DISSERTATION

SYSTEMS ENGINEERING ANALYSIS AND APPLICATION TO THE EMERGENCY RESPONSE SYSTEM

Submitted by

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ABSTRACT

SYSTEMS ENGINEERING ANALYSIS AND APPLICATION
TO THE EMERGENCY RESPONSE SYSTEM

This research seeks to apply systems engineering methods to build a more effective emergency response system (called the Engineered Emergency Response System – EERS) to minimize adverse impacts and consequences of incidents. Systems engineering processes were used to identify stakeholder needs and requirements, and then systems engineering methodologies were used to build the system. Emphasis was placed on building a more capable engineered system that could handle not only routine emergencies, but also events containing increased complexity, uncertainty, and severity. The resulting EERS system was built on suitability constraints including conformance to the National Response Framework, the National Incident Management System Framework, and the community fragility concept, as well as ease of transformation from the existing system. Empirical data from two complex events in Colorado’s El Paso County, the Waldo Canyon Wildland Urban Interface fire in 2012 and the Black Forest Wildland Urban Interface fire in 2013, were used to inform the system’s design and operation. These complex and dynamic events were deemed representative of other complex events based on existing publications and research. After the engineered system was built, it was validated: 1) using the Functional Dependency Network Analysis model with data obtained from the two fires, 2) evaluating best practices that were integrated into the EERS, 3) qualitatively assessing system suitability requirements, and 4) conducting a Delphi study to assess the value of applying systems engineering to this research area; and, the feasibility of implementing the

EERS into existing systems. The validation provided evidence that the EERS is more effective than the existing system while showing that it is also suitable and feasible. The Delphi study provided evidence that using the systems engineering approach was deemed valuable by the subject matter experts. More research is needed to determine system needs and capabilities for specific communities in consideration of their unique organizations, cultures, environments, and associated hazards, and in areas of command and control and communications.

ACKNOWLEDGEMENTS

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DEDICATION

For my mother, Bonita S. Matchulat –

“Gratitude is what turns what you have into enough.”

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CHAPTER 1: INTRODUCTION

1.1 Purpose and Objective

The purpose of this research is to evaluate whether systems engineering can be used to build a more effective emergency response system. According to the United States Coast Guard, an effective emergency response system "minimizes adverse impacts and consequences of the incident and maximizes public confidence and stakeholder satisfactions" (United States Coast Guard, 2014, p. 4-13). This research considers "effective," as applied to emergency response, as largely pertaining to minimizing the adverse impacts and consequences of an incident because when this is achieved, public confidence and stakeholder satisfaction follow (Bimal, 2002; The White House, 2003). Once the system is built, data obtained from two complex Wildland Urban Interface (WUI) fires will largely validate the design. Such fires, like other types of complex emergency response scenarios, mandate fast response times, effective integration of many different stakeholders/responders, and quick adaptation to event dynamics. In the case of the Waldo Canyon fire, this response consisted of thousands of people and over a hundred organizations (refer to Appendix G for a listing of organizations). Because of such similarities, the two WUI fires provide a way to empirically validate the emergency system not just for fighting fires, but also for responding to other complex events (United States Coast Guard, 2014; Donahue & Tuohy, 2006).[1] For this reason, this research is likely applicable beyond the Colorado Springs, Colorado area (where the two fires occurred) onto other communities where an improved emergency response system could help curtail loses and save life and limb.

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[1] According to the United States Coast Guard, 80 percent of response operations share common principles and procedures. In addition, Donahue and Tuohy (2006) investigate 20 complex events found that all 20 events shared five similar problems areas. The report goes on to suggest a strong consistency exists among major categories of lessons.

The complexity involved in the responses to the two fires is best displayed by their sheer size and impact. In just 17 days during 2012, the first fire, in Waldo Canyon (about four miles northwest of Colorado Springs), consumed approximately 18,247 acres and 347 facilities, and resulted in two deaths. The second, in Black Forest (about 20 miles south of Colorado Springs), occurred just under one year later (in 2013) and took only 10 days; it burned approximately 14,280 acres, destroyed 489 facilities, and caused in two deaths (State of Colorado, 2013). Complicating the response to these devastating fires were that they occurred in the WUI and the large number of Red Flag (extreme fire warning) days that accompanied them. Both fires eventually stressed the response systems to the point of failure.

Analysis of the fires suggests that system inadequacies in areas such as speed of response, initial attack, and integration/management of people and resources all contributed to the less than desired outcomes produced by the system (Marzolf & Sega, 2018). This analysis provides the detail needed to identify those areas that worked well and those needing rework, so that a more optimized and capable system can be built to handle complex events — events that will occur with more frequency and severity in the future (United States Department of Energy, 2013). Conducting emergency response in these types of incidents becomes very complicated and complex for two primary reasons: first, there exist many hierarchal layers of subsystems, components, subcomponents, and parts that contain significant amounts of human-machine interfaces and interactions (e.g., oftentimes thousands of people and over a hundred organizations). Second, the system operates in a complex and dynamic environment that changes, often quickly, with time. This demands that the system, if it is to respond successfully, must smartly learn and adapt —perhaps even predict (Shen & Shaw, 2004).[2]

[2] This is essential as large-scale complex events contain unknowns and surprises making the event diverse and dynamic. A system that contains modularity is one way to achieve such adaptability.

The hierarchal aspects of emergency response systems relate directly to the large number and layers of subsystems and components needed to execute many of the system's functions. These functions include awareness (i.e., the need to detect, characterize, and understand), responsiveness (i.e., the need to decide, direct, and deploy), and sustained engagement (i.e., the need to engage with resources and then support those resources so that the system continues to operate during protracted events). These functions are allocated among many different system components, and they must properly integrate via interfaces and interactions, in order to be effective and efficient in generating successful outcomes.

Integration is also important to learning and adapting. It generally becomes more difficult in complex, fast moving events where normal channels of communication become ineffective because of saturation or loss of coverage due to location. In such cases, the feedback higher level decision makers need from responders working at the scene is largely quelled. This absence of information leaves decision makers without the critical information they need to effectively support the event, while lower level responders at the scene are left on their own, not having received the support they need to better respond to event dynamics. The upshot is that integration depends on effective communications, as do learning and adaptation. This does not always equate with the quantity of communication, as it is shown that too much communication actually lowers awareness and effectiveness (Turoff & White, 2008).

Another aspect of integration is the need to work across jurisdictional boundaries. Here, a variety of different stakeholders exist at the federal, state, county, and city levels, and they must unite to form shared values, a spirit of cooperation, and unity of effort. After-action reports from the Waldo Canyon fire suggest that achieving this is sometimes difficult, especially in events where key stakeholders have not built the prerequisite trust and relationships (Donahue &

White, 2006).[3] This makes finding common ground more difficult and can lead to a mismanaged and/or incongruent response. This becomes very harmful, because most emergency-type events degrade over time when left unattended and, therefore, require a fast response system to minimize losses (Zebroski, 2019). Thus, finding the correct balance between the reactionary (i.e., acting/reacting to stimuli) versus the predictive (acting on the expected) is difficult, and practically impossible if conducted via an non-disciplined approach. This research addresses these needs and others using systems engineering that emphasizes overall system performance.

1.2 Framework

In considering the systems framework for emergency response, please refer to Figure 1. At the bottom of the figure are a variety of events ranging in severity from simple (i.e., a car accident) through wide-spread devastation (e.g., a hurricane or tornado). The blue arrow just above these events displays their size and complexity starting on the left with simple events and ending on the right with very severe, complex events. The green, yellow, and red bar above the blue arrow labeled "Events A and B – Current System Capability" depicts the current system's capability to handle increasing severe events, such as those listed at the bottom of the figure. The system is "green," or very capable, when responding to simple-to-moderately complex events, but "red," or not very capable, when responding to the more severe and highly complex events shown on right.

[3] This problem occurs in many large, complex events.

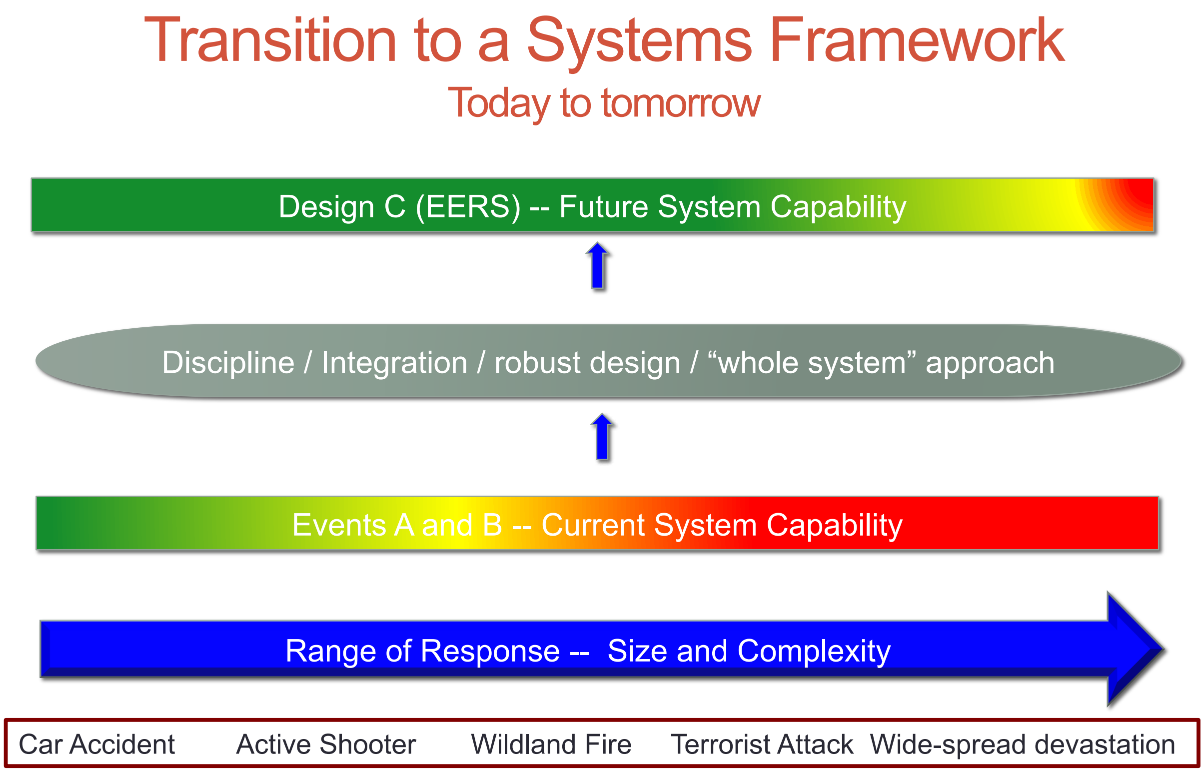


Figure 1. Transition to a Systems framework for Emergency Response

In this regard, Events A and B refer to the Waldo Canyon fire and Black Forest fire, respectively. Here, the response system started in Event A as a primarily reactive system, and then transformed into an interactive and reactive system in Event B. This is supported by evidence presented in Chapter 6 of this research. The oval bar shown above current system capability displays a few of the systems engineering design and operating attributes of discipline, integration, robust design, and a “whole of system” approach that help forge a pathway toward a developing a successful system. Many of these attributes focus on transforming the reactive, undisciplined to the disciplined, the piece-meal conglomeration of components to more integration, low knowledge/situational awareness into knowledge/wisdom, and the reactive to the more proactive and anticipatory. Applying these attributes and design objectives along with a number of others listed in Chapters 3, 4, and 5, the goal is to build the Engineered Emergency

Response System (EERS) shown at the top of the figure and depicted as “Design C – Future System Capability.”

The EERS design possesses more “green,” which represents an interactive and proactive system that is more effective in responding across the entire continuum of events to include those containing the higher levels of severity and complexity. Effectiveness is largely centered on two operational requirements:

- The EERS shall operate on the expectation of chaotic and imperfect information associated with chaotic, complex events. As such, the system shall seek out needed information, learn, and adapt.
- The EERS shall be capable of handling complex/dynamic/multi-jurisdictional events, yet still have the means to handle the mundane, non-complex, emergency events that happen daily.

As in most system designs, systems generally must fit into a larger system – a system of systems – so that the newly developed system has the ability to interface and interact properly in its external environment. As an example, consider the gas-powered automobile. A new gasoline powered automobile should probably comply with existing gas station fueling options. If it did not, new standards of fueling would be required that could delay or inhibit the new automobile’s ability to function in the existing marketplace. The same is true when building a more effective emergency response system for the future. Because of the need to remain compliant with existing external frameworks, the following suitability requirements are offered:

- The EERS shall follow guidelines as established in the National Response Framework and the National Incident Management System Framework. A couple of the applicable framework requirements include: (a) the system shall be tailorable, scalable, and layered, and (b) the system shall use the Incident Command System's unified command concept.

- The EERS shall support the community fragility concept as presented in Chapter 4. This concept addresses community resiliency and is grounded in three areas: community connectedness, stability, and sustainability. These areas are essential in helping to increase community wellness (Hodges, 2015).
- The EERS should strive to morph itself into existence from the existing response system using non-monetary solutions. Monetary investment is limited.[4]

Systems engineering is a disciplined approach that is well suited in guiding system design, development, and overall function so that the resulting end-state system meets such constraints as those above, along with other stakeholder goals and objectives. Systems engineering, as applied in this research, is largely derived from two sources: *The International Counsil on Systems Engineering (INCOSE) Handbook* (2015), and the textbook, *Systems Engineering Principles and Practice (Kossiakoff, et al., 2020)*.

1.3 Structure of the Report

Before using the systems engineering "V" model, lifecycle models, and methodologies offered in these two sources to start building the EERS, Chapter 2 first begins with a literature review to help inform and focus system needs by investigating what has, and what has not, been previously accomplished in this research area. Chapter 3 then presents the material from the two sources to define systems engineering to include its goals, purpose, the "V" model, and the systems engineering lifecycle – all of which are used to build the EERS. Chapter 4 then applies this to build the EERS. This includes conducting stakeholder and needs analysis, requirements

[4] See Delphi Study Comments, Question #5, Appendix B for expert opinion on this matter.

definition, architecture definition, and integration where functional allocation and aggregation connect system components with interfaces and interconnections to build a functioning system. This is largely accomplished through the use of tables, figures, and a Systems Machine Language (SysML) Activity diagram. Building on Chapter 4, Chapter 5 verifies EERS operation and its effectiveness in regard to complex events. The chapter accomplishes this by establishing a set of prioritized components and processes that helps verify that the EERS can generate more desirable outcomes when facing large, complex events. Chapter 6 is an empirical analysis addressing how El Paso County's emergency response systems performed when stressed by the two fires. The analysis is conducted in six areas (detection, command and control, resources, preparation and planning, communications, and support). The chapter identifies system obsolescence, failures, and successes for each fire event, and then compares those failures and successes across both events in order to gain insight into how changes made during and after Waldo Canyon helped (or hindered) the Black Forest response. These findings are used in Chapters 7 thru 9 to validate the EERS. Chapter 7 explains the validation strategy and process. It begins by explaining test and evaluation, how it functions, and the processes that will be used to validate the system. Chapter 8 validates EERS effectiveness in a realistic, operational scenario using the Functional Dependency Network Analysis (FDNA) model to evaluate how well the EERS meets requirements. Chapter 9 continues the validation through empirical data that evaluates the impact of using best practices as determined from empirical data from the two fires. It also validates suitability requirements. A Delphi study follows and is used to garner the opinions of subject matter experts to gain insight into the feasibility of employing EERS in the context of transforming from the existing response system. The Delphi study also assesses the value of using the systems engineering approach within this research space. The chapter concludes with an overall assessment of the EERS. Chapter 10 concludes the research with an overview of the findings and areas for future work.

CHAPTER 2: LITERATURE REVIEW

A literature review is conducted to inform and focus this research by investigating what has, and what has not, been done to contribute to this area of work. The review is organized starting with systems engineering applications to emergency response systems and continuing with command and control, decision-making and knowledge, and system integration, planning, and training. The review concludes with emergency response system problem areas in responding to complex, large-scale incidents.

Systems engineering is well entrenched across industry in helping guide the development of complex, technical systems. Systems engineering proved vital to the successful development of early space and aviation systems and has continued to expand into other complex system areas. Its rigorous, multidisciplinary approach employs verification and validation along the developmental pathway to not only inform and confirm, but also to decrease risk. The benefits of this approach have fostered the expansion of systems engineering applications into less technical but still very complex systems containing extensive human-to-human and human-to-machine interactions. Such is the case of the emergency response system.

