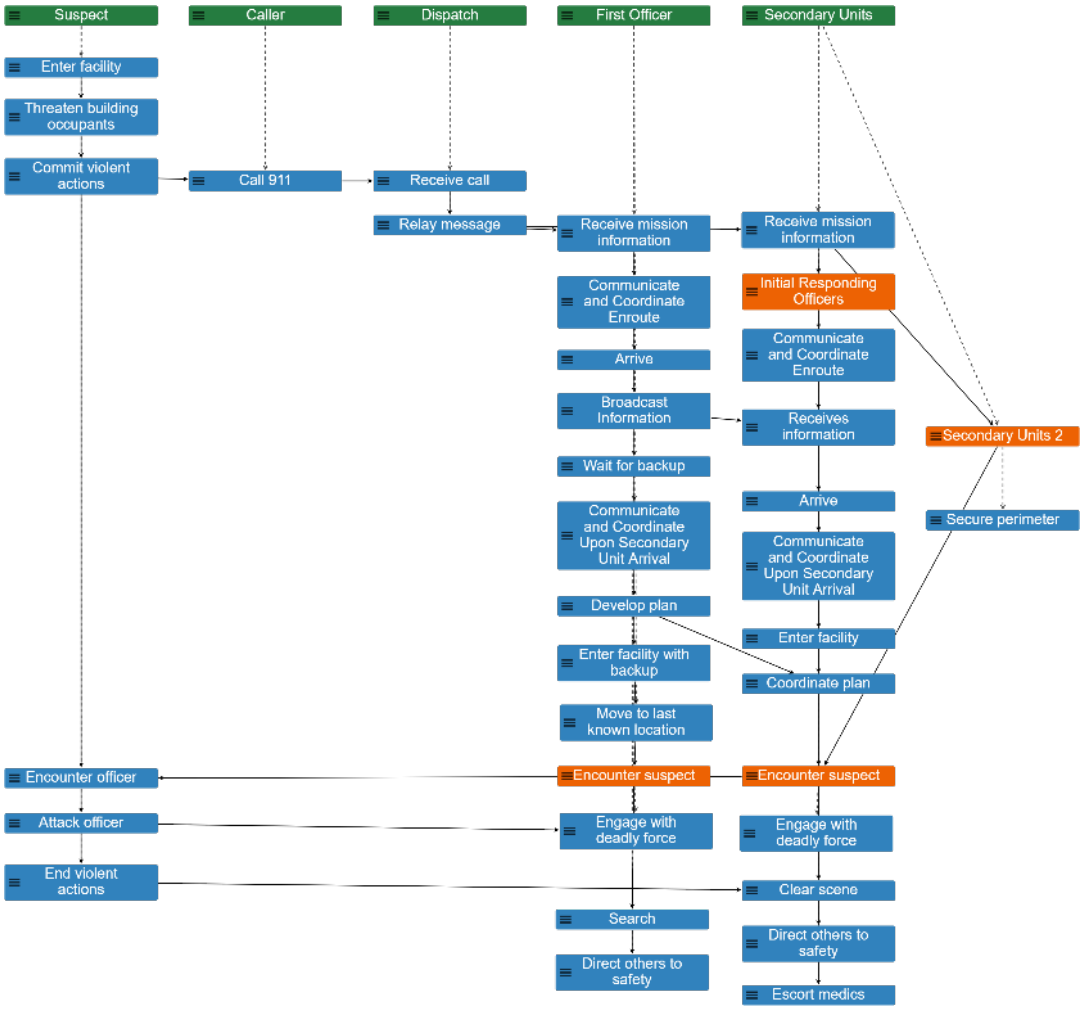

Figure 12. Third draft of the alternative scenario model where the First Officer and Secondary Units enter the facility together, and encounter the Suspect at the same time

7. Alternative Scenarios—Fourth Draft

We evaluated the 28 event traces that the third draft provided and determined that some events were not taking place in the alternative scenarios. The events that were not represented included actions within the "Encounter Suspect" action grouping. We made changes to some actions within the roots and to the auxiliary grammar rules.

We believe that the previous auxiliary grammar rule that linked the "Encounter Suspect" and "Encounter Officer" actions was an issue with a dependency between a non-composite event and a composite event saying that the whole composite event had to occur before anything else could happen. We removed that auxiliary grammar rule and ensured that the actions within the grouping were listed individually. We added an auxiliary grammar rule to fix a scenario where the Secondary Units engaged with deadly force, but the Suspect did not attack. The auxiliary grammar rule linked the Suspect's action of "Attack Officer" to the Secondary Unit's action of "Engage with deadly force." A similar auxiliary grammar rule existed for the First Officer but did not exist with Secondary Units.

The model involved 160 event traces, yet the model ran slower than desired. In order for the model to run quickly, the roots were rearranged to be optimized for the MP trace derivation process. Each role was analyzed to determine the number of events and variables. First Officer was the largest root and placed first to accelerate the speed with which the model reported the event traces. The second largest root was the Secondary Units, followed by the Suspect. This left the Dispatch and Caller at the end. Figure 13 shows the rearrangement of the roles with the previously mentioned simplification adjustments.