2.1 Literature Review

One worthwhile book addressing this area is the *Handbook of Emergency Management—Human Factors and Systems Engineering Approach* (Waugh & Hy, 1990). This book's 30 chapters contains works from many authors on a variety of emergency management functions. None of the articles in the book addresses the emergency response system holistically; rather, the articles address different aspects of the system from various perspectives. Also of value is *The McGraw-Hill Homeland Security Handbook* (Kamien, 2012). This book contains works from a large number of authors, and it is largely focused on homeland security issues. There are a number of excellent articles that address emergency management from a whole of community approach with an emphasis on creating more resilience in the system. The Federal Emergency Management Association (FEMA) advocates strongly for establishing that approach, and much of it is on display in this book. Abrahamsson, Henrik, Hassel, and Tehler (2010) suggest using a system-oriented framework that contains a four-step process to help determine, after the fact, what happened during an incident. They then suggest ways of dissecting the event using counter-factual "what if's" to find lessons in hope of creating a better system for the future.

Because the emergency response system is a public system governed at the federal, state, and local levels, there are numerous policy documents with guidance to shape and help ensure the system functions effectively. The National Response Framework sets overarching guidance (Homeland Security Agency, 2019). The National Incident Management System, published by FEMA, issues specific operating frameworks, processes, and procedures. (FEMA, 2017). In many cases, these documents contain guidance that is not authoritative, allowing communities to establish, organize, and execute their response systems as they wish. If the communities decide to not follow this guidance, however, sometimes they lose the opportunity to compete for federal grant money that is available to help them establish and execute their response systems. This occurs because the grant money is contingent on compliance with the guidance. As such, the implication is either to follow the guidance (and compete for grant money) or go it alone. This, of course, provides great motivation for most communities to follow the guidance even if it is not optimum for their system.

Command and control is an area where this very evident. The National Incident Management System (NIMS) provides overarching federal guidance on emergency management functions across all levels of government. This guidance is subject to the National Response Framework (NRF) and establishes the Incident Command System (ICS) as a standardized approach for handling all incidents, regardless of size, type, and location. One of the main ICS tenants is the mandatory use of a centralized, hierarchal command and control system (FEMA, 2017). As is mentioned later in this treatise, and as suggested by Van Crevald (1985) in his book *Command in War,* this mandatory approach runs counter to the ability to tailor the command and control system based on the needs of an event. Moyniham (2009) addresses these conflicts, examining a variety of case studies. A new structure is not formulated, yet considerable doubt is placed on the existing ICS to meet command and control needs. More research exists offering even more detailed alternatives.

Chen, Sharmen, Rao, and Upadhyaya (2008) suggest less hierarchy and the need for a common operating picture (COP) so that responders on the scene have the awareness to act as they see fit. Drabek (1985) supports this approach by decomposing the types of events, responders, and locations to show the need for flexibility in complex incidents. Midkiff and Bostian (2002) also advocate for this type of system, suggesting the use of rapidly deployable broadband wireless networks as a means to implement it. Turoff and White (2008) also advocate for a more deployable, mobile system that can disperse yet still function in the face of an extreme event. Turoff and White go on to suggest placing authority at lower tactical levels where onscene responders can best assess the situation and react accordingly. Yet, even while many researchers advocate for less hierarchy, Meissner, Luckenbach, Risse, and Kirchner (2002) still support the ICS approach and offer a complex management and information system in an attempt to make the existing ICS framework function across all events, regardless of size and complexity.

A number of researchers are in favor of abandoning the ICS command structure altogether and suggest a flat, distributed command and control structure is best. To achieve this, Turoff, Chumer, Van De Walle, and Yao (2004) propose a high-tech solution called the Dynamic Emergency Response Management Information System. Here, a framework is presented for mapping premises and concepts into a generic communication system design to create a sensible and flexible information system. Two key facets of the system is its ability to deploy and mobilize without physical, geolocated command centers. Houghton, et al. (2006) conduct a social network analysis and advocate for a distributed approach to command and control. Waugh and Streib (2006) support building the system from the ground up based on high levels of collaboration among leadership, suggesting that half of the stakeholders are not involved. Another contribution in this area comes from Comfort (2007); he advocates for a flat command and control structure that stresses shared situational awareness and self-synchronization, addressing the plethora of response actors and the environment as a complex adaptive system.

Another area of command and control advocated by some researchers is to accept the ICS hierarchal approach, but to add balance. Here, Wise and Nader (2002) suggest the need for more coordination to make the centralized command and control work. Harrald (2006) advocates for more agility and discipline within the existing construct as a means of improving system performance. Good insight is provided into requirements and integration, but there is little to no mention as to exactly what the resulting command and control structure looks like. Another framework to consider as a command and control construct—a framework used later in this paper—is John Boyd's Observe-Orient-Decide-Act (OODA) Loop. As is explained more fully in Chapter 4, the OODA Loop is a fast-paced command and control construct developed and used largely in military applications.[5] Two worthwhile books on John Boyd that also explain the workings of his OODA Loop are written by Hammond (2004) T*he Mind of War*, and by Coram (2004) *Boyd — The Fighter Pilot Who Changed the Art of Air Warfare*.

Another pertinent area of review, an area related to command and control, is decision-making and knowledge. Here, Li et al. (2008) offer a practical ontology to create an information management system based on emergency response workflow. Their main thrust is to create the system based on common emergency response communication needs, but they do not specify exactly how the system is constructed. Sensor networks and associated broadband connectivity networks are addressed by several researchers. Lorincz addresses the challenges and opportunities of creating a network (Lorincz et al., 2004). Kwan and Lee (2005) advocate for creating a three-dimensional geospatial system to help in micro-spatial environments. Midkiff and Bostian (2012) create a wireless broadband system that addresses emergency management and response needs. Turoff (2002) suggests the need to train like you fight and advocates for a highly flexible, yet also structured, system. Manoj and Baker (2007) provide valuable insight into communication challenges that helps inform the above research through a comprehensive approach, suggesting that technological, sociological, and organizational aspects are all important in creating an effective communications system to support command and control. Comfort (2007) and Zebroski (2019) advocate for enriching the available information to responders to enhance decision making. All of these decision-making contributions are important, as complex events are generally characterized by not having enough information at

[5] The main thrust behind the OODA Loop is creating speed by executing the "loop" faster than one's opponent. In the case of a complex, dynamic emergency event, the opponent is the crisis itself. McKay (2021) also writes on Boyd, providing background and OODA Loop application as adopted by business and other entities where the need to learn and adapt is necessary for success. Boyd's approach is largely decentralized in nature and can be applied at all levels of the response , from higher level decision makers all the way down to responders at the scene. Zebroski (2019) advocates for a similar approach.

the start of the incident, while having way too much information later. This results, at the beginning, in high levels of uncertainty for lack of information, and later, in high levels of uncertainty for having to wade through too much incoming information to differentiate what is valid and what is not.

To address this need, research conducted by Shen and Shaw (2004) strongly advocates for the need to make better decisions by first mandating that responders have adequate knowledge of the emergency. Balfour (2014) addresses this need through an information sharing framework incorporating geolocation to build more understanding of the event. Tufekci and Wallace (1998) focus on creating a decision-making system to allow the response system to react faster and in better ways. They generally take a holistic view of the problem set and advocate for advanced communications, computing, and analytic procedures and models. Hollnagel and Woods (1983) support this approach, advocating for man-machine and automated decision-making processes. Their work stresses learning through cognitive processes and "intelligent action" to avoid human biases and thus make better, more effective decisions (p. 585). Other researchers focus on cognitive aspects of the system. Buchler et al. (2016) stresses that more information does not equate to better decisions if it overwhelms and is not correctly focused.

This research suggests that too much information can actually detract from making good decisions and result in a worse state of affairs. This is supported by Donahue and Tuohy (2006). Of course, many books also address this area. *The Interaction of Complexity and Management* (Lissack, 2005) is particularly worthwhile and applicable in this study because it focuses on human behavior and cognitive ability. As mentioned earlier, the emergency response system must operate in a variety of environments, many of which are complex and often dynamic.

Addressing how responders function both physically and cognitively in this environment generates a high motivation to create such tools as those mentioned.

Another area of research focuses on system integration, planning, and training. Here, Quarantelli (1998) evaluates several system areas (e.g., communications, authorities, coordination) and provides guidance on how to achieve better system integration by first understanding organizational problems, and then being able to quickly overcome them in fast moving, tactical events. McLoughlin (1985) advocates for a more structured, integrated approach to emergency management. Hazard analysis and mitigation plans, feedback from participants, and integrating the solution across a multi-year plan are all presented. Schipper and Pelling (2006) address disaster risk reduction, climate change, and development from a holistic vantage point, suggesting that integration of all areas is essential to obtaining a sustainable solution. Perry and Lindell (2003) address planning to integrate emergency response, suggesting that planning is a continual process and that there is no one-size-fits-all integrated response system. They go on to suggest that planning spurs coordination among actors but does not abrogate the need to train and exercise to reduce friction and generate an effective system. Donahue and Tuohy (2006) provide recommendations on how best to train responders in complex events advocating for a systematic approach that is comprehensive.

A literature review was also conducted to seek out common emergency response system problem areas, especially those encountered when dealing with complex, large-scale incidents. By doing this, it was hoped that some insight could be gained into how closely the problems found in the response systems used to combat the Waldo Canyon and Black Forest fires correlated to other complex disasters. Zebroski (2019) advocates for response speed in all incidents in order to suppress the severity of the incident and thereby transform the crisis into a linear, more normalized activity. The United States Coast Guard (2014) suggests that 80 percent of all incidents share common principles and procedures, leaving only 20 percent as unique to a particular event (e.g., oil spill, search and rescue, etc.). Alkhaldi, et al. (2017) examine crises in a hyper-volatile, uncertain, complex, and ambiguous environment and suggest a more cohesive support structure is needed that contains a crisis advisor position to help the leader shape and execute the response. Repoussis, Paraskevopoulos, Vazacopoulos, and Hupert (2016) focus on mass casualty incidents; they stress the need to optimize preparedness and medical resources based on individual needs, seeking to use not only appropriate medical resources, but also the best resources of any type, based on available capabilities and geolocation.

A very useful contribution is conducted by Hugelius, Becker, and Adolfsson (2020) that addresses mass casualty and disaster challenges. The research selects 20 different complex incidents and then examines them to find commonalities. Findings show that five common response system problems are an inability to manage uncertainty, lack of conformity to transform existing contingency plans into an effective response based on the real situation, ineffective crisis management organizations, ineffective information management, and inability to adapt to generate a resilient response. The research indicates that most disasters are unpredictable, uncertain, and dynamic, and the authors suggest ways to help overcome these obstacles — suggestions supported by research mentioned earlier in this review. Donahue and Tuohy (2006) take a similar approach examining a host of different complex events. Their research includes interviews, a document review, and a focus group to identify and explore common disaster response lessons in an attempt to figure out why the lessons are so often repeated. The authors offer three broad themes for improvement: radically improving training and exercises, establishing a nationally sanctioned organization to serve as a clearinghouse for gathering and validating best emergency response practices, and creating incentives to implement the best practices at all levels of government.

2.2 Contribution to the Body of Knowledge

After conducting analysis of the 2012 Waldo Canyon WUI fire and the 2013 Black Forest WUI fire, to include an in-depth analysis of the emergency response systems that were used to combat them, it became apparent that a need existed to transform the existing emergency response system into a more effective, engineered system – the EERS – particularly when combatting large-scale, complex incidents. Many of the identified problem areas found in the analysis are addressed in the aforementioned areas of this review. Yet, none of the existing literature in this review applied systems engineering, a field of study known and proven for dealing with complexity and uncertainty, to formulate a new system specifically designed to handle such phenomena. Yes, many system parts and pieces are addressed, but there are no dedicated research efforts that use systems engineering to actually build a holistic emergency response system. Hence, the objective of this research is two-fold: first, to make a contribution to the emergency response body of knowledge by extending systems engineering into this relatively obscure but highly important and complex area, and, second, to make a contribution to the systems engineering discipline by expanding it into a less-technical, yet highly complex area in a new and novel approach. This research formalizes both contributions by identifying key system parameters and elements, developing systems engineering-based solutions that results in the EERS, and validating the results.

CHAPTER 3: SYSTEMS ENGINEERING APPROACH AND APPLICATION

This objective of this chapter is to help the reader understand key aspects of systems engineering. This understanding lays the foundation to build a new system —in this case, to develop the EERS. The chapter begins by introducing the systems engineering discipline and then explains key aspects of the framework needed to build the system. The chapter explains the goals and purpose of systems engineering and its origins; it then presents the systems "V" model and the systems engineering lifecycle. After this, general systems engineering thought processes and best practices are introduced. The chapter concludes with a brief summary.

3.1 Goal and Purpose

The primary goal of systems engineering is to produce successful systems. Systems that meet stakeholder requirements, that are developed on schedule, and that are developed on (or under) budget. While this may seem trivial or otherwise easy to accomplish — when it comes producing the state of the art, or when developing systems containing large amounts of complexity where uncertainty, lack of data, and back-of-the-envelope calculations loom large — it is not. This is evident today even when using the best computer simulations, modeling, and other advanced tools. For example, take the Boeing 787 airliner: this aircraft ended-up three years behind schedule and four times over budget (estimated cost of $5B, but actual cost approximately $20B), and it was then plagued with a variety of design problems that further complicated the aircraft's delivery and future performance (Barthakur, 2021). This less than desirable outcome was accomplished in the wake of the highly successful Boeing 777 aircraft, which heavily buttressed modeling and simulation, won accolades to quickly garner ETOPS certification, and performed very well both in performance and safety (Soar, 2021). The difference, of course, is that the Boeing 787 was not the Boeing 777. The Boeing 787 was globally outsourced and used advanced materials (i.e., composites) to reduce weight, incorporated high amounts of electrification. It also used high bypass turbofan engines that, when combined with the weight savings, promised 20 percent less fuel burn than other like aircraft. In short, the Boeing 787 sought the state of the art, and because of this, the design was fraught with risks and uncertainty that ended up plaguing the aircraft's development. This led to problems –problems that at times were discovered quite late in the design, engineering, and production timeline.

When problems are discovered late in the design/engineering timeline, or worse yet, if found by end-users after production, costs needed to rectify the problems increase exponentially. It is not unusual for the cost of finding a deficiency in the field to be 50-100 times more than if discovered early in development. As Figure 2 shows, design changes late in the process produce a larger development bill; if the problems are discovered earlier (i.e., as shown as desired practices), overall costs are reduced. This allows the project to remain within budgetary constraints and on schedule, as late design changes serve to lengthen the overall project timeline. Thus, understanding the technologies, application, and various complex interfaces/interactions, and also having a logical, thought out plan to address uncertainty, conduct developmental testing, operational testing, and readiness reviews early in the developmental process are critical in helping to avoid surprises later.

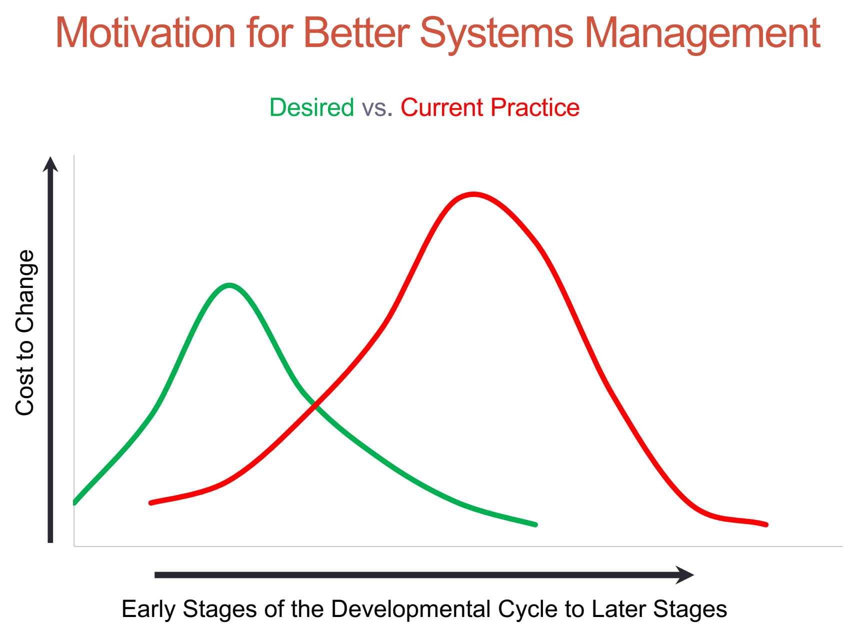


Figure 2. Motivation for Better Systems Management[6]

If the goal of systems engineering is to produce successful systems, then its *modus operandi* is to properly guide a system's development and production efforts. This equates largely to informing the engineering (and at times, the management) functions so that the proper pathway is selected to achieve project success. When done correctly, the pathway ensures a logical, efficient, and economical approach is selected and usually integrates a multi-disciplinary engineering and management team. A key aspect of the pathway is that it focuses on the system as a whole. This means that finding balance is important so that risks/uncertainty are kept in check with associated tradeoffs, that quality and costs remain acceptable, and that maintainability, further upgrades, and product improvements are all properly engineered to ensure the system has a long, useful operating life.

3.2 Origins

[6] Blanchard & Fabricky, 2013.

The origin of systems engineering dates to the late 1940's and early 1950's with the invention and application of advanced technologies. Here, the advent of the vacuum tube and, later, the solid-state transistor, along with the start of the nuclear age and space races between the United States and the former Soviet Union, all provided the need to build complex systems. These complex systems mandated a methodology capable of developing and producing these systems in a logical framework to ensure success. At the time, problems were simply fixed as they were discovered, yet, as the problems were fixed, it was found that they often gave rise to even more problems (Swenson & Alexander, 1966). There was no disciplined methodology available to guide the development of the system. To correct this deficiency, systems engineering was developed as a multi-disciplined and logical framework to guide the development of these complex systems. Based on the many needs of the time, especially in the air and space domains, it was quickly adopted into practice. Because it was so successful, Congress eventually mandated systems engineering and its associated system validation tests be used by all those working on complex, technologically-advanced governmental projects. Over time, it expanded to other government agencies too. Systems engineering methodologies of emphasis focused on technology development, readiness reviews, adopting the milestone decision framework, and incorporating test/integration/validation frameworks along the developmental pathway to achieve logical progression that would ensure eventual system success. Still today, these mandates continue.

3.3 Systems Engineering "V" and Lifecycle

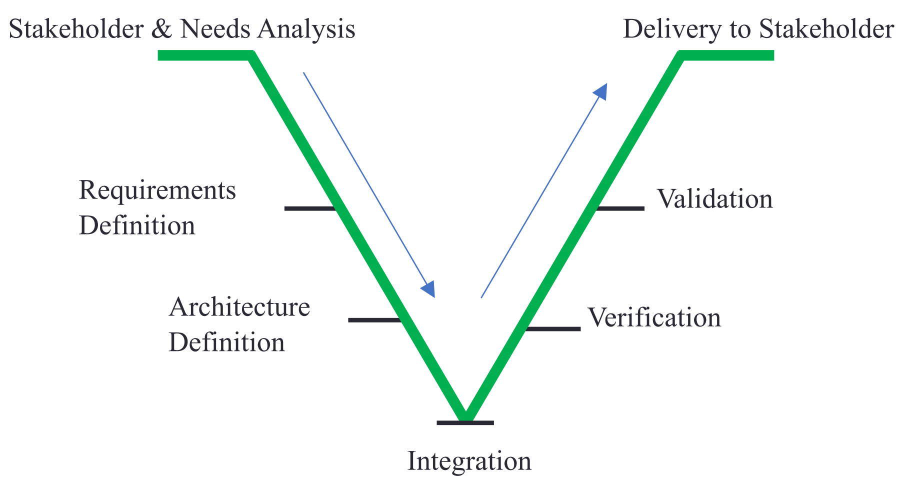
The systems engineering "V" and lifecycle used in this research primarily follows that presented in the book, *Systems Engineering Principles and Practice* (Kossiakoff et al., 2020). The author realizes, and thus is making known to the reader, that the systems engineering methods presented are not universally accepted. For example, the Department of Defense, the International model ISO/IEC 15288, INCOSE, and the National Society of Professional Engineers, all vary in their definitions of the system lifecycle model —in some cases very little, in other cases by more. These variances, while important, have little impact on this treatise's goal to design and build an emergency response system. This fact exists largely because all the models use a structured, logical, and deliberate process to help avoid *ad hoc,* non-integrated, or otherwise reactionary efforts that often lead to or produce problems later. Such efforts are needed to save and/or salvage a project in light of the unexpected. The main idea, then, is for systems engineering to guide the development of complex systems with the main emphasis on using a disciplined, logical, and deliberate process. Differences in how that gets accomplished across the framework are important but not critical to achieving success.

3.3.1 Systems Engineering "V"

The systems engineering "V" is likely the best known and most advertised model that outlines the systems engineering process. This research incorporates this model because it provides a consistent, coherent, and formal framework in which to complete the research. The "V" model used in this work was modified slightly from its original version to better accommodate needs. The modified version is shown in Figure 3.[7] The "V" process begins with Stakeholder & Needs Analysis, and through a process of decomposition and analysis follows the "V" down through Requirements Definition and Architecture Definition until arriving at Integration. During this decomposition process more and more detail is added (as will be explained in the next section of this chapter – The Systems Engineering Lifecycle) so that more understanding and fidelity is gained so that the system can then be built through aggregation and

[7] An unmodified version of the "V" is offered in Kossiakoff, et. al., 2020, pp. 16-18.

integration. As the system is integrated into larger and larger sections (e.g., into components and subsystems), verification follows to ensure the aggregation and integration of the system into these larger and larger partitions function as intended before going further. This process of verifying is important because it helps discover the "unknown-unknowns" and other emergent behaviors during the build process and before the system is completed. Once the system is built, sometimes qualification testing is then used to confirm system operation in harsh, limiting scenarios.



<u>Figure 3. The Systems Engineering "V"</u>

Once verification ends with a fully functioning, production-representative system, and thereby confirming that it was "built right," validation follows to confirm that the "right system was built."   Here, focus is placed on determining whether or not the system meets end-user and stakeholder operational interests and other operating requirements such as key performance parameters, measures of effectiveness, performance, and suitability. In many government programs, validation is also known as operational test and is oftentimes a mandated event that must occur before the system enters full-rate production.[8] Once the system has been validated through this validation process, the system is deemed ready for full-rate production and deployed to end-users for use in the marketplace. The next section explains the systems engineering lifecycle.

3.3.2 Systems Engineering Lifecycle

The systems engineering lifecycle is displayed in Figure 4. The lifecycle is broken down into three primary stages: Concept Development, Engineering Development, and Post Development, each with various inputs and outputs. This structured approach is sequential in nature, yet what is not shown, is the heavy iterative emphasis that is accomplished within each stage. The iterative nature of system development largely stems from the high amounts of system complexity, uncertainties, interactions between stakeholder and gaining consensus thereof, advanced technologies, costs and schedule constraints, and copious amounts of discovery that leads to new insights and solution sets. In essence, a change in one area drives a number of changes across the others. This iteration usually mandates that the system's design space start quite broad, and over time and through high amounts of iteration, revisiting, and discovery, the system's design space decreases as it homes in on the correct solution. Over time, the concept is validated to ensure necessary confidence and balance exists within the design.

The iteration is best understood and conducted by decomposing each stage into a number of phases. The phases build upon prior information to generate the necessary outputs. In this way, the process follows a disciplined, logical flow within and across each stage that eventually propagates across the entire systems engineering lifecycle. Although outside the scope of this report to render a full accounting of how all of this happens, it is especially important to

[8] See Chapter 7 for more discussion on this topic.

understand the Concept Development Stage. This stage is responsible for ensuring the front part of a project and/or system design is correct to help avert large cost and schedule overruns later. Thus, the following discussion focuses on this particular stage.

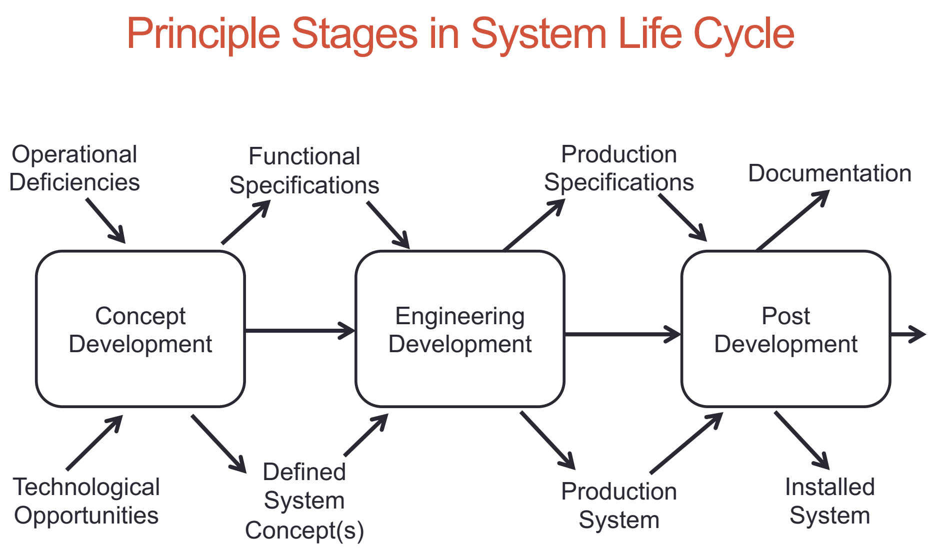


Figure 4. Principal Stages in System Life Cycle[9]

The Concept Development Stage investigates and explores various system concepts capable of meeting stakeholder needs/objectives, eventually resulting in the selection of the most appropriate concept based on a set of criteria.   In short, this equates to the translation of stakeholder needs/objectives into an appropriate concept that is defined in engineering terms and ready for follow-on technical/engineering development. To achieve this, this stage is decomposed into three phases: Needs Analysis, Concept Exploration, and Concept Definition. Please refer to Figure 5 below.

Needs Analysis is the first phase in the Concept Development stage and analyzes stakeholder goals, needs, and objectives in relation to current system operational deficiencies and technological opportunities. Current system operational deficiencies are generally supported by

[9] Kossiakoff et. al., 2020, p. 67.

data/metrics showing limitations and/or problems with the existing system and/or product. Comparing these limitations and/or problems to the expectation of using new or potential technologies via system studies and operational analysis provides insight into the feasibility and efficacy of building a new system, or perhaps modifying the existing system to achieve stakeholder objectives.

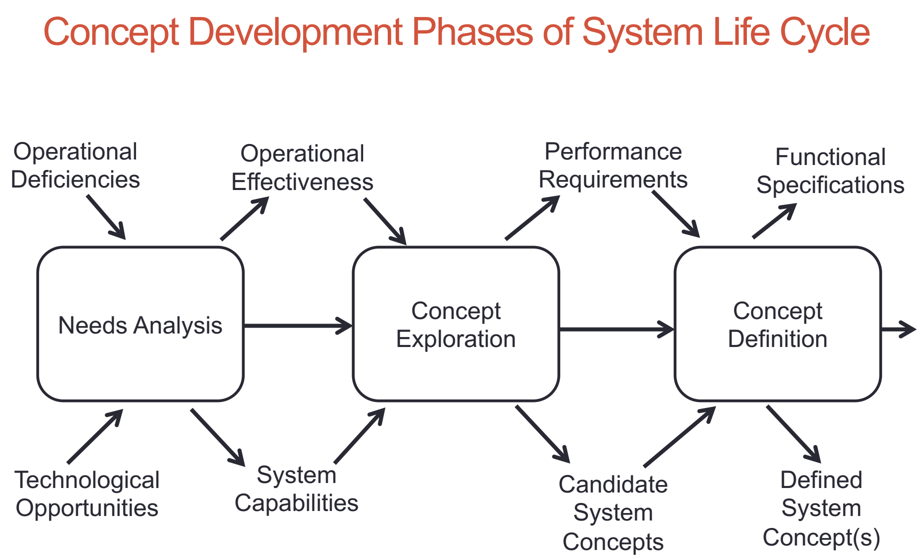


Figure 5. Concept Development Phases of System Life Cycle[10]

In formulating a feasible system concept, stakeholder needs are decomposed into operational objectives that determine what has to be achieved. The "what" decomposes and determines necessary system functions. For example, if an operational requirement was for an aircraft to fly 2 hours at 90,000 feet at Mach 6, and with a 25,000-pound payload, then the system must functionally create lift, have a form of propulsion, have a means to carry the payload, and have the ability to sustain itself for 2 hours. Decomposing further based on these stated performance requirements of time, altitude, speed, and payload serves to inform the concept's design space, as some technologies/approaches could likely be discarded immediately. Yet, by using functions to guide the discovery process, it helps spur inquiry into using new

[10] Kossiakoff et al., 2020, p. 68.

technologies, advanced materials, and/or methods that could possibly achieve these objectives – perhaps in ways never before accomplished. In short, looking at the problem set functionally helps enable new thought and innovation regarding how to accomplish the needed function vs. immediately favoring one solution over another based on established prescriptions. This process of asking "how might we accomplish this function" leads to discovery, and through the discovery process a feasible system concept that has a reasonable chance of meeting stakeholder needs/objectives is sought and found. The concept's feasibility calculus usually includes expected system costs and benefits, time to develop and produce, risk, and system effectiveness and suitability. Making the calculus is complex and requires detail to achieve necessary confidence before proceeding to the next step in the systems engineering lifecycle. If the calculus is deemed satisfactory, the next step in the lifecycle is Concept Exploration.

The purpose of the Concept Exploration is to further reduce risk and uncertainty by investigating, analyzing, exploring, considering alternative technologies and readiness levels, and formulating other concepts in order to more fully flesh-out a variety of solutions capable of meeting stakeholders' objectives. A risk chart is shown in Figure 6. As is displayed, one of the main goals is to rapidly reduce risk. To reducing risks and uncertainties this phase focuses on problem areas, either known or suspected, with the intent of finding and refining a design that is optimal when examined across the system's entire lifecycle. Inputs to this phase (that were generated in Needs Analysis) include operational requirements and needed system capabilities. The phase transforms these inputs into more refined system performance requirements and a list of candidate system concepts.

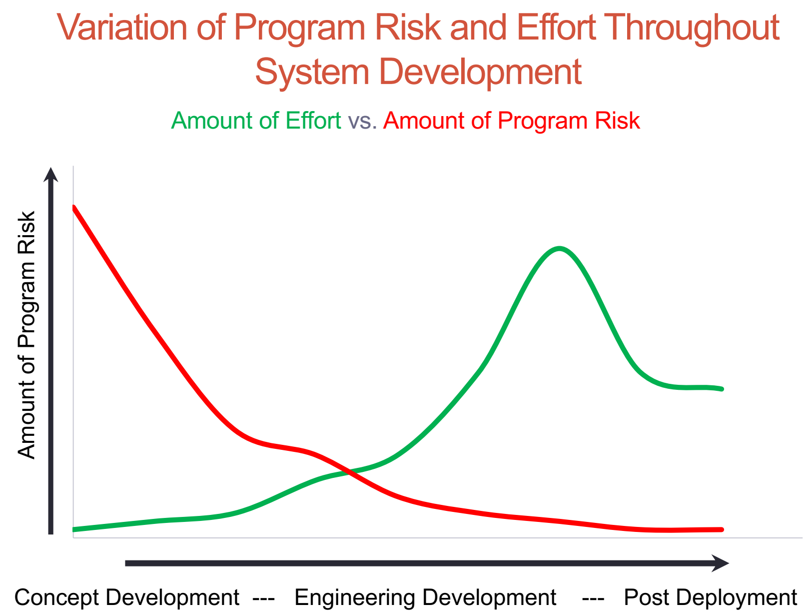


Figure 6. Variation of Program Risk and Effort Throughout System Development[11]

To achieve this, the phase conducts analysis, synthesis, and feasibility experiments to formulate alternative concepts based on acceptable levels of technological risks and other desired and/or undesired risks that could limit and/or enhance overall system success. Because some of the technologies may not be ready for application, experimentation or other means of scientific inquiry usually are needed, and this usually mandates time and money. The outputs of Concept Exploration are the basis for the next phase Concept Definition. In this phase a concept will be selected and further defined before it enters into the Engineering Development Stage, where it is fully engineered and built.

Concept Definition is the last phase in the Concept Development stage. This phase builds upon the outputs of Concept Exploration (i.e., a list of candidate systems and refined system performance requirements) and then applies a set of criteria to select the best concept for system development. The criteria are usually based on stakeholder and developer preferences, with different weights applied to each preference. The main objective is to select the correct

[11] Kossiakoff, et. al., 2020, p. 329.

concept by following a logical methodology that helps ensure proper evaluation and grading. Once selected, the concept is further defined with enough depth and specificity to allow Engineering Development to follow. Engineering Development consists of the Advanced Development, Engineering Design, and Integration and Evaluation phases, which, when accomplished, result in a production-representative system with associated detailed specifications. The Post-Development stage then takes the representative system and fields it via two phases: the Production and Deployment phase followed by the Operation and Support phase.

Though this is a very broad discussion of the systems engineering lifecycle, with little to no mention of execution in practice, the key to systems engineering's success is the disciplined, logical, and systematic approach to diligently working through the different stages and phases of the lifecycle and validating progress along the way. Investing necessary time, effort, and money to conduct inquiry via experimentation and/or test and evaluation are all necessary costs that are needed to guide the developmental pathway. These costs are often shrugged off by project managers, but they are small in comparison to the high costs created by design changes needed to rectify problems found late in the development cycle. Also of importance, and not emphasized earlier, is the systems principle of concurrent engineering, i.e., ensuring all aspects of the system are addressed and engineered into the system as early in the process as possible. Aspects such as safety, availability, reliability, maintainability, producibility, and compliance with regulatory laws and/or standards are all essential and must be addressed right from the start with the other system requirements.