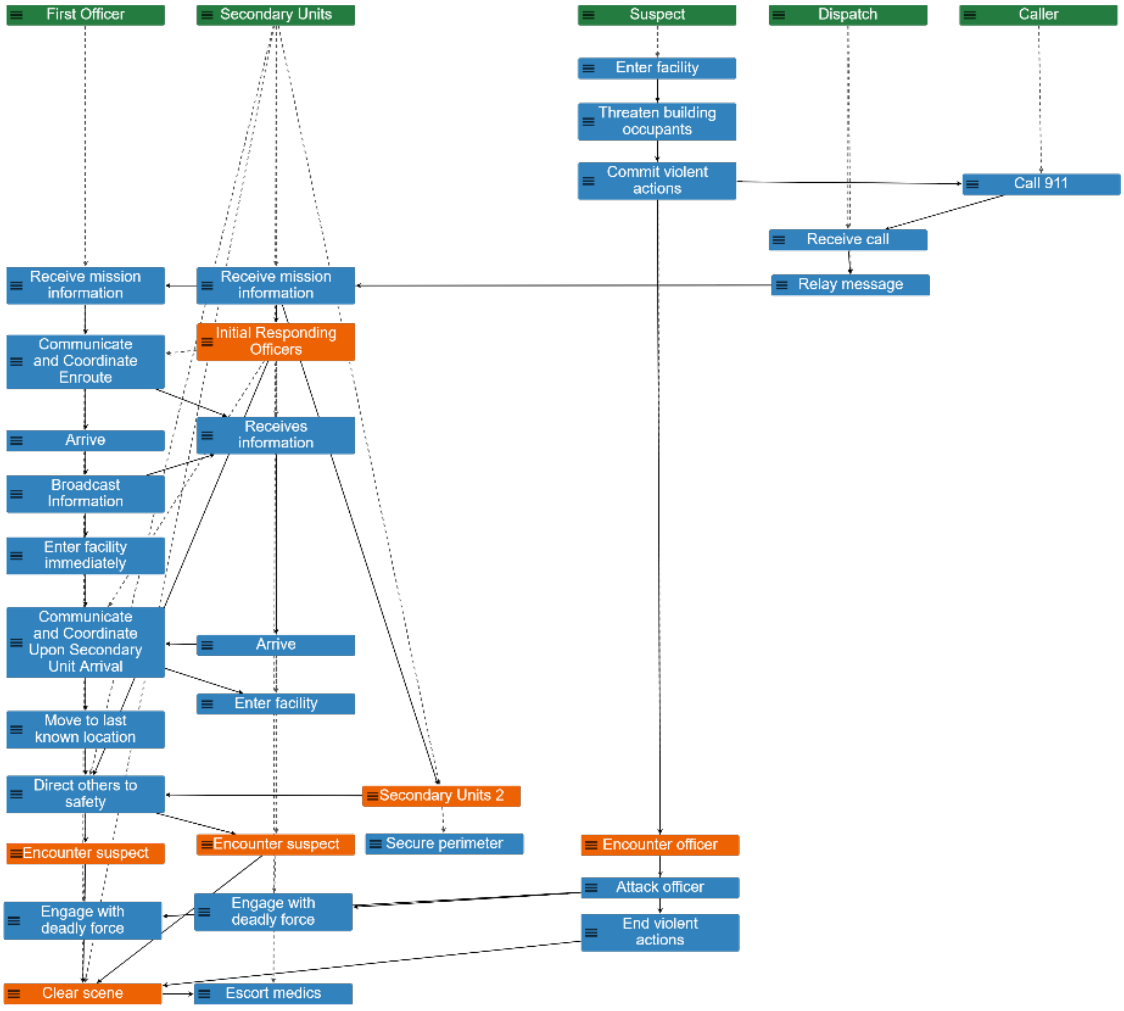

Figure 13. Fourth draft of the alternative scenario model where the First Officer and Secondary Units engaged with deadly force correctly, following an attack from the Suspect

8. Alternative Scenarios—Final Model

We reviewed the latest draft model and although it appeared that the actions and possible alternative scenarios were correct, there was a minor issue with the order of the actions within the code. In the draft model, certain actions that should occur within the Secondary Units were listed under Initial Responding Officers. Having listed the actions under Initial Responding Officer made it appear that those actions did not occur with the Secondary Units 2. We therefore moved the actions affected above the composite event.

Figure 14 is the final alternative scenario model with the four main decision points that were previously discussed.