As the system concept is developed and refined with the intent to eventually build, produce, operate, sustain, and dispose of a system, decision makers must remember what is "best." It is commonplace for stakeholders and developmental engineers to determine what is "best" through their own individual perspectives. That is, a structural engineer is more likely to advocate for, develop, and then want to build the "best" system as determined from a structural standpoint, just as a propulsion engineer might emphasize the best propulsion solution based on that unique discipline. Because these systems are complex and usually have many constraints, such advocacy generally comes at the expense of another system function. Said another way, the design space is limited, and the increase of one function often comes at the expense of another. The upshot is the that the "best" solution is often a blending, or balance, of many different areas. Thus, the role of systems engineering is to continually remind the multi-disciplinary developmental team of this fact and thus help optimize the design based on overall system function and performance.

3.4 Summary

In summary, this chapter introduced systems engineering. The goal of systems engineering is to design, build, produce, and sustain successful systems. It is especially adept when applied to complex systems featuring the state of the art and/or where high levels of risk and uncertainty exist. The purpose of systems engineering is to guide the development pathway following the system's engineering "V" with more detail and processes provided in the systems engineering lifecycle. The lifecycle contains three stages (Concept Development, Engineering Development, and Post Development) that provide a formalized methodology and process for completing the task. Inside of each stage are sub-stages (i.e., phases) that are sequentially-based but usually executed iteratively based on discovery and high levels of risk/uncertainty that exist among the variety of functions needed to achieve success.   Ingrained within the process is a constant focus on the overall system: The "best" solution is comprised of multi-disciplinary judgements that seek balance, effectiveness, and efficiency within the system's design space, while meeting project schedule and budgetary constraints.

CHAPTER 4: BUILDING THE EERS

This chapter follows the systems engineering "V" model and employs methodologies from the systems engineering lifecycle concept development stage to formulate a concept for the EERS. The chapter is divided into two sections. The first section addresses needs analysis and the requirements definition by explaining the national policies that provide normative guidance and overarching direction for the emergency response system, resulting in a hierarchal system-of-systems enterprise across all levels of government. The section then defines the system's architecture definition that shows how the different actors are networked to meet the needs and requirements of different sized incidents and those of different severity. The second section refines the concept and explains how the system operates by introducing and then examining necessary response system functions (i.e., what the system needs to accomplish). Integration of requirements, architectures, and functions follows that results in a SysML Activity diagram that describes and models EERS operation and behavior. Discussion follows explaining how four process loops inside the model enable the EERS to respond, adapt, and manage different types and severities of emergencies. The chapter ends with a brief summary.

4.1 Stakeholder & Needs Analysis

4.1.1 Stakeholders, National Policy, and Regulation

To fully understand the need for an Emergency Management System, one must first look at the National Strategy for Homeland Security, which provides overarching guidance to organize and unify America's homeland security efforts (Homeland Security Agency, 2008, p. 12). The strategy presents four goals: (1) prevent and disrupt terrorist attacks, (2) protect the American people, critical infrastructure, and key resources, (3) respond to and recover from incidents, and (4) continue to strengthen the foundation to ensure our long-term success. Of these four goals, responding to and recovering from incidents is an area of particular importance, because the changing environment is making such "incidents" ever more frequent and with more severe consequences (p. 1). Some environmental changes are seen every day, not just in the form of more wildfires (e.g., as was evidenced in Colorado in the summer of 2020, when 26 major wildfires served to produce devastation beyond that ever recorded in state history), but also in the form of more intense and more frequent weather events (Wikipedia, 2020).[12] Other events are more elusive and tend to remain hidden until failure occurs. These events exist largely in cyberspace, where automated systems are dependent on networks highly susceptible to hacking that often leads to system degradation and/or destruction. America's aging electrical system is another example, and one of the most vulnerable, as it is a heavily interconnected system permeating American society. The Defense Department admits that a cascading disruption in the electrical grid on critical infrastructure would be a huge challenge to overcome (Department of Defense, 2013). Add the threat of non-state terrorism, biological weapons, pandemics, mass migration, humanitarian crisis, and ethnic/religious conflict, along with the litany of other threats not mentioned, and it quickly validates the need to prevent, mitigate, respond to, and recover from such events.

The primary mechanism used to respond to such incidents is outlined in the NRF (See Figure 7). The framework provides a tailored, scalable, and layered approach that works in conjunction with the NIMS to provide standardized command and management structures for use by all participating entities (local, state, tribal, federal, and private sectors) (Department of Homeland Security, 2008). When the NRF and NIMS are combined with their full complement

[12] Of the 26 major wildfire events, the Cameron Peak fire was the largest in state history burning over 208,000 acres, 469 destroyed structures, with a duration of over 90 days.

of supporting actors and processes, the nexus is a system of such magnitude as to provide a national response. The system largely focuses on four areas: detecting and assessing emerging incidents, taking initial actions (i.e., in the emergency response vernacular, known as initial attack), scaling operations as needed, and commencing recovery actions to stabilize the area.[13] It is within and across these four areas that lower levels form the basis to design, build, and operate their emergency management systems.

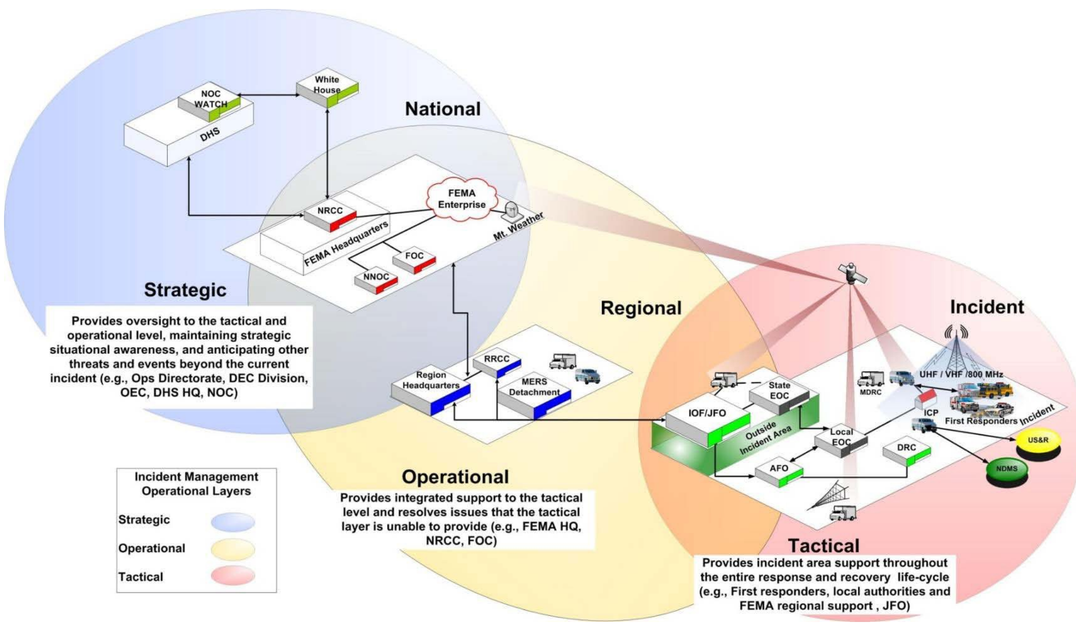


Figure 7. National Response Framework[14]

4.1.2   Requirements Definition – Controls

In order for a system to respond (i.e., to react to a stimulus), it must accomplish four fundamental functions: (1) an ability to observe/sense (i.e., detect the need to respond), (2) an ability to understand and characterize the observation in order to decide how to respond, (3) an ability to act (i.e., direct resources to physically conduct the response), and (4) an ability to garner feedback in which to refine the response as conditions change (i.e., to cycle back through

[14] Department of Homeland Security, 2008, p. 4.

steps 1-3). One framework that helps explain these functions and how the steps are executed is John Boyd's OODA Loop. This framework is well adapted to emergency response because it (1) embraces uncertainty as a basic condition; (2) provides a methodology to handle dynamic and unforeseen events; (3) follows engineering principles of observation, hypothesis, and test; (4) is a learning system that continually questions (i.e., breaks apart and analyzes) the past and present; and (5) stresses non-technical solutions as a means to decrease dependencies. Please refer to Boyd's OODA Loop in Figure 8.

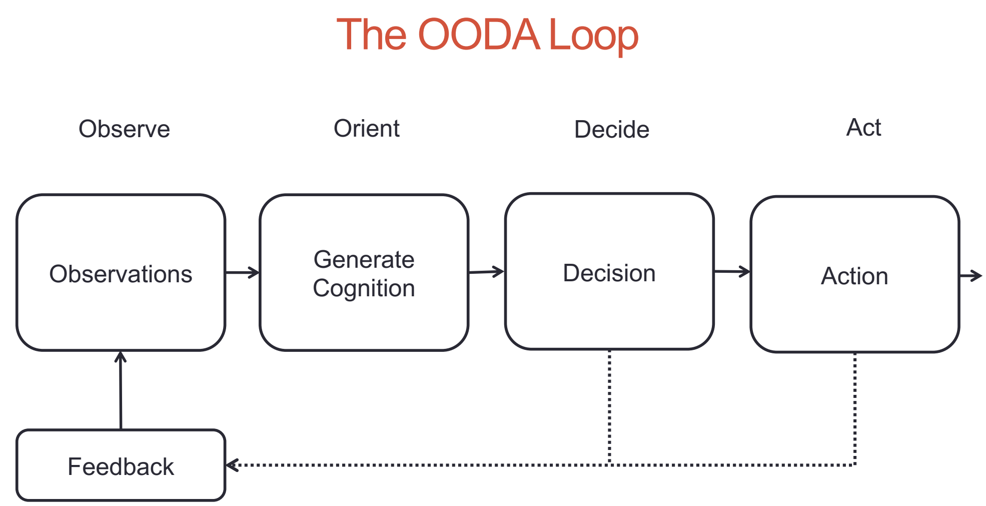


Figure 8. John Boyd's OODA Loop[15]

The OODA Loop was created by John Boyd, an American fighter pilot who took his highly acclaimed work on Energy Maneuverability and his dogfighting experiences to develop a response system that helps explain and model necessary actions in the fast-changing environment of aerial combat. To do this, he formed the OODA Loop through a synthesis of three theories (2nd Law of Thermodynamics, Godel's Incompleteness Theorems, and Heisenberg's Uncertainty Principle) that helped him infer that ambiguity and incomplete information always exist, and,

[15] Osinga, 2007.

because of this, a response (e.g., strategy, decisions, and actions) must account for this often overlooked reality.

Though Boyd's OODA Loop suggests it is a step-by-step process, Boyd actually envisioned it as a system where all parts of the loop run at the same time –that is, the response is not an "action, wait, and see" event but, instead, a continual process of adaptation. This makes the OODA loop a smart "learning" loop in which all parts are actively working together. Boyd asserted that, because the world around us is constantly changing, if a system disregards these changes for too long it becomes isolated and no longer in touch with reality. This results in a less than desirable response, because the system is no longer responding to actual or predicted future conditions.

To help overcome this problem of acting on stale or dated information, observation is necessary. This serves as the initial mechanism to help better align the perceived image of the world to reality. Here, outside information, unfolding circumstances, implicit guidance and control (feedback from the orientation stage to help direct sensors in order to obtain needed information), along with input from the other steps, are gathered. Once accomplished, this information is processed in the orientation stage.

Orientation is the process where information from observation is analyzed (i.e., deduced) and rebuilt (i.e., induced) to form a more accurate picture of reality. Boyd suggests that through orientating one may need specific information to help form the correct mental model. Thus, it is not enough to simply wait for the information to arrive but to actively pursue information when needed. Orientation's goal, then, is to take information and use it to adjust one's mental model of the world to better align it with reality. To do this, Boyd suggested a process called "destructive deduction," where a person breaks down his mental image into parts and, after applying the new information along with previous experience, cultural traditions, genetic heritage, and as many theories/fields of knowledge as possible, then builds a new mental model that more closely aligns with reality. It is this constant process of reorienting that helps to create a learning environment capable of higher levels of cognition. The general idea is to eliminate preconceived notions until evidence suggests otherwise. With a more informed and aligned mental image of reality, the next two steps are to Decide and Act.

The Decide and Act phases follow from orientation and consist of choosing actions most likely to achieve a decision maker's objectives; then, based on the hypothesis that these actions will achieve some desired effect, the actions are taken and the outcomes observed to see if the hypothesis is correct. Through this cycle of smart learning, the process repeats itself to become a continual process of adaptation. The faster a system can execute the OODA Loop processes, the faster the system can respond and adapt to events.

When taken holistically, the OODA Loop system is an overarching framework that provides a mechanism well suited for dealing with dynamic and chaotic situations where imperfect information exists. Through continual adaptation/learning (constant reorientation) from actively seeking needed information with sustained analysis and synthesis, the framework generates better and faster response actions. Such time critical actions are often vital in emergency situations where a catastrophe worsens exponentially with time.

Another aspect of Boyd's model worth mentioning is how the system helps to handle misinformation and situations where information overload exists. In his book, *Thinking Fast and Slow*, Danial Kahneman (2012) suggests that decision makers often weigh the last bit of incoming information too heavily, allowing it to skew their decision-making into a realm not supported by the majority of available evidence. March (1994) suggests that this also occurs when decision makers make less than optimum decisions due to not considering all available data; said another way, decision makers tend to consider only the data that best support their preconceived notion of reality (i.e., confirmation bias). Boyd addresses this negative behavior and suggests that, in order to overcome it, decision makers must use all available tools, including a study of mathematical logic, physics, thermodynamics, biology, psychology, anthropology, and game theory. He goes on to suggest that it is by such knowledge and study that decision makers formulate more mental models and, in so doing, are able to make better judgements that lead to better decisions.

4.1.3 Requirements Definition – Community Resiliency

In helping to define other factors impacting the emergency management system at the tactical (or lower levels), it is important to understand how the system interacts with environmental factors such as community attributes to form the basis for an effective response. Here, Lori R. Hodges (2015, p. 15) suggests fragile communities have a difficult time overcoming crisis. Fragility is defined as "a quality that leads to weakness or failure within a system, sometimes resulting in cascading effects (the domino) that can lead to systemic failures and collapse." She goes on to suggest that fragility is measured by three key community indicators: connectedness, stability, and sustainability. Each of these is further defined by four criteria. Holistically, these twelve criteria—derived from ecological, social, socio-technical, and complex adaptive systems—provide a systematic framework that can help evaluate and predict how well a local community will respond and recover to crisis. See Table 1.

Table 1. Causal Prediction Model of Community Fragility[16]

If	Then	Thereby
Community has no loss of leadership or a community lead during or after the emergency, and… Communities are not isolated, have multiple routes in and out, and work with neighboring communities, and… Communities have high social capital in the forms of trust in formal systems, a high degree of community engagement, and strong social cohesion, and… Communities use a hybrid approach to incident management through the use of 1) a formal incident management system to work with governmental entities, and 2) a collaborative approach using horizontal authority structures to ensure inclusion of non-governmental partners.	Community Connectedness is Strong	The community's overall fragility is decreased, leading to increased ability to recover, adapt, and gain strength before the next disaster
Communities have strong relationships with nonprofit, non-governmental, private sector and volunteer organizations, and… The emergency management structure involves key support hubs, or compartmentalization to ensure each priority can be met, and… Communities have strong leadership from both the informal community as well as the formal government structure, and… Communities have flexible and adaptable plans and procedures that are able to change as needed to meet the circumstances of the disaster.	Community Stability is Strong	
Communities have strong resources management plans, mutual aid agreements, and supply chain management procedures, and… Communities have redundancies and/or the ability to quickly recover the lost lifelines to continue efforts toward recovery, and… Communities are resilient through mitigation efforts, system redundancies, and strong community ties… Communities have systems in place to recognize small system disruptions or disturbances, reducing the chance of cascading or full systemic failures.	Community Sustainability is Strong	

[16] Hodges, 2015, p. 130.

4.1.4 Architecture Definition

Taking these three indicators along with other requirements (from above and those listed in Chapter 1) and expanding them across the whole of government at the tactical, operational, and strategic levels results in a system-of-systems architecture where individual systems and elements must all work together in order to mount an effective response. State-level elements often include the governor, emergency operations center, military forces, state/regional field managers, and cooperation agreements (e.g., Emergency Mutual Aid Compacts (EMAC)). Federal-level entities can include the President, FEMA, Emergency Support Functions (ESFs), the National Incident Command Center (NICC), and active duty and reserve military forces acting under the Stafford Act's Defense Support of Civil Authority (DSCA). Because of the complexity of so many interactions and interfaces among so many systems, systems engineering is a good discipline to use in seeking out valid solutions. Here, DeLaurentis and Calloway offer a system-of-systems framework that can help simplify the matter (DeLaurentis & Calloway, 2004).

The framework divides systems and/or components into six hierarchal levels—α, β, γ, δ, ε, and θ—starting at the lowest level (e.g., a house) and ending up at the highest level (e.g., an entire country). Hence, the α-level contains individual elements, followed by β-level that contains groups of elements, and so forth until ending up at the highest (i.e., θ-) level, which contains enterprise-level entities. Because it allows the user to decompose the system-of-systems into smaller groups of entities based on their operating levels, the framework clarifies how interactions occur across, up, and down at each level, thus helping to understand overall function. See Agusdinata (2006) for a good example of this framework, as applied to the energy sector. DeLaurentis and Calloway go on to suggest that when solving complex system problems, it is often difficult to make meaningful change by addressing entities only at the α-level. This is akin to designing trees and not the forest. Their suggestion resonates well with systems thinking that also emphasizes overall performance (i.e., the forest) in lieu of making changes at only the lower levels (i.e., the trees) that might do little or nothing to enhance overall performance. The framework is shown in Table 2.

Table 2. Hierarchal EERS Framework

Level	**Elements**				
α (house)	Fire Truck	Police Car	Medical Vehicle	Other supporting infrastructure	
β (neighborhood)	Fire Network	Police Network	Medical network	*Dispatch* *Call Center*	
γ (city)	All of Above Working Together		*Mayor* *Community* *Leaders* *Emergency* *Manager*	*Incident* *Commander* *(ICS/NIMS)* CIKR	Community: Connectivity Stability Sustainability
δ (county)	All of Above Working Together	*Emergency* *Operations* *Center* Local Executive Steering Functions (ESFs)	*County Sheriff* Joint Information Center	VOAD Gov't/Tribal *IMTs* Business/Supply Chains	Local Mutual Aid Agreements Title 10 Federal Military Forces (DSCA-IRA)
ε (state)	All of Above Working Together	*State* *Emergency* *Operations* *Center*	*State* *Governor* State Executive Steering Functions (ESFs)	*Regional Field* *Manager* *Dual-Status* *Commander*	EMACs Title 32 State- owned Military Forces
θ (federal)	All of Above Working Together	*NICC* Federal Executive Steering Functions (ESFs)	*President* *FEMA* NORAD NORTHCOM	Title 10 Federal Military Forces (DSCA)	Other National Level Assets DOE, DOT, DOJ, etc.

Italicized elements infer key decision-making areas

With normative guidance from the NRF and NIMs frameworks, and when simplified and presented as nodes along with common interfaces, the following architectural definition is developed. See Figure 9 below. Acronyms are presented in Appendix A.

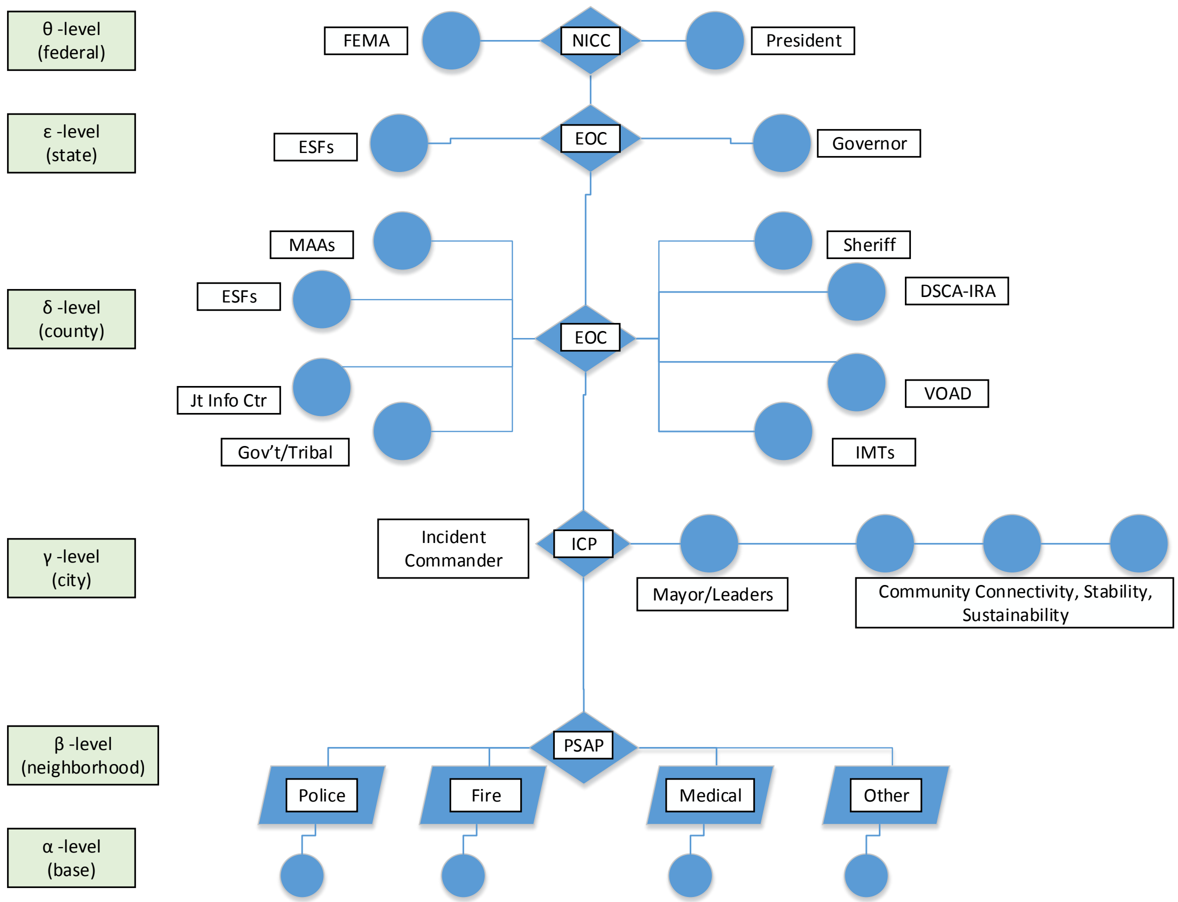


Figure 9. The Hierarchal EERS Architecture

The EERS architecture (shown above) must enable the system to respond to any and all incidents, regardless of size and complexity. For purposes of this research, incidents are defined as actual or potential emergencies and disasters resulting from all types of threats and hazards, ranging from accidents and natural disasters to cyber intrusions and terrorist attacks (Department of Homeland Security, 2013, p. 5). As such, and as suggested earlier, the EERS architecture provides a tailored, scalable, and vertically layered framework; and it is offered to become the nation's *modus operandi* to provide standardized command and management structures for use by all participating entities.

Based on the mantra that all emergencies start locally, the architectural framework is designed to start small and then grow based on an incident's severity and needs. Because daily incidents are usually small and easy to handle, the system's baseline operation (running 24/7) contains α and β-levels. Here, the people report incidents to the Public Service Access Point (PSAP), and the PSAP dispatches responders to the handle the situation. As incidents grow in severity, an Incident Command Post (ICP) is established, along with an Incident Commander (IC) to provide additional support. If even more support is needed, Emergency Operations Centers (EOCs) are activated to weld and integrate additional resources to meet the community's needs. At catastrophic levels where Presidential Disaster Declarations are made, federal-level entities such as FEMA and the NICC join the mix to help support the incident. See Chen, Sharman, Rao, and Upadhyaya for an explanation of the phases and goals of each level. Although preliminary research suggests that problems exist at the higher levels in the hierarchal system, this research will bypass them in favor of investigating α, β, γ, and δ-levels (i.e., up to and including the county levels), where research indicates the bulk of response activities occur in complex emergency events including what happened in the Waldo Canyon and Black Forest Fires.

4.2 Integration

This section integrates the requirements definition, architecture definition, and necessary functions and processes to build the EERS. This integration includes allocating functions to system elements (i.e., subsystems, components, controls, interfaces, and interactions). A SysML Activity diagram is used to show the EERS to include explaining system operation and the four process loops needed for the system to respond, adapt, and manage uncertainty associated with different types and severities of incidents.

4.2.1 Functional Allocation

As mentioned earlier, the four fundamental functions needed for a response system are: (1) an ability to observe/sense (i.e., detect the need to respond), (2) an ability to understand and characterize the observation in order to decide how to respond, (3) an ability to act (i.e., direct resources to physically conduct the response), and (4) an ability to garner feedback in which to refine the response as conditions change (i.e., to cycle back through steps 1-3). Here, systems engineering modeling language, or SysML, is an extension of the Unified Modeling Language (UML) that can help clarify how to build and understand systems operation and behavior (Holt & Perry, 2014, p. 23). Specifically, SysML suggests using an activity diagram to model the behavior of an object by capturing its condition and/or activities (p. 64-65). When applied to α, β, γ, and δ-levels (i.e., up to and including the county levels), the EERS is shown in Figure 10.

The subsystem's operation begins by observing using the (A) sensing and detecting component. This component consists largely of people who are responsible for reporting emergency situations as they deem appropriate. People report by dialing 911 that connects directly to (C) PSAP Call Center. Common situations reported are automobile accidents, medical emergencies, house fires, and other routine mishaps. The key interface is (B1) Communicate, which generally occurs through mobile cell phones or via Voice over Internet Protocol (VoIP) devices located in people's homes. Once the interaction is established between the caller and the call center, the call center enters into a Cognition Loop where it garners information so that it can understand the situation, orient itself, and then act by generating the appropriate response.

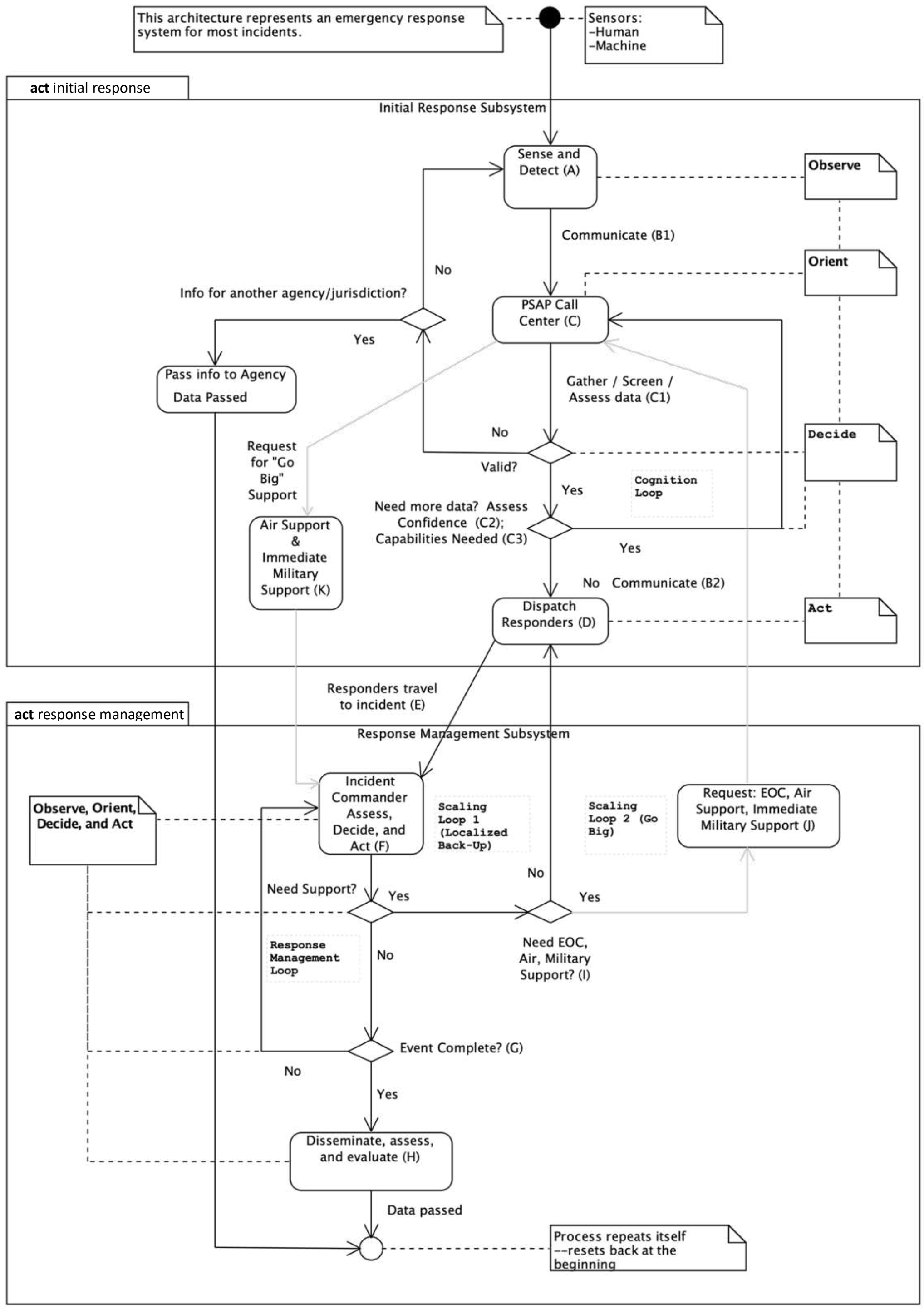


Figure 10. EERS Activity Diagram

4.2.2 System Operation—Interfaces and Interactions

The Cognitive Loop within (C) PSAP Call Center consists of two areas: (C1) Gather, Screen, and Assess, and (C2) Assess Confidence, in order to send the right response. The loop begins by gathering, screening, and assessing whether or not the call is valid. That is, the center conducts a preliminary analysis to determine if the caller is reporting a valid situation requiring a response, or if the call is a prank, a non-critical event, or something for another jurisdiction/ agency to assist. If the call is deemed valid, the loop continues with (C2) Assess Confidence.

(C2) Assess Confidence addresses that portion of the OODA Loop's Orient function by seeking to obtain as much pertinent information about the situation as possible in order to determine (1) the timeframe for the response, and (2) the appropriate size/scope of the response. By asking the caller questions about the location, type, and size of the situation, the Call Center increases its confidence about the event at which time a determination is made as to the number and types of responders needed to help quell the event. When the caller is vague or unclear as to what is happening, either more time is needed to probe the caller for more information, or more time is needed for other callers to report to provide additional information. In either case, more information equates to more confidence, and more confidence equates to more discernment when deciding whether to respond or not.

If or when the determination is finally made to generate a response, the response is sent via (B2) Communicate to (D) Dispatch Responders. Here, (D) Dispatch Responders include a variety of first responders (e.g., fire, police, and medical) who can handle a variety of events, and, because of this, the response usually consists of a predetermined set of these response capabilities depending on the typical needs of the event. For example, the standard response for a backyard barbecue fire might be a fire truck; the average car accident might require two police cars, an ambulance, and a fire truck; a medical situation might dictate only an ambulance with associated medical technicians. In some specialized events, such as where a motorcycle or bicyclist is hit by a car, the standard response might also include a helicopter to airlift victims to the hospital, as experience suggests these types of mishaps require patients to receive advanced medical treatment along with faster transport to associated facilities. In the end, a certain degree of confidence is needed to act, and obtaining this confidence often means asking for, or sometimes waiting for, the right pieces of information to arrive. These delays, again, are the result of the PSAP Call Center's need for confidence to act as determined by the event's severity and associated costs of waiting. Once a decision is made to act, responders then (E) Travel to the Incident. This, too, takes some time, depending on mode of transportation, distance, speed, and obstacles encountered along the way such as traffic and road conditions. Having completed the Initial Response Subsystem as responders travel to the incident, the Response Management Subsystem begins when the responders arrive at the scene.

Arriving at the scene, the response team designates an IC, and, if complex enough, an ICP. The IC is selected based on the type of incident and the responders with the preponderance of forces. The ICP supports the incident and can be as simple as the IC's vehicle, or a specially designed vehicle that contains a variety of communication devices, planning features, and other support equipment.

Since this subsystem also involves a response, another OODA Loop begins with the IC's arrival. Here, just as explained earlier, the Response Management Loop is continual but will be explained in sequence for simplification. The first step is to observe, followed by to orient, then to decide, and then to act. In doing so, the IC begins this process upon arrival at the scene by observing and orienting to assess the situation.

Accomplishing this is generally easier for simple incidents where getting "eyes on" equates to good understanding and confidence. In other cases, such as a complex event (e.g., an active shooter situation) getting “eyes on” might still result in low understanding due to the larger span of geography making it difficult to see the entire area, high numbers of people and congestion adding confusion to the melee, and/or quickly changing event dynamics that make staying abreast of the situation difficult. In these cases, the IC must decide whether to continue the response with the resources currently on the scene or to increase (or decrease) the size of the response by scaling it as needed. When scaling, two loops are generally used: (1) Scaling Loop 1 (localized back-up) and (2) Scaling Loop 2 (Go Big) to obtain those assets requiring higher levels of authorization and/or shared assets located outside the immediate area that require additional coordination.