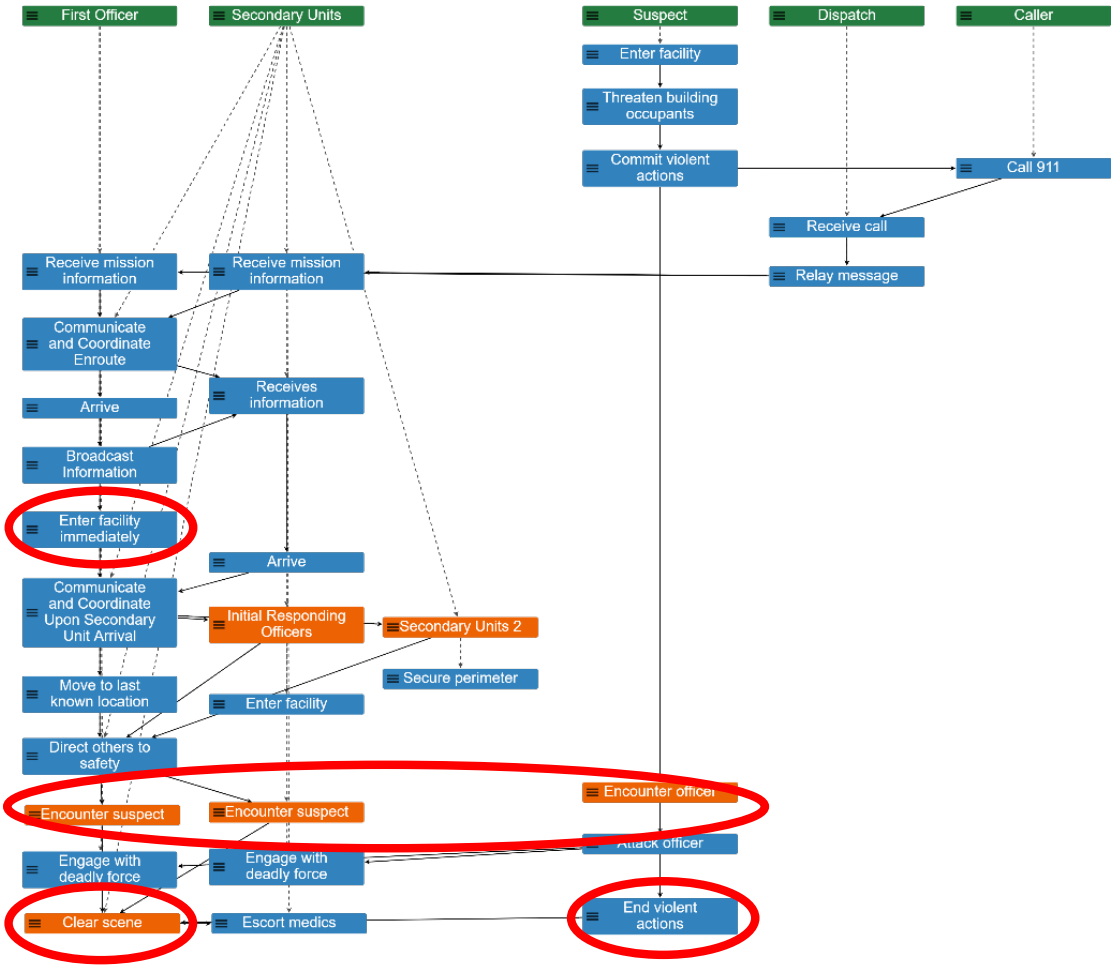

Figure 14. Final alternative scenario model with four main decision points highlighted

B. EMERGENT BEHAVIOR ANALYSIS

Emergent behaviors occur within the models and are brought to light by MP. These behaviors can be unexpected or expected. The first unexpected emergent behavior discovered in the alternative scenarios occurred during the third draft model. We noticed the First Officer was the only role to encounter and respond to the Suspect's actions. This emergent behavior was unexpected and not intentional. Although we wanted to keep this

option within the possible scenarios to account for the First Officer encountering a Suspect alone, we also needed to include the possibility of an encounter within the Secondary Unit's role. We corrected this by including the same action grouping for "encounter suspect" within the First Officer's role into the Secondary Unit's role. This addition was necessary for the best representation of other possible scenarios and still allows for the officers to encounter the Suspect alone or together. Figure 15 shows an example of a scenario where the First Officer enters the facility alone and encounters the Suspect before Secondary Units are able to rendezvous.