Scaling Loop 1 is used to obtain local back-up in order to increase the size of a response when conditions warrant. In most cases, the IC simply requests (on its own authority) additional fire, police, and/or medical support that is readily available in the IC’s jurisdiction. This is witnessed daily as police call for backup even with routine traffic stops, or when firemen call for additional tankers/fire support when the situation dictates.

Scaling Loop 2 is used to obtain more specialized support such as activating the county’s EOC, or requesting air support (e.g., for evacuation from a vehicle accident), firefighting air tankers, or military support as authorized by the Stafford Act’s Immediate Response Authority. Other requests go to federal level entities, such as when requesting to use a federal Incident Management Team (IMT) specially trained to manage complex incidents that often exceed local expertise and/or capabilities. In these cases, the IC’s request for support routes through the PSAP Call Center (C) and follows established protocols to receive authorization and approval for the necessary support. In some cases, these requests route through the sheriff’s office, or through other government offices, to also authorize funding before permission is granted to use such capabilities. Thus, Scaling Loop 2 usually takes longer to complete, not to mention the time after approval that it takes for these assets to travel to the scene (in the case of air and military support), or in the case of activating the EOC, the additional time needed to notify personnel, have them arrive at the EOC, and then begin operations.

As the OODA Loop is executed and the response scaled accordingly, integration of assets and resources becomes critical so that the response is effective based on response priorities and incident dynamics. Here, the Response Management Loop follows the OODA Loop construct with focus on integration of, for example, manpower and assignments; facilities and vehicles; food and water; internal communications needed for response teams; external communications to convey instructions for the public; orchestration of community businesses, Red Cross, and volunteer groups; and the need to coordinate with other jurisdictions. The orchestration of all of these resources is based largely on a spirit of cooperation among actors, using a command-and-control construct called unity of effort. In this construct, there is no single commander given sole authority to exercise these assets; instead, the different actors are chartered to work together toward a common goal with a shared understanding. Hence, as long as the decision makers are able to achieve shared goals and understanding, the construct can work. As explained later, however, the construct has occasionally not worked due to lack of consensus, and when the construct does fail, it often results in catastrophic outcomes. The Response Management Loop continues until it is deemed by the IC that the event has ended, at which time the system resets and starts over again. In some cases, an event hotwash is conducted in the aftermath to Assess, Evaluate, and Disseminate (H) any lessons learned from the event. It is with this understanding of EERS operation that some specific system functions and needs are addressed in the next chapter.

CHAPTER 5: VERIFICATION OF EERS FUNCTIONS AND PROCESSES

This chapter verifies the EERS to gain confidence that its design and functions can meet requirements before proceeding to validation. To do this, the verification uses WUI fires as an exemplar, based on their applicability to other, similar complex events. The chapter contains three sections: Section 1 describes WUI fire behavior and environmental factors; it then determines and verifies the impact of time on the detect, initial attack, and scaling loops contained in the EERS. Section 2 verifies the Response Management Subsystem, which orchestrates and integrates the response from the time when first responders arrive on scene through the event's conclusion. Here, the OODA Loop is examined specifically in relation to this subsystem's functions. Section 3 combines findings from the first two sections and then correlates them to verify overall emergency response system functions, operations, and processes discussed in Chapter 4. The verification identifies and prioritizes critical system attributes, operations, and processes necessary for the EERS to achieve expected performance parameters. When necessary, findings from the verification are used to modify EERS design to make it more effective. Later in Chapter 8, the findings are also used to inform the system's operational concept that explains how the system will be employed in complex incidents to meet stakeholder requirements.

5.1 Verify IRS Operation

This section addresses complex event behavior through the lens of the EERS responding to WUI fires and environmental aspects. This verification is used to help identify the most important design features needed to generate an effective response, and to verify those features are present in the EERS design. Addressing specific WUI aspects of firefighting is important, because the WUI environment places a strong emphasis on working to preserve the land, infrastructures, and lives, generally demanding a complicated and time-sensitive response. Most, if not all, of these WUI firefighting aspects (involving thousands of people and over a hundred organizations) are also needed to respond to other complex events. The United States Coast Guard suggests that 80 percent of response operations share common principles and procedures—the other 20 percent are unique to the type of incident, such as rescue or oil spill (United States Coast Guard, 2014, p. 1-1). This suggests that some unique response considerations are necessary for atypical events – yet most events follow similar protocols. This fact was also asserted by Donahue and Tuohy (2006) who assessed a whole host of different complex events seeking to find out why the same (or similar) response problems occurred over and over again. They concluded that there was a striking consistency among all complex events that involved major categories of identified problem areas (p. 5). Hugelius and Adolfsen (2020) go even farther after having investigated 20 different complex events suggest five similar challenges that pertain to all mass casualty and disaster events – event identification and associated uncertainty, solving the mismatch between the established contingency plan and reality, establishing a functional (i.e., integrated) crisis/response organization, adapting the medical response to meet needs, and ensuring a resilient response. Because of this evidence, and because in-depth analysis conducted on the two WUI fires revealed complex behavior, using WUI fires as an example scenario to build an emergency response system is logical.

The analysis uses an Input – Process – Output (IPO) model. The model's inputs are the independent variables; the model's processes are the WUI fire behaviors and environment factors; and the model's output are the dependent variables that are associated with response effectiveness. Table 3 shows the IPO model and associated variables.

Table 3. IPO Model and Associated Variables

Independent Variables (Input)	WUI Fire Behavior and Environmental Factors (Processes)	Dependent Variables (Output)
Detection & Initial Attack		
	Type/Dryness of Fuel	
		Acres Burned
	Slope	
Command, Control, and Communications	Humidity	Infrastructures Lost
	Wind	
Resources	Temperature	Fatalities/Injuries
	At Risk Infrastructures	
Training, Preparation, and Planning		Response Costs
	At Risk Population	
EOC Support		

Like many other complex emergency events, fires generally get worse with time. They are largely characterized by the fire's ability to grow (a function of the type of fuels, slope of the terrain, wind direction and intensity, and temperature) and the ability of the fire to impact what is most important: people, infrastructures, and the environment. In considering this, dead-fallen dry timber along with dry brush and/or grass are usually very ripe for fire; moist/wet conditions, such as live trees with healthy canopies, are less ripe. Slope of terrain also impacts the fire's speed, as a ten percent increase in slope can double the fire's ground speed. Humidity, temperature, and wind are also large factors where dry, warm winds both fan (i.e., increase oxygen flow) and blow burning embers well ahead of the fire line, thus greatly propagating the spread. In other cases, winds blow a ground fire up into the tree-tops (i.e., the crown), thus making the fire more difficult to extinguish, even with air tankers delivering retardant.[17] All of these factors, taken together with the associated costs to displace a large number of people and the large amount of destruction to WUI homes and infrastructures, create a high motivation either to prevent WUI wildfires, or when prevention is not possible, to have a response system capable of meeting demands.

To more fully understand this motivation, it is helpful to address how complex events such as WUI fires propagate over time. Studies have shown that fires, when left alone, grow exponentially (Ramachandran, 1982). That is, a fire that consumes five acres in ten minutes will double that size (i.e., consume ten acres) over the next ten minutes. Thus, the fire follows a second-order growth pattern as shown in Figure 11, below. The data shown in Figure 11 begin with a small five-acre fire at one-hour which then grows to over 2,500 acres just ten hours later. While the time lapse data of one hour used in this diagram does not wholly represent the Waldo Canyon or Black Forest fires, the Waldo Canyon fire generally followed this growth profile, consuming over 4,000 acres in roughly 20 hours; both fires on occasion grew even faster than this rate due to strong winds that created spotting (i.e., embers blown out in front of the fire that rapidly increase fire spread) (Department of Commerce, 2015). The 2020 Cameron Peak fire is a more recent example that far exceeded the 2nd order growth pattern, consuming 78,000 acres in

[17] Air tankers drop retardant (called "slurry," a mixture of water and fertilizer) onto a fire from above. The retardant is usually placed in strategic areas to control or to slow down the fire allowing other ground-based assets to become more effective. In addition, retardant it is not as effective extinguishing elevated fires (e.g., fires located in the crown) than in combatting ground fires. (Paul Delmonte, personal correspondence, July 12, 2014).

just 3 days (United States Forest Service, 2020). Winds exceeding 70 miles per hour were a significant contributor to the rampant spread (Countryman, 1966).[18]

<u>Figure 11. Second-Order Fire Growth Pattern</u>

Considering the growth pattern shown above, the easiest fire to extinguish is the fire that has not yet started; thus, prevention is the best approach. However, as is witnessed each year, wildfires are prevalent and likely becoming more prevalent, as global warming is leading to more extreme drought and weather events. This is also true of large, complex events in general (Zebroski, 2019).[19] If true, then preparing for and having the ability to respond to such events is also becoming more and more important.

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[18] Wildfires and their ability to spread quickly is dependent on a variety of factors. Countryman offers an interesting article based on environmental considerations.

[19] High-impact, low probability threats are routinely attributed to an increasingly and interdependent world.

As stated earlier, because these events generally get worse with time, the sooner a response is generated, the smaller the impact (e.g., the fire), and thus the easier it is to control and eliminate (i.e., extinguish). Response time, then, is a critical factor. And, because of the way a fire propagates, response time is more important earlier in the event than later, because of the limited time that exists soon after the fire starts, when it is still possible to control and extinguish the fire with available resources. After this time expires, the fire grows so large that the available resources are no longer sufficient to suppress the fire, leading to an out of control situation. The upshot is that the need to get sufficient response resources fast enough on the scene is a fleeting opportunity, and once that opportunity is gone, it is no longer about extinguishing the fire but about trying to manage the situation in hopes of minimizing its impact. Since there is such a high dependence on time and effectiveness/adequacy of response, the independent variables of detection, initial attack, and communications are of vital importance.

When considering where and how these three variables fit into to the EERS (see Figure 12, reprinted here from Chapter 4), two observations are made and verified: (1) Any problems occurring in these (or other related) system functions propagate delays downstream, serving to increase overall system response time, and (2) because of the criticality of time in responding to a fire, any proactive measures taken early to ensure adequate response resources arrive on the scene sooner are helpful.

The first observation relates to “getting enough, soon enough” onto the fire. Doing so is largely the responsibility of the Initial Response Subsystem (IRS). That is, the subsystem’s ability to Sense and Detect (A); Communicate (B1 and B2); exercise the Cognition Loop to Gather, Screen, and Assess Data (C1); and then evaluate Confidence to dispatch the Needed Capabilities (C2) for the response. Thus, it is critical these system components and processes operate effectively, efficiently, and quickly. Of note, this is one of the most difficult system areas to accomplish in complex events due to the large amounts of uncertainty, disjointed information, and surprising situations that accompany them (Donahue & Tuohy, 2006).

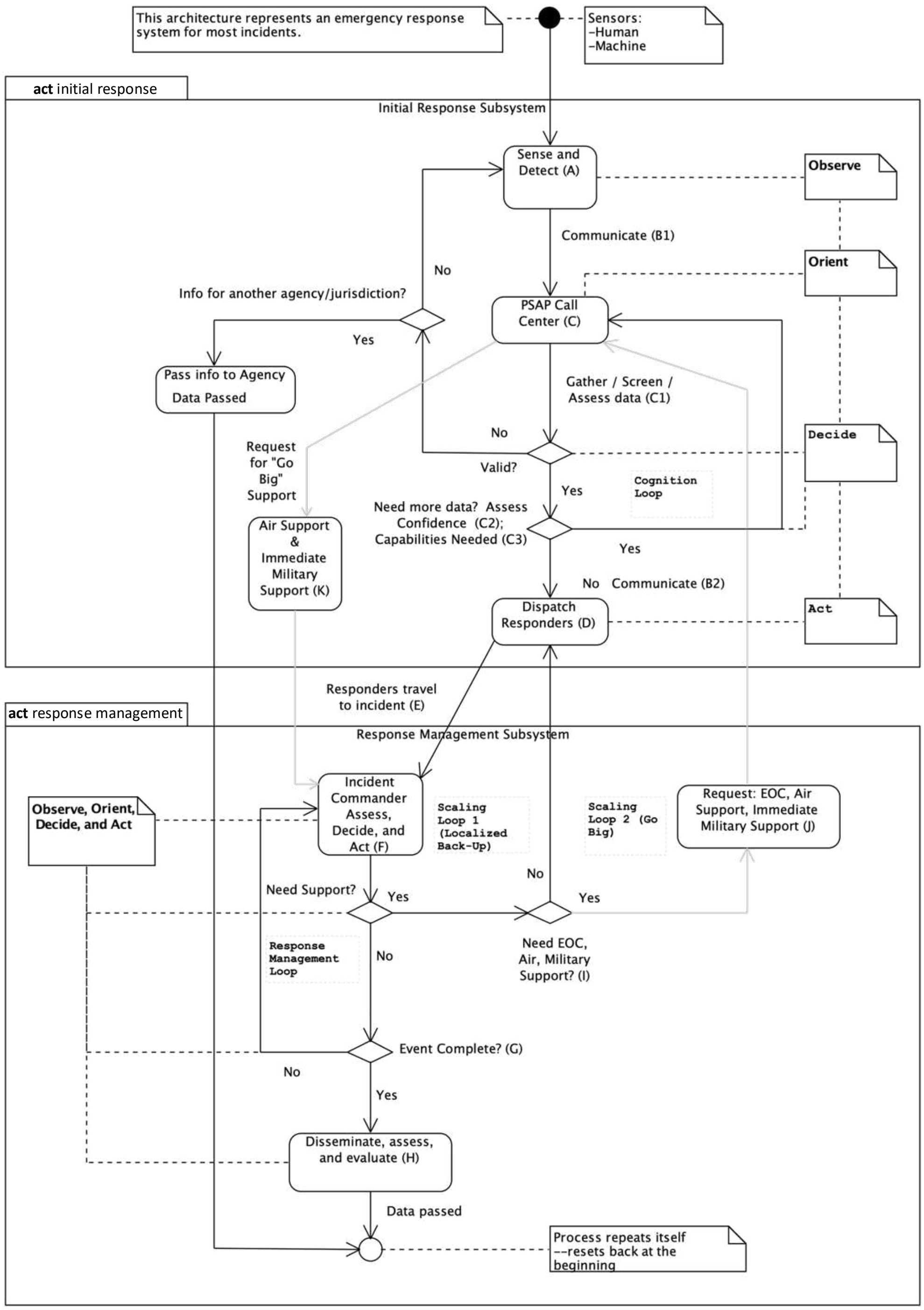

Figure 12. EERS Activity Diagram

The IRS Subsystem is constructed mostly in series, requiring that outputs from components leading to response actions be accomplished sequentially. This type of architecture propagates delays and/or failures downstream, such that a delay and/or failure occurring in one part of the system cascades to other processes and components, thereby degrading overall system operation. This problem area is thus verified; and it will be shown later in Chapter 8 that the EERS will overcome this limitation by using smart learning and adaptable architectures to transform from series into a parallel configuration when needed.

The second observation is that once the first responders arrive on the scene and the Response Management Subsystem begins, the time required to make any adjustments to resources and/or needed capabilities that were missed or not addressed earlier in the IRS also hinder the response. These adjustments are made in Scaling Loop 1 and/or Scaling Loop 2. The purpose of the scaling loops is to provide an ability to grow the response in the event the IRS underestimated the situation. To be effective, the scaling loops must execute fast enough for additional resources to arrive before it's too late to control the situation. Accomplishing this task in a timely manner is often difficult to achieve due to the availability of assets and needed travel time.

Because of the potential for these delays to occur, a proactive approach is necessary to ensure that adequate resources arrive on the scene at the start. Here, the PSAP Call Center (C) can make sure that sufficient capabilities arrive quickly without the use of scaling loops—thus helping to make certain the situation is successfully managed (i.e., the fire is controlled and extinguished)—verses taking the chance that it might grow out of control and result in higher losses. It must be recognized that taking proactive actions to ensure adequate resources raises the possibility for over commitment of resources and resulting cost increases. Sending too many responders and resources to a single event could also sacrifice the system's ability to handle other incidents simultaneously, should they occur. Thus, a cost/benefit calculus is needed to achieve a reasonable balance between (1) risk for an out-of-control event and its potential impacts and cost, and (2) the need to hold resources in reserve to respond to other events if necessary.