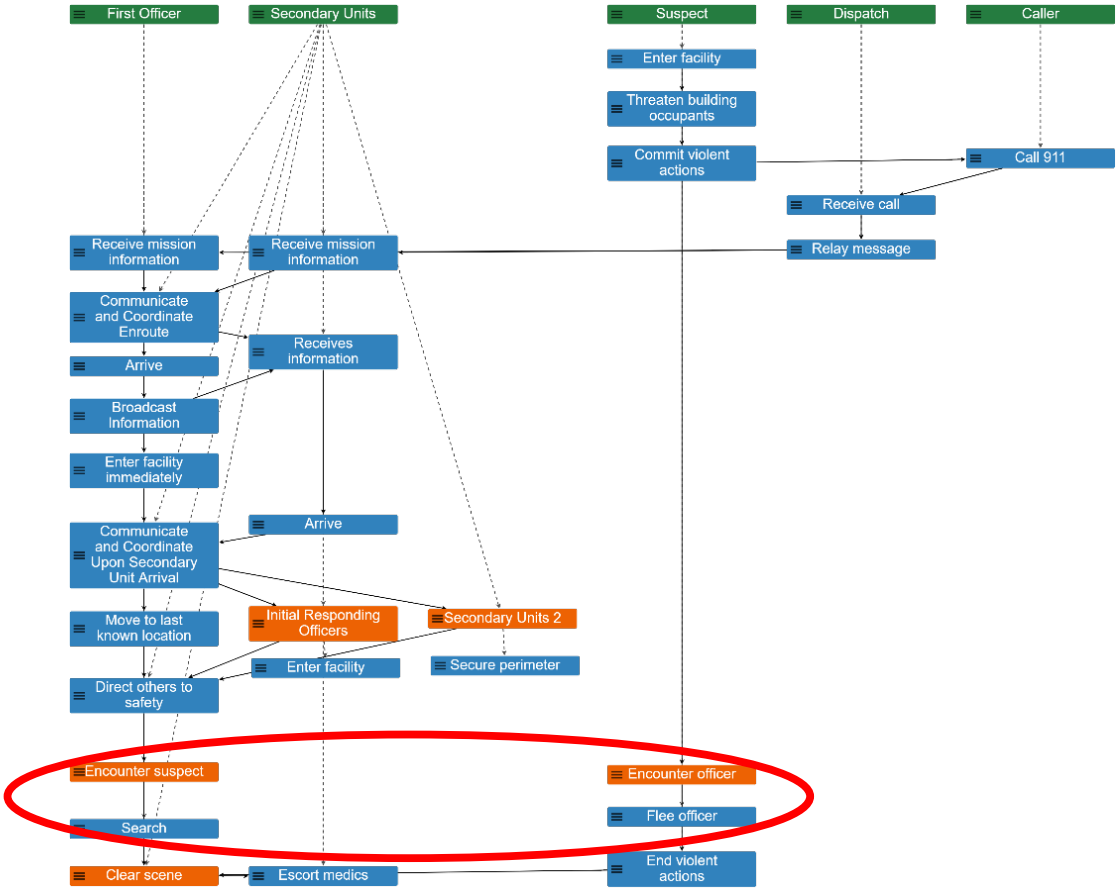

Figure 15. Emergent behavior—First Officer encounters the Suspect without Secondary Units

We also discovered an unexpected emergent behavior in an earlier draft model that involved officers engaging with deadly force without the Suspect first attacking. We

expected to see officers only engage with deadly force when the Suspect attacks an officer. Officers could respond with deadly force if the Suspect attempted to draw a weapon and fire upon the officers. Another possibility for this scenario involves the Suspect firing upon victims, which would result in the officers engaging in deadly force. Multiple event traces exhibited officers engaging with deadly force where the Suspect only threatened officers, or in some cases, surrendered to officers. To properly link these actions and reduce the number of event traces, we coordinated the actions within the proper corresponding reactions through constraints. An example of this emergent behavior where Secondary Units engaged with deadly force on a hiding Suspect is seen in Figure 16.

Figure 16. Emergent Behavior—Secondary Units engage with deadly force while Suspect hides

Next, we discovered an emergent behavior when the Suspect could surrender to the officers and is disarmed but then commits suicide. We did not expect this scenario since we believed that if a Suspect was disarmed, then there would be no weapon to cause harm. Possibilities for this event occurring include if the Suspect decides to attack or flee and the officers respond with deadly force or the Suspect flees into a dangerous situation such as oncoming traffic. Another possibility is that the Suspect has concealed another weapon such as a knife or substance that they are able to use to commit suicide after being disarmed. The discovered emergent behavior within the event trace is shown in Figure 17.

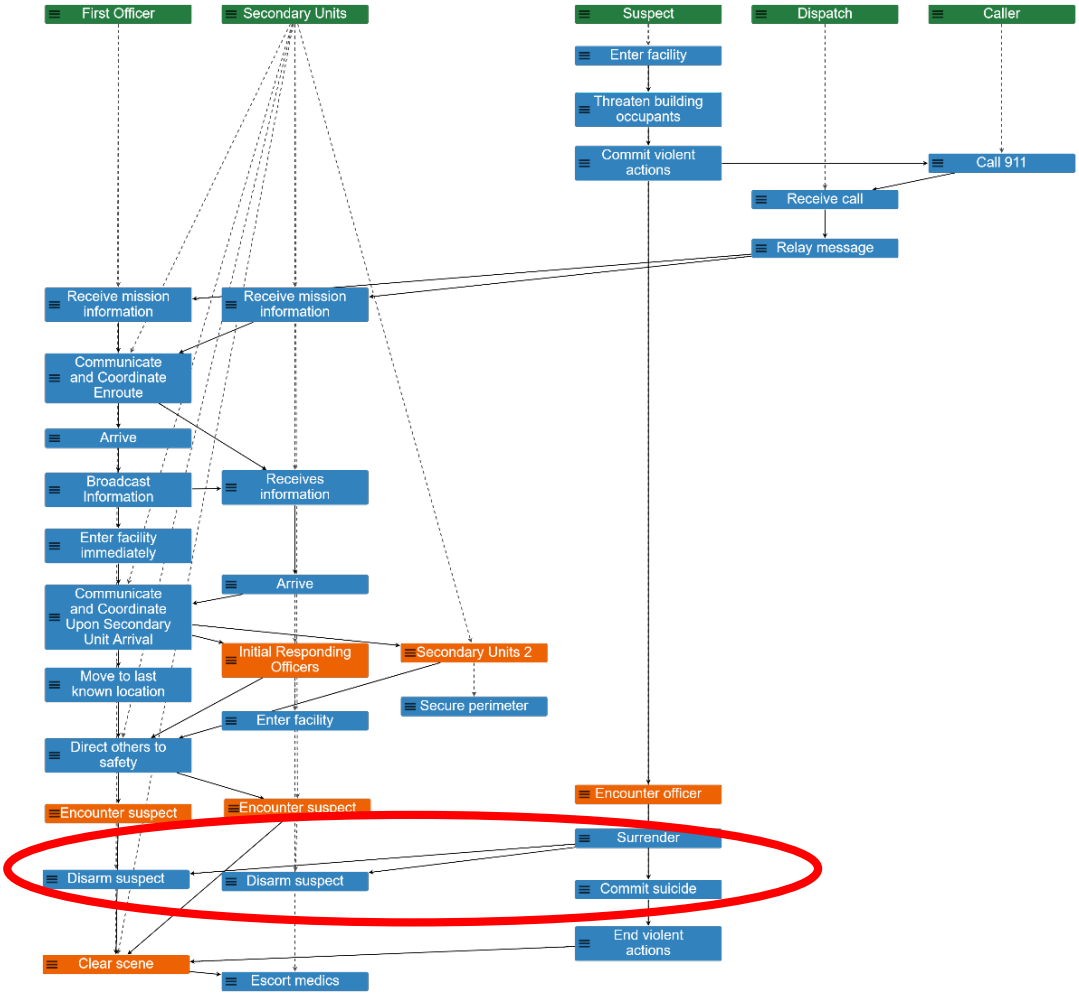

Figure 17. Emergent behavior—Suspect commits suicide after disarmed

Lastly, an emergent behavior was found with the “Clear scene” event and the discovery of an additional Suspect. Previously, we believed that additional Suspects would require an increase in the scope since the “Encounter Suspect” action was on a loop in order to see more than one Suspect. However, after looking through the models, we discovered that it could be possible that a new Suspect could emerge during the officers’ actions of clearing the scene and escorting the medics. We expected the officer to encounter and eliminate all Suspects before clearing the scene and escorting the medics. We unexpectedly discovered that the officers could encounter another Suspect but continue the path of actions by clearing the scene and escorting the medics without eliminating the threat. After some thought, this scenario could occur if an officer encounters a Suspect but does not know it. Encountering a Suspect without knowing it is possible if the Suspect blended in with the surroundings, changed their appearance to hide in the crowd, or posed from the beginning as one of the crowd. The First Officer had a “search” action following the unknown encounter. The search action could occur because they were aware of a second Suspect after the missed encounter. The officers could become aware when informed by the public or discovered evidence while assisting victims, such as another weapon. This scenario ending with a “search” action is an example of a Suspect that successfully evaded capture. An example of a scenario where a second Suspect was encountered following clearing of the scene can be seen in Figure 18.