The diagram shown in Figure 13 depicts these benefits (or costs) of achieving (or not achieving) this balance. The diagram contains four different lines – No Resources, Not Enough (resources), Adequate (resources), and Abundance (of resources). The No Resources line is used for comparison and follows second-order growth as described earlier in Figure 11. The Not Enough line depicts the case where responders arrive at the scene without adequate resources, and even though scaling occurs later, it is too late and/or inadequate, resulting in a fire that grows into an out-of-control situation. As the fire gets bigger, the resources needed to adequately combat it are not available, so the fire continues to propagate. The Right Sized line depicts a response where adequate forces respond and arrive on the scene in time to control and extinguish the fire. In this case, the fire initially expands before forces arrive, but once they are on the scene, the forces are able to limit the fire's growth to the point where the fire is no longer expanding at a rate greater than their suppression. This results in the fire getting smaller and more manageable over time, and as fuels and heat deplete, the fire is eventually extinguished.

The last line, Abundance, occurs when more than enough resources are dispatched to the scene so that the fire is contained and extinguished even faster. This response limits damage and destruction to the greatest extent; the extent depends on the fire's characteristics, accessibility of its location, and the actual amount of excess capacity. Accessibility is a key factor, because it can limit how many responders can gain access to the site, possibly leaving some resources sitting idle as the fire expands. This was not observed in either the Waldo Canyon or Black Forest fires, but in some difficult to reach events access could be limited. In the end, this verifies that the EERS' objective of striving for adequate resources and numbers of responders and, when in doubt, to "go big" with a proactive approach is appropriate. When situations occur where this objective is not met, scaling is helpful provided it is done quickly enough for additional responders and resources to arrive in time to gain control of the situation.

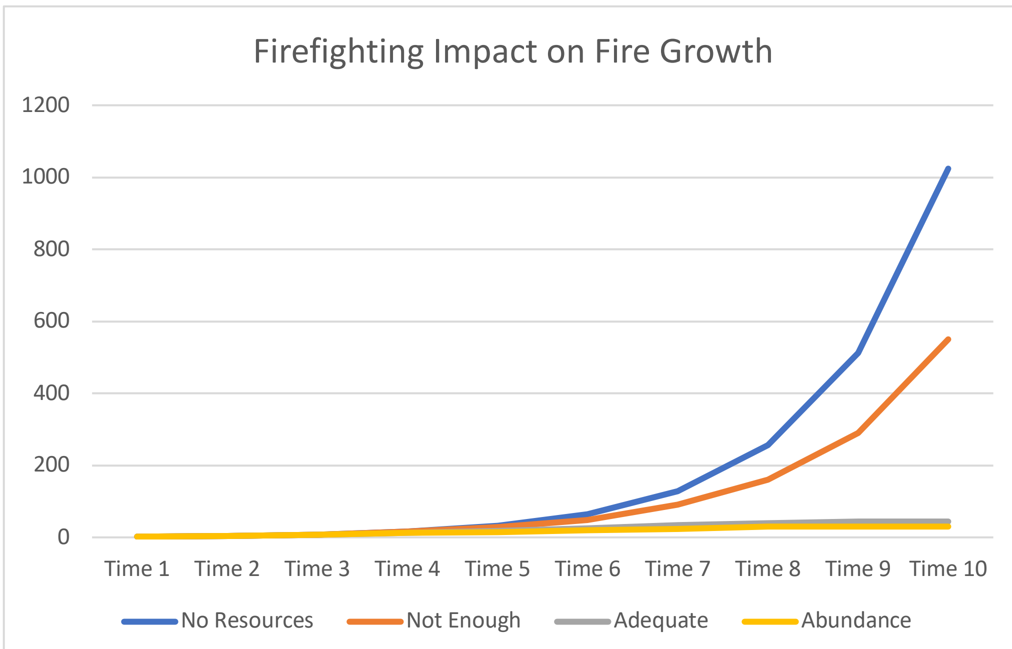

Figure 13. Firefighting Impact on Fire Growth

If it is critical to dispatch adequate numbers and types of responders quickly to the fire, then it follows that dispatch should not wait to gain more confidence before deciding to dispatch. Waiting only serves to delay, and delays, as discussed earlier, lead to a worsening situation. And if waiting to gain increased confidence still resulted in the need to execute scaling loops to further tailor the response, even more time would be needed before adequate forces could arrive to mount an effective response. The upshot is that rushing to the fire with limited responders and then scaling is a better option than waiting to act in hope of receiving more information to build more confidence. This suggests getting "eyes on" the situation quickly (even with small numbers of responders) and then adapting is better than waiting to generate the perfect plan. This is also deemed better because the National Fire Danger Rating System suggests that different resources and equipment are needed for an adequate defense, depending on flame length and fire line intensity (Andrews & Rothermal, 1982). Thus, getting "eyes-on" early to acquire real-time situational awareness may need to happen regardless of circumstances, to make sure of having the right types of resources and equipment at the outset, and also requesting additional responders soon after, or at least staging additional resources in case they are needed. This offers increased confidence by verifying EERS functionality provided the aforementioned cost-benefit calculus is supportive.

5.2 Verify RMS Operation

Having verified the Initial Response Subsystem and the importance of time and resources based on complex events such as WUI fire propagation and behavior, this section verifies the Response Management Subsystem, which relies heavily on integration, teamwork, and sustainment for its operation. This subsystem is of critical importance, as is it is not enough to just have responders arrive on the scene; rather, mounting an effective response requires proper orchestration of the responders to generate a successful outcome. Refer to Figure 12.

The Response Management Loop that resides within the Response Management Subsystem contains the OODA Loop actions taken by the IC along with all other supporting elements to execute the response. Within this loop special emphasis is placed on four requirements that enable the system to function as an integrated team of responders with associated resources. The four requirements are: (1) command, control, and communications;

(2) resources and equipment; (3) training, preparation, and planning; and (4) support and sustainment as provided by the Emergency Operations Center.

The first requirement for effective Response Management Loop function is command, control, and communications. This requirement is somewhat different from the command and control executed in the Initial Response Subsystem, due to the increased emphasis now placed on forming the response team, learning, adapting, and executing the response. As mentioned earlier, complex events are often rapidly changing, and, as such, demand that OODA Loop processes keep up with event dynamics (Zebroski, 2019).[20] This requires fast feedback via observation and orientation (e.g., understanding) so that correct decisions are made and communicated. As actions are made, feedback is necessary to confirm efficacy or to change direction in hope of improvement. To accomplish this, the command and control construct must support this type of behavior. Here, centralized and decentralized command and control schemes are worth mentioning.

The centralized command and control approach generally encourages decision makers to observe from a distance and then actively order subordinates to react based on their understanding of the situation. This approach requires a fast OODA Loop with reliable communications so that timely instructions and feedback can be passed up and down the supervisory-subordinate command chain. At the other end of the spectrum is decentralized command and control. Here, decentralized decision-making structures rely on delegating authority to subordinates to act consistently with the supervisor's general intent. The intent is general in nature, usually specifying a desired outcome. The subordinates then use their authority along with the supervisor's intent to decide how best to accomplish the task. In his

[20] Failures can quickly cascade across interdependent systems of systems causing a domino effect of problems to services such as electricity, water supplies, communications, and transportation.

book *Command in War*, Van Crevald (1985) suggests there are no one-size fits all typologies. He goes on to suggest that each situation is different and should use a command and control construct based on event and decision maker requirements.

When considering such requirements for complex events such as WUI wildfires, what is clear is that communications are often saturated, strained, and/or unavailable. This occurs due to loss of mobile/cellular networks (e.g., the fire is located in secluded areas) or terrain features that hinder line-of-sight between cellular devices and the network, making communications impossible. Such failures are common -- communication failures are evident in most complex events (Hugelius et. al, 2020). This communication failure and/or degradation necessitates a command and control framework that can still function when such failures occur. This alone also necessitates that authority flow down to those on the scene where the action is taking place (Turoff et. al, 2004). These facts suggest that the EERS use a decentralized command and control framework that favors subordinates following intent using mission-type orders (or something similar) that is better suited. Mission-type orders provide the who, what, where, and when but not the how. This allows subordinates to decide how to accomplish the task based on the situation and/or changing event dynamics. This approach does not preclude feedback and centralized direction when communications allow —It serves only to enable the system to perform across a variety of complex events without the heavy reliance on communications that is needed for the centralized command framework, a framework that will likely falter when instructions and feedback do not get received.[21]

[21] The concept of mission-type orders is grounded in the German word *auftragstaktik*. The main thrust of the idea is to give a subordinate a mission, and then allow them to determine how best to carry it out. To do this, the subordinate must have the skills, training, and resources to accomplish the task—of which must be learned and/or provided beforehand.

Another facet of command and control is the spirit of cooperation. This requirement is hugely important due to the Incident Command System's dictum that unified command concept is the only specified command concept for large, multi-jurisdictional incidents (United States Coast Guard, 2014, p. 5-2). This dictum prevents one person from taking responsibility for the entire incident, but, instead, allocates authority across the leaders of the different jurisdictions (i.e., in the Unified Command structure) so that each has an equal voice in the response. Because there is no way to force these different leaders to comply with a specified course of action, or to make them do anything against their will, the only method of gaining their cooperation is through rigorous collaboration and/or compromise.[22] Working via collaboration produces a shared understanding that leads to shared goals and objectives. Collaboration is more than coordination and cooperation—it is mutual agreement to work *together* on the same tasks (Turoff & White, 2008). Once this is achieved, the leaders are able to agree on a course of action, consolidate resources, and accomplish the task. Achieving this collaboration depends heavily on forming strong relationships, trust, and confidence —all of which take time to create.[23] Because large, multi-jurisdictional incidents do not occur often enough to forge these relationships, they are best formed intentionally before a complex, multi-jurisdictional event occurs. There is simply not time to build the relationships, trust, and confidence once a large, complex event begins. The relationships must already be established. Recognizing this, EERS leaders across jurisdictions must build the necessary relationships via meetings, training events, and large exercises so that the EERS and its elements can work together, learn, and adapt in complex and chaotic situations.[24]

[22] The members of the unified command must make the system work.
[23] Failure to achieve this results in big problems, as evidenced in Donahue and Tuohy (2006) and again in Hugelius & Adolfsson (2020).
[24] For a systematic approach to achieve this, see Donahue and Tuohy (2006).

The second requirement is resources. Resources come with the responders and have differing qualities in terms of mobility, range, and functionality, depending on the type of responders those resources accompany. Responders can be categorized generally as fire, police, and medical, each with its own types of resources: Firefighting resources include fire engines, tenders, hand crews, bulldozers, brush trucks, helicopters, and air tankers. Police resources include squad cars, riot control gear, swat teams, and search and rescue teams. Medical resources generally include ambulances and, when needed, air evacuation; hospitals and medical clinics, when required, are extensions of on-scene medical resources.

Most response resources, by necessity, have some degree of mobility in order to travel to the scene and operate. Firefighting resources generally have the most mobility and range in order to access backwoods logging roads and other difficult to reach areas where forest fires generally occur. They must carry a large portion of their food, water, equipment, and gear into these areas so they can mount an effective response without being immediately dependent on others. Of course, prolonged responses require sustainment. In order to provide the most capability to combat a wide variety of fires, multi-functional equipment is used to reduce the amount of equipment.[25] This also reduces weight and eases transport.

The third requirement is training, preparation, and planning. This area goes beyond just training to do a specified task or to comply with accepted standards, but to also integrate with other response elements as part of a larger, collaborative effort. Large, multi-jurisdictional events such as combatting WUI wildfires require teamwork, and teamwork is best garnered beforehand by exercising required command, control, communications; learning mission-type orders; working in cross-integrated teams; and seeking feedback so that responders learn how to work

[25] A firefighter's special hand tool is called a Pulaski. It is both an axe and a mattock—able to chop wood and also dig soil based on its multi-functional design.

together overcome difficulties. As mentioned earlier, this breeds trust and confidence among team members to work toward shared objectives rather than each individual's concerns.

The fourth requirement is the system's ability to sustain the response effort. Here, the EOC's job is to support (e.g., garner resources, provide communications support, and provide necessary care and feeding to responders) (Donahue and Tuohy, 2006).[26] The EOC accomplishes this through close communication with the IC along with predicting the IC's needs, so that anticipated resources are available and ready when needed. Accomplishing these tasks necessitates that the EOC have a good understanding of the immediate situation; management capabilities to request, contract, and track resources; and adequate communications across the plethora of agencies supporting the incident. In sum, the EOC plays a critical part in generating an effective response, possessing the same spirit of cooperation, shared understanding, and shared goals/objectives as the other team members.

5.3 Verify Premises to Inform EERS Design and Operation

This section verifies emergency response premises for EERS design and operation. It accomplishes this by combining the findings from the two preceding sections, then correlating them to what occurred in the two fires, to show necessary how the premises function when responding to complex events. The correlation helps to identify and prioritize critical system attributes, operations, and processes and serves to help premises addressing EERS functionality and performance parameters needed to handle complex incidents. Please see Table 4.

The priorities listed in the table—Very High (VH), High (H), and Moderate (M)—are based on discussion points made in Sections 1 and 2. For instance, time-based components and processes are deemed a very high priority because of their criticality in responding quickly with

[26] For more on EOC functions, see United States Coast Guard, 2014.

enough resources to control the event. Failure to achieve this kind of response often results in much higher damages and costs (Shen & Shaw, 2004). Scaling loops are deemed high priority, as their timely use allows for quick adaptation if other time-based components and processes prove inadequate.

Table 4. Priority Response Factors For Complex Events

Response Area	Independent Variables	Associated Components and Processes	Priority (VH/H/M)	Rationale
Speed of Response	Detection	Sense and Detect (A)	VH	Time
		PSAP (C, C1)	VH	
	Communications (IRS)	Communications (B1, B2)	VH	
		Dispatch (D)	VH	
Initial Attack Response Effectiveness	Initial Attack	Confidence (C2)	VH	Time
	Resources (Adequate)	Initial Capabilities	VH	
	Resources (Scaling)	Scaling Loop 1	H	
		Scaling Loop 2	H	
Response Management Effectiveness	Command and Control	Response Management Loop	H	Integration
	Communications		H	
	Spirit of Cooperation		H	
	Resources Applied Holistically		M	
	Training/Preparation		M	
	EOC Support		M	

(VH-Very High, H-High, M-Moderate)

Response management effectiveness areas of (1) command, control, communications, and (2) spirit of cooperation are also deemed high because they provide the mechanisms for smart, adaptive learning and teamwork, and effective execution of the response.[27] Other response management areas are rated moderate as they, too, are very important, but they do not prohibit a response. Instead, they serve to enhance response effectiveness, helping to spur

[27] The need for a smart system that can learn and adapt is well established in complex event response literature. (Turoff et. al., 2004; Turoff & White, 2008).

integration and sustainment. From the above table, and from discussions presented earlier in this chapter, the following premises are offered in Table 5.

Table 5. Verified Premises for EERS Design and Operation

#	IF:	THEN:	RATIONALE:
P-1	Response time decreases	Probability increases for less damage and a better outcome	Complex events generally get worse with time.
$P\text{-}1_{A1}$	Detect time decreases	Response time decreases	Provided rest of IRS (e.g., cognition loop) remains constant
$P\text{-}1_{B1}$	Cognition loop time decreases	Response time decreases	Provided rest of IRS (e.g., observe/detect) remains constant
P-2	Adequate Resources Respond	Response effectiveness increases; probability increases for less damage and a better outcome	Cause and effect
P-3	Response effectiveness increases	Probability increases for less damage and a better outcome	Cause and effect
$P\text{-}3_{A1}$	Team Integration increases	Response effectiveness increases	Enhanced teamwork and shared goals
$P\text{-}3_{B1}$	Command, Control, and Communication integration increases[28]	Feedback and awareness increases	Mandates communications; active participation
$P\text{-}3_{B2}$	Feedback and awareness increases	Knowledge increases[29]	Cognitive processes occur
$P\text{-}3_{B3}$	Knowledge increases	Better decisions[30]	Cognitive application
$P\text{-}3_{B4}$	Better decisions	Response effectiveness increases	Cause and effect

These premises are incorporated into the EERS design and functionality, and they help to verify the ability of EERS to meet requirements. The next chapter presents empirical data from the two fires to further understand how El Paso County's emergency response system operated

[28] "The key obstacle to effective crisis response is the communication needed to access relevant data or expertise and to piece together an accurate understandable picture of reality" (Turoff et. al., 2004, p. 10).
[29] Information sharing on its own accord does not necessarily improve situational awareness. Here, too much information distracts users, lowers situational awareness, and hinders performance. Thus, the goal is to find a balance between sending pertinent, needed actionable information that is pushed down to users and the need for higher levels of command to obtain the needed information to make more informed (and effective) decisions (Buchler et. al, 2016).
[30] Sophisticated learning that is associated with gaining knowledge requires synthesis and evaluation. This requires time for individuals to reflect and make cognitive associations (Donahue and Tuohy, 2006, p. 26).

when facing two complex events. This data is used later in Chapters 8 and 9 to validate the system.