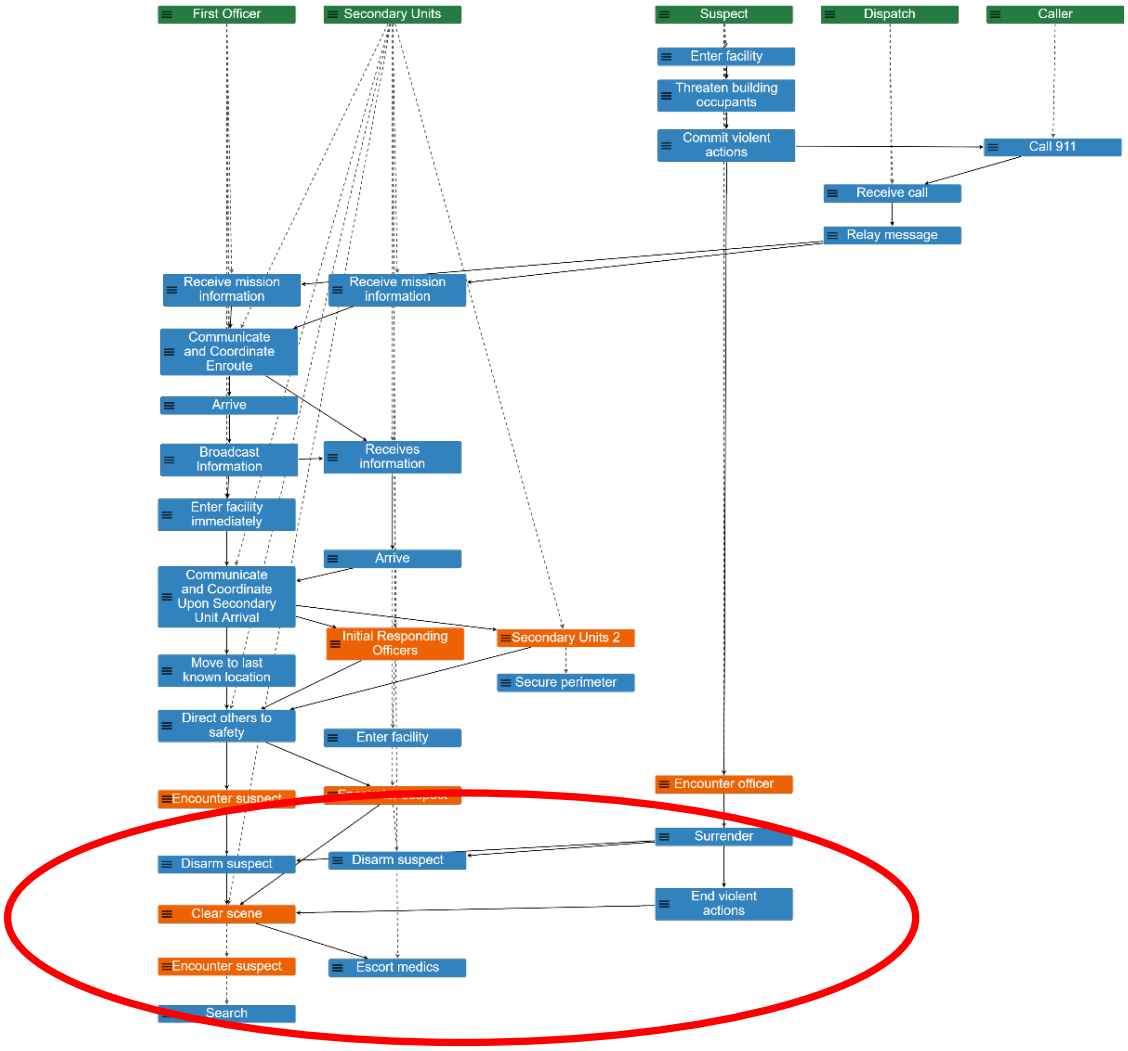

Figure 18. Emergent behavior—Officer encounters Suspect after scene is cleared

C. FOUND CONSTRAINTS AND ASSUMPTIONS

Although the initial constraints and assumptions are still valid, throughout the modeling process, additional items were added. First, despite a loop being added to the code to allow for multiple Suspects, the scope was only limited to one. The scope was limited to one Suspect to reduce the number of traces. If we increased the scope to two Suspects, it increases the event traces from 160 to 2376.

We also added constraints to the model that relate to the interaction between officers and the Suspect. We added three new constraints since we identified scenarios

where the officers were engaging with deadly force when it would not be proper to do so. First, we added a constraint that states if a Suspect attacks an officer, then the officer will respond by engaging in deadly force. In a similar manner, we linked each of the Suspect's actions to the proper officer reaction. This included adding a constraint where if the Suspect threatens an officer, the officer will respond by negotiating. Next, we added a constraint for the Suspect's action of surrendering to the officer's response of disarming the Suspect. We also added a missing constraint that connected the end of violent actions from the Suspect and the action of clearing the scene by the officers. We added this constraint to match the input received from the SME regarding when officers initiate clearing a scene.

For assumptions, we added that the Suspect does not commit suicide before encountering the officer. Although there are real-world instances of the Suspect committing suicide before officers arrive, this model assumes that the officer will be encountered first. This was not deliberately built in but rather a result of the model and was discovered during analysis. We decided not to include it earlier in the model to reduce the complexity of the model and therefore the number of traces.

V. CONCLUSIONS AND RECOMMENDATIONS

We built the typical-case model from the mission narrative, developed from FBI and FEMA procedures, and then edited them through two separate interactions with a local law enforcement SME. The typical-case model was the foundation for the alternative scenario models with the inclusion of the variables. We added decision variables as alternative events into the MP baseline model, which increased the number of possible scenario variants significantly. The addition of the decision variables offered multiple scenario instances on which responders could practice decision making. Since our focus was on the First Responding Officer, Secondary Units, and Suspect, all added decision variables corresponded to these roles. The added decision variables corresponded to inserted alternative events that result in 160 alternative scenarios.

In order to answer the question of to what extent Monterey Phoenix (MP) behavior modeling can be used to support low-risk training for emergency responders, we looked at the developed models. The MP models, both the typical-case model and the alternative events model, provided deeper insights into the roles and their actions during an active shooter scenario. In the alternative events model, we also saw the variables that can occur within the scenario, enabling us to more easily identify where critical decisions are made by the corresponding roles. Although there are three main decision-making roles within the scenario, the interactions among them produce four major points within the model where significant changes could result based on a specific role's actions and the corresponding reaction. We identified these four major points as: (1) First Officer's actions upon arrival on scene, (2) Suspect encounter, (3) end to violent actions and (4) clearing the scene. At these four major points, a decision is made that can have a large impact on the following events.

The addition of decision variables to the typical-case model increased the number of possible scenario variants significantly. These decision variables offer multiple scenario instances through which responders could practice decision making in advance of an actual active shooter scenario. As such, both models are useful tools for improving training programs or logically understanding many more decision points than can physically be

experienced in physical training. These models also have applicability to other emergency responders, and future work might show how other emergency responders are equipped for the same scenario variants.

Lastly, we analyzed the alternative scenarios and discovered some emergent behaviors that MP brought to light. Each of the emergent behaviors were unexpected and extremely valuable since MP helped expose scenarios that were not explicitly discussed with a SME but are still possible. This information provides further insight into what is possible and offers additional opportunities to improve training programs.

The first unexpected emergent behavior discovered, the First Officer was the only role to encounter and respond to the Suspect's actions. Although we wanted to keep this option within the possible scenarios to account for the First Officer encountering a Suspect alone, we also needed to include the possibility of an encounter within the Secondary Unit's role.

We also discovered an unexpected emergent behavior that involved officers engaging with deadly force without the Suspect first attacking. We expected to see officers only engage with deadly force when the Suspect attacks an officer. Officers could respond with deadly force if the Suspect attempted to withdraw a weapon and fire upon the officers. Another possibility for this scenario involves the Suspect firing upon victims, which would result in the officers engaging in deadly force.