CHAPTER 6: EMPIRICAL ANALYSIS OF TWO FIRES

With an understanding of how the EERS functions and operates from Chapter 4, along with more in-depth analysis and verification conducted in Chapter 5, this chapter analyzes two recent disasters occurring in El Paso County that significantly stressed the region's response system: the Waldo Canyon and Black Forest fires. Each fire was categorized at the time as the worst fire in the region's history, and, because of the magnitude of the fires, each provides good insight into how the response system functioned under a stressful scenario (State of Colorado, 2013).[31] By comparing the responses to the two fires and their associated outcomes, conclusions are made as to what worked, what did not, and the extent to which each system component contributed in mounting an effective response. In Chapter 8, these shortfalls are prioritized based on Chapter 5's criteria, and then EERS solutions are offered showing how the EERS' operation corrects the deficiencies identified in the current chapter and, thereby, are an improvement in response system performance.

6.1 Approach

The discussion begins with the Waldo Canyon Forest fire, its associated facts, and the specific areas where the system excelled or broke down. Upon investigation, the analysis is decomposed into six areas that include (1) detection, (2) command and control, (3) resources, (4) preparation and planning, (5) support as provided by the EOC, and (6) communications. After the Waldo Canyon discussion, the Black Forest fire is dissected in a similar manner. As both fires are discussed, key elements from each are compared and contrasted in order to determine

[31] The Waldo Canyon fire's total cost was estimated at $15.7 million, and the Black Forest fire's total cost was estimated at $13 million. Yet at the time, the Black Forest fire was deemed the single most destructive fire in Colorado history based on residential properties lost (State of Colorado, 2013, pp. 1, 7).

what elements were most important in bringing forth a successful response, what elements hindered the response, and how such elements interacted within the system.

6.2 Waldo Canyon Fire

The Waldo Canyon fire burned from June 23 to July 10, 2012. Over the course of these 17 days the fire consumed 18,247 acres, destroyed 347 homes, and killed two residents (City of Colorado Spring, 2013, p. 5). The fire took place in El Paso and Teller counties, an area consisting of multiple jurisdictions, a variety of federal, state, and private lands, and the largest city in the region, Colorado Springs (population 403,000). Of note, Colorado Springs accounted for 70% of El Paso County's population of 575,850, of which 36,000 homes are located in the wildland-urban interface(El Paso County, 2008, p. 17). Because the fire threatened these homes, it was classified as a "wildland urban interface (WUI)" fire. This definition is important, because it indicates increased complexity by necessitating the evacuation and sheltering of citizens, the relocation of domestic animals, and — within available resources — the prioritizing of saving lives, homes, and infrastructure. Clear and concise communications are needed to direct the resources while also providing support to the local community.

Accomplishing these tasks is easier in slow moving fires, because they are generally more predictable. Thus, they allow decision makers more time to gather information, respond, and inform the community to take proper action. In essence, slowly changing conditions decompress the decision-making timeline, so that more communication can occur among key actors. More communication results in better understanding, and better understanding results in better decision-making. Unfortunately, the Waldo Canyon fire was anything but slow and predictable.

The hallmark of the Waldo Canyon fire was its ability to change directions fast and burn large areas quickly. The antithesis of stability, the fire shifted, changed directions, and did the unexpected as decision makers stood in wonder. This behavior was most prevalent on five consecutive Red Flag Warning days (June 23 thru June 27) (City of Colorado Springs, 2013, pp. 11-33).[32] During this period, low humidity combined with high temperatures and erratic winds set conditions for rapid ignition and propagation. If the five Red Flag days were not already difficult enough, the other "non-Red Flag" days still provided tough conditions, as excessive heat and strong winds (up to 65 mph) spurred the fire onward (City of Colorado Springs, 2013, p. 30).[33] Together, these tough "day-after-day" conditions created an unpredictable fire that would demand a highly structured, integrated, and well exercised response system to bring it under control. Qualities such as anticipation, accurate and timely observation, quick decision-making, and a plethora of networked and organized communications and fast response resources were needed to save the day. Yet careful analysis of after-action reports and news articles suggests that if these qualities were present, few were there from the onset, and many were absent throughout.

6.2.1 Detection

The effort to locate the fire began on June 22, 2012, at 7:50 PM, when the El Paso County Sheriff's Office received a phone call reporting smoke just north of Cave of the Winds in the Pyramid Mountain-Waldo Canyon area. After more reports followed, four fire departments and the El Paso County Sheriff's Wildland Crew drove to the area at 8:22 PM in search of the fire. Because the fire was located on United States Forest Service (USFS) land, the USFS owned

[32] Wikipedia defines: "A Red Flag Warning also known as a *Fire Weather Warning* is a forecast warning issued by the United States National Weather Service to inform area firefighting and land management agencies that conditions are ideal for wildland fire combustion, and rapid spread. After drought conditions, when humidity is very low, and especially when high or erratic winds which may include lightning are a factor, the Red Flag Warning becomes a critical statement for firefighting agencies."

[33] Large thunderstorm clouds formed above the fire, and when the updrafts collapsed, the downdrafts created winds upwards of 65 mph (p. 30).

jurisdiction and took command of the incident at 8:36 PM. The USFS called it "Pyramid Command," and the teams set out on foot to locate the fire. At 9:48 PM, with darkness falling on the region, and having not yet found the fire, the USFS released all county resources with the aim of trying again the following morning (El Paso County Sheriff's Office, n.d., p.1).

The search resumed the next morning (June 23rd) at 6:48 AM by USFS and Cascade Fire Department personnel. Later, at approximately 12:00 noon, the El Paso County Sheriff's Dispatch received more reports of smoke that, when relayed to Assistant Deputy Fire Marshall Campbell, caused enough alarm that he requested air support at 12:20 PM. Soon after, Campbell again ordered additional resources and activated the EOC. With the additional reports, fire fighters were able to home in on the fire and, once on scene, conclude that the fire threatened the communities of Green Mountain Falls, Chipita Park, and Cascade, all of which were ordered to evacuate. Up to this point, approximately 16 hours had elapsed from the initial report.

Because small fires are easier to extinguish, the faster firefighters can find a fire the less chance it has to grow out of control. Hence, the fact that the Waldo Canyon fire burned for 16 hours before it was found is a serious problem that needs to be addressed. In after-action reports and news articles, three reasons were generally offered. First, the El Paso County Sheriff's report suggested that incoming calls contained conflicting information: Some callers were saying the fire was on the south side of Pyramid Mountain; others were reporting the fire on the north (El Paso County Sheriff's Office, n.d., p. 16). Not knowing exactly where to look in difficult-to-access forest land sent the limited number of responders on a wild goose chase. The second reason blamed the dispatcher who received the initial call. It was found that the dispatcher did not initially send the information on to the sheriff's fire center, thus delaying the response (Gabbert, 2013, May 1). The final reason focused on jurisdictions: The fire was located on

USFS land, and, because of this, it was not the local authorities' responsibility to combat it.[34] Thus, there was not a sense of responsibility and/or urgency from local teams to find the fire. Considering that several local teams initially responded in search of the fire, this argument seems flawed. On the other hand, the teams went home at dusk at the request of USFS command. And calls for air support from local authorities — support that could have helped find the fire — were non-existent. It was not until approximately 12:00 noon on June 23 that USFS requested air support. This was well after the fire was located and long after the initial reports received from the day prior (El Paso County Sheriff's Office, n.d., p. 2). Making matters worse, the first air tanker did not show up until approximately 08:23 AM on June 24, some 36 hours after the fire was first reported. In the end, all three factors help explain the excessive delays. According to reports, the USFS' first assessment of the fire occurred at 00:17 AM on June 24th, with some 4,000 acres burning (El Paso County Sheriff's Office, n.d., p. 2). The fire had grown large because too much time was taken by inadequate firefighting resources trying in vain to locate and extinguish it. It would now take a much larger effort to save lives, homes, and infrastructure as the fire raged out of control.

6.2.2 Command and Control

With the fire located, a multi-jurisdictional firefighting command and control system was implemented in accordance with the NRF and ICS.[35] Under the unified command concept (i.e.,

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[34] According to the Annual Wildfire Operating Plan for El Paso County (El Paso County Colorado, 2011): "The El Paso County Sheriff is ultimately responsible for fire control on all unincorporated, non-federal, lands within El Paso County. On federal lands, the agency charged with managing those lands is responsible for fire control" (p. 10). After this, general procedures are outlined below: all dispatches will go to the closest responders (p. 8). Later, "…all agencies shall send forces promptly to start suppression action unless it is clearly and mutually understood that one agency will promptly attack and/or follow through on all necessary action" (p. 14). "If after being notified, the jurisdictional agency does not or cannot respond to the fire, then the assisting agency may be reimbursed for costs incurred" (p. 14-15).

[35] ICS is the accepted command/control system for use in El Paso County among responders (El Paso County Colorado, 2011, p. 13).

multiple entities working together, each with their own command), the USFS took overall command of the incident, the Colorado Springs Fire Department established their command and staging at a nearby Safeway grocery store, and El Paso County established a Type 3 IMT, which included USFS personnel, at a local Christian center.[36] Because of the fast moving nature of the fire, the USFS requested help from a Federal Type 1 IMT at 3:00 PM on June 23rd (El Paso County Colorado, 2011).

The Type 1 team arrived a day later and was commanded by Rich Harvey. All affected jurisdictions except the City of Colorado Springs provided Harvey with their objectives and delegated local firefighting resources for his use (City of Colorado Springs, 2012, p. 21).[37] Harvey's Type 1 team, coined the Great Basin IMT, was one of only 16 nationally designated teams specifically trained to handle large-scale complex disasters.[38] With delegation letters signed, and armed with firefighting crews, Rich Harvey took command of the incident at 06:00 AM on June 25th.

Although Colorado Springs retained control of its firefighting capabilities, the city wanted a coordinated response between city and Type 1 responders, so Colorado Springs Mayor Bach assigned Steve Dubay (the Colorado Springs Fire Department Branch Director) to act as a liaison with the Type 1 team (City of Colorado Springs, 2013, p. 16). It was suggested that Mayor Bach wanted to retain his forces, because he didn't fully trust Rich Harvey to properly

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[36] An IMT 3 team normally consists of about 30 people and has an incident commander along with operations, plans, finance, and logistics section chiefs. Other leaders can also be included that focus on communications, food, medical, supply, public information, and safety (El Paso County Sheriff's Office, n.d.). Emergency Management, All-Hazards Type 3 "Incident Management Teams Are Catching On," Retrieved November 11, 2014, from http://www.emergencymgmt.com/disaster/All-Hazards-Type-3-Incident-Management-Teams.html.

[37] All CSFD resources remained under CSFD control except three CSFD task forces that were assigned to the Type 1 team.

[38] Type 1 IMT is defined as: "a Federally or State-certified team; is the most robust IMT with the most training and experience. Sixteen Type 1 IMTs are now in existence." Retrieved December 27, 2014, from http://en.wikipedia.org/wiki/Incident_management_team

allocate the city's resources. If the city were compromised, city residents might well voice outrage (Zubick, 2012, p. 7).[39] In the end, this was a chance Mayor Bach could not take. But his decision to retain forces bifurcated the region's resources, resulting in a situation where there were not enough resources to meet the wants/needs of the city (as determined Mayor Bach) and the wants/needs of the region (as determined by Rich Harvey).

If the NIMS' unified command construct were working properly (i.e., with all parties working together for the common good), retaining control of one's own assets would have been workable, because each party would give and take to accomplish the overall goal. In the case of the Waldo Canyon fire, however, the situation was so dynamic that the paradigm backfired. Here, city decision makers not trained in firefighting could not keep up with the rapidly changing conditions (Zubick, 2012, p. 7).[40] The upshot was a mismanaged fire response: Some areas (i.e., Cedar Heights) were over-allocated with firefighting resources, while others (i.e., Mountain Shadows) were grossly under-allocated (Gabbard, 2013, April 5). Hence, some fire fighters were severely overworked, while others sat idly by (Zubick, 2012, p. 3). In the end, houses burned while city decision makers tried to develop and execute a late-to-need evacuation plan that left two people dead in the Mountain Shadows area.[41]

Another area deserving discussion is the disjointed information that flowed from the city's Policy Group to the residents. The Policy Group (consisting of elected and key officials) attempted to give accurate and timely information to those affected by the fire (State of Colorado, 2013). The Policy Group held *ad hoc* meetings for the first two days of the fire, but

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[39] In a July 16 interview, Mayor Brown said that no one else would have control if the fire crossed into Colorado Springs.
[40] Brown did not have a day-to-day presence at the ICP – instead he relied (as did other officials) on daily reports.
[41] The two deaths were a husband and his wife assigned to Schriever Air Force Base that died after helping neighbors evacuate (Zubick, 2012, p. 1-2).

then formalized meetings daily before 08:00 AM press conferences. During these meetings, the Group was briefed by Type 1 agency representatives on the latest situation updates (City of Colorado Springs, 2013, pp. 21-22).

As the fire destroyed more and more homes, the Policy Group wanted to meet with the fire's victims (in person) to provide them information about their loss. After discovering that this was practically impossible because accurate contact data did not exist for their whereabouts, the Group discarded the idea and turned its attention to informing affected residents at a public meeting (City of Colorado Springs, 2013, p. 39).

The public meeting was advertised, and it convened at 8:00 PM on Thursday, June 28th at the Gallogly Events Center. Approximately 4,000 residents attended (City of Colorado Springs, 2013, pp. 39-40. Other than failing to answer some residents' questions regarding what properties were actually destroyed, the meeting was generally considered a success (pp. 40-41). The most pressing unanswered question was how to allow the residents back into the area to visit their properties.

Because of safety concerns, the Policy Group devised a plan to bus residents to their properties. The plan would allow city officials to control access while providing oversight to assure the residents' safety. The plan was communicated to affected residents via email, and a press conference was scheduled so that officials could convey the plan to residents who lacked email. Before the press conference occurred, however, the Group changed its decision based on new information that suggested the plan would create more problems than it would help. The Group quickly abandoned the idea in favor of allowing residents to visit their home sites unescorted. This change was announced at the scheduled press conference (City of Colorado Springs, 2013, pp. 43-46).

There is little doubt that the Policy Group had good intentions by trying to help victims in a personal and meaningful way. It is also clear that the Group didn't think things through very well, because they often had to rethink, revise, and re-communicate. This disjointed discourse created confusion and, ultimately, it fostered distrust on behalf of the residents as officials changed their stories. More predictable and consistent messages would have helped breed more trust. Whether the Group tried to glean lessons from past fires before rushing to make these decisions is unclear. Neither is it clear how much situational awareness the Group actually had at the time. What is clear is that the Group did not provide a clear and consistent message to the public.

6.2.3 Resources

Resources used in the Waldo Canyon fire can be classified into four public areas (city, county, state, and federal) and one private area (private and/or non-governmental organizations). As stated earlier, the USFS and county fire department crews responded first to locate the fire. Once the fire was found on Day 1 (June 23rd), more resources were added: the EOC, Colorado Springs Police, the County Animal Response Team, the Humane Society, the American Red Cross, and the Young Man's Christians Association. Congressman Cory Gardner requested support from Colorado's Emergency Fire Fund.[42] In response, the Colorado State Fire Service took responsibility and authority for fighting the fire. But since the fire was already on Forest Service land, this was inconsequential as the Forest Service already had jurisdiction (El Paso Colorado, 2011, p. 10, 19). As the fire grew on Days 2 and 3, a Federal Type 1 IMT was delegated authority to take charge of the incident, and the El Paso County Sheriff requested 60

[42] The fund was bankrupt until Lower North Fork Fire mandated response funds. $13 million was allocated to the fund, which was used to help pay for Waldo Canyon (Senator Kent Lambert, personal correspondence, September 14, 2014).

additional officers from the Department of Corrections to help with security. On Day 4 a call went out at 5:11 PM from the El Paso County Sheriff's Wildland Crew Superintendent asking all Fire Task Forces from across the county to assemble at the firebase. Soon after this, the EOC requested help from Pueblo, Colorado for all available fire resources. On Day 6 Colorado National Guard forces helped with trail and road closures. On Days 8 and 9, electric and gas companies assisted in the effort. Later, on Day 15, inmates helped fill 5,000 sandbags for use in the burned areas (El Paso County Sherriff's Office, n.d., pp. 1-6).

While the above resources are certainly not all-inclusive, available after-action reports all mention similar resources and levels of interaction. Of note, it is not mentioned in any report that active-duty or reserve military forces were used to help combat the fire. This is important, because the Air Force Reserve owns C-130 firefighting tanker aircraft based at Peterson Air Force Base (AFB), Colorado, very close to the fire (Gabbert, 2014).[43] These aircraft might have been especially helpful finding, extinguishing, and/or controlling the fire in its early phases. According to the Stafford Act, Federal military forces (either active-duty or reserve) can be used after a presidential emergency declaration, but this declaration did not occur until late on Day 6, after Colorado Governor Hickenlooper