Next, we discovered an emergent behavior when the Suspect could surrender to the officers and is disarmed but then commits suicide. We did not expect this scenario since we believed that if a Suspect was disarmed, then there would be no weapon to cause harm. Possibilities for this event occurring included if the Suspect decides to attack or flee and the officers respond with deadly force or the Suspect flees into a dangerous situation such as oncoming traffic. Another possibility is that the Suspect has concealed another weapon such as a knife or substance that they are able to use to commit suicide after being disarmed.

Lastly, an emergent behavior was found with the "Clear scene" event and the discovery of an additional Suspect. Previously we believed that additional Suspects would require an increase in the scope since the "Encounter Suspect" action was on a loop in order

to see more than one Suspect. However, after looking through the models, we discovered that it could be possible that a new Suspect could emerge during the officers' actions of clearing the scene and escorting the medics. We expected the officer to encounter and eliminate all Suspects before clearing the scene and escorting the medics. We unexpectedly discovered that the officers could encounter another Suspect but continue the path of actions by clearing the scene and escorting the medics without eliminating the threat. After some thought, this scenario could occur if an officer encounters a Suspect but does not know it. Encountering a Suspect without knowing it is possible if the Suspect blended in with the surroundings, changed their appearance to hide in the crowd, or posed from the beginning as one of the crowd. The First Officer had a "search" action following the unknown encounter. The search action could occur because they were aware of a second Suspect after the missed encounter. The officers could become aware when informed by the public or discovered evidence while assisting victims, such as another weapon. This scenario ending with a "search" action is an example of a Suspect that successfully evaded capture.

A. RECOMMENDATIONS

We had two interviews with the SME, and they provided copious amounts of information for the model build. To make a limited number of discussions more effective, we recommend a good starting point from information gathered through a variety of online sources or even an "educated guess." If possible, this information can be modeled to provide the SME with an example of the product that is the expected result of the research and also opens discussions on how to improve the roles and actions.

First, we gathered information from the SME, then organized the variable information. We recommend keeping a modeling journal to annotate all changes made and include why they were made. Regarding draft models, with each significant change, we recommend saving the code and an event trace as an easy reference.

B. FUTURE RESEARCH OPPORTUNITIES

This thesis has potential applicability to other emergency responders. A similar modeling technique could be used for another emergency responder since occupational

injuries and fatalities occur at a high rate for other emergency responders as discussed in Chapter II. A comparable research opportunity exists for firefighters where open source data is available for an emergency response situation that then can be combined with collaboration with a SME.

Another opportunity is to use a similar modeling approach with a scenario that involves multiple types of emergency responders. This opportunity would create new roles within the scenario that may interact but are completely different actions. This means that there would be fewer shared actions but more constraints regarding actions of coordinating roles. An example is a terrorist attack. Additional interactions among multiple emergency responders could also provide even more insights into unexpected emergent behaviors to increase understanding of the roles and corresponding actions within a scenario.

This thesis provides a follow-on research project opportunity by taking this information and creating a way to implement the understanding of this scenario and create a safer and more economically friendly training tool. An example includes using this information to gain a better understanding of the information within the scenario and how to develop a platform to safely practice the skills required to properly train emergency responders on these decision points.

Alternatively, the information gathered from this research could be used to adjust or tailor a current training program. The information within the model can help assess current training programs for a similar scenario to see if improvements can be made. Adjustments may be necessary within a training program because injuries or fatalities have occurred during training. Improvements may also be needed if a training program has overlooked a potential option within a scenario that has not been trained with responders.

APPENDIX A. BASELINE "TYPICAL-CASE" MODEL CODE

```
SCHEMA Active_Shooter_Event

ROOT Caller: Call_911;

ROOT Dispatch:  Receive_call
                Relay_message;

ROOT First_Officer: Receive_mission_information
                    Communicate_and_Coordinate_Enroute
                    Arrive
                    Enters_facility
                    Broadcast_Information
                    Communicate_and_Coordinate_Upon_Arrival
                    Develop_plan
                    Eliminate_threat;

ROOT Secondary_Units: Receive_mission_information
                      { Initial_Responding_Officers, Secondary_Units_2 }
                      Clear_scene
                      Escort_medics;
        Initial_Responding_Officers:
                      Communicate_and_Coordinate_Enroute
                      Receives_on_scene_information
                      Arrive
                      Communicate_and_Coordinate_Upon_Arrival
                      Enter_facility
                      Direct_others_to_safety
                      Coordinate_plan;
        Secondary_Units_2:
                      Secure_perimeter
                      Direct_others_to_safety;

/* Interactions */

COORDINATE  $a: Call_911    FROM Caller,
            $b: Receive_call    FROM Dispatch
    DO ADD $a PRECEDES $b; OD;

COORDINATE  $a: Relay_message   FROM Dispatch,
            $b: Receive_mission_information FROM First_Officer
    DO ADD $a PRECEDES $b; OD;

COORDINATE  $a: Relay_message   FROM Dispatch,
            $b: Receive_mission_information FROM Secondary_Units
    DO ADD $a PRECEDES $b; OD;

COORDINATE  $a: Broadcast_Information FROM First_Officer,
            $b: Receives_on_scene_information   FROM Secondary_Units
    DO ADD $a PRECEDES $b; OD;

COORDINATE  $a: Develop_plan FROM First_Officer,
            $b: Coordinate_plan FROM Secondary_Units
    DO ADD $a PRECEDES $b; OD;

COORDINATE  $a: Eliminate_threat FROM First_Officer,
            $b: Clear_scene FROM Secondary_Units
    DO ADD $a PRECEDES $b; OD;

First_Officer, Secondary_Units SHARE ALL Communicate_and_Coordinate_Enroute,
                                         Communicate_and_Coordinate_Upon_Arrival;
```

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APPENDIX B. ALTERNATIVE SCENARIO MODEL CODE

```
SCHEMA Active_Shooter_Event

ROOT First_Officer: Receive_mission_information
                    Communicate_and_Coordinate_Enroute
                    Arrive
                    Broadcast_Information
                    (   Enter_facility_immediately
                        Communicate_and_Coordinate_Upon_Secondary_Unit_Arrival|
                        Wait_for_backup
                        Communicate_and_Coordinate_Upon_Secondary_Unit_Arrival
                        Enter_facility_with_backup      |

                        Remain_outside  )

                        Move_to_last_known_location
                        Direct_others_to_safety
                    [Encounter_suspect
                    (+  Clear_scene +)];

        Encounter_suspect: ( Engage_with_deadly_force |
                             Disarm_suspect           |
                             Negotiate_with_suspect   |
                             Search);

        Clear_scene: [Encounter_suspect];

ROOT Secondary_Units: Receive_mission_information
                      Communicate_and_Coordinate_Enroute
                      Receives_information
                      Arrive
                      Communicate_and_Coordinate_Upon_Secondary_Unit_Arrival
                      { Initial_Responding_Officers, Secondary_Units_2 }
                       Direct_others_to_safety
                       [Encounter_suspect]
                       Clear_scene
                       Escort medics;

       Initial_Responding_Officers:
                    Enter_facility;
       Secondary_Units_2:
                   (+    Secure_perimeter  +);


COORDINATE  $a: Broadcast_Information FROM First_Officer,
            $b: Receives_information    FROM Secondary_Units
    DO ADD $a PRECEDES $b; OD;

First_Officer, Secondary_Units SHARE ALL Communicate_and_Coordinate_Enroute,
                                         Communicate_and_Coordinate_Upon_Secondary_Unit_Arrival,
                                         Direct_others_to_safety,
                                         Clear_scene;


ROOT Suspect: Enter_facility
              Threaten_building_occupants
              Commit_violent_actions

              (*  Move_to_new_location
                  Continue_violent_actions
               *)

              (+  (Encounter_officer)

               +)
              [Commit_suicide]
               End_violent_actions;

    Encounter_officer: (Threaten_officer     |
                        Attack_officer       |
                        Surrender            |
                        Flee_officer         |
                        Hide_from_officers);
```

```
72
73 COORDINATE  $a: Threaten_officer FROM Suspect,
74            $b: Negotiate_with_suspect  FROM First_Officer
75     DO ADD $a PRECEDES $b; OD;
76
77 COORDINATE  $a: Threaten_officer FROM Suspect,
78            $b: Negotiate_with_suspect  FROM Secondary_Units
79     DO ADD $a PRECEDES $b; OD;
80
81 COORDINATE  $a: Attack_officer FROM Suspect,
82            $b: Engage_with_deadly_force FROM First_Officer
83     DO ADD $a PRECEDES $b; OD;
84
85 COORDINATE  $a: Attack_officer FROM Suspect,
86            $b: Engage_with_deadly_force FROM Secondary_Units
87     DO ADD $a PRECEDES $b; OD;
88
89 COORDINATE  $a: End_violent_actions FROM Suspect,
90            $b: Clear_scene FROM First_Officer
91     DO ADD $a PRECEDES $b; OD;
92
93 COORDINATE  $a: End_violent_actions FROM Suspect,
94            $b: Clear_scene FROM Secondary_Units
95     DO ADD $a PRECEDES $b; OD;
96
97 COORDINATE  $a: Surrender FROM Suspect,
98            $b: Disarm_suspect FROM Secondary_Units
99     DO ADD $a PRECEDES $b; OD;
100
101 COORDINATE  $a: Surrender FROM Suspect,
102            $b: Disarm_suspect FROM First_Officer
103     DO ADD $a PRECEDES $b; OD;
104
105
106 ROOT Dispatch:  Receive_call
107                Relay_message;
```

```
108
109 COORDINATE  $a: Relay_message   FROM Dispatch,
110            $b: Receive_mission_information FROM First_Officer
111     DO ADD $a PRECEDES $b; OD;
112
113 COORDINATE  $a: Relay_message   FROM Dispatch,
114            $b: Receive_mission_information FROM Secondary_Units
115     DO ADD $a PRECEDES $b; OD;
116
117
118 ROOT Caller: Call_911;
119
120
121 COORDINATE  $a: Commit_violent_actions  FROM Suspect,
122            $b: Call_911    FROM Caller
123     DO ADD $a PRECEDES $b; OD;
124
125 COORDINATE  $a: Call_911    FROM Caller,
126            $b: Receive_call    FROM Dispatch
127     DO ADD $a PRECEDES $b; OD;                                    >
```

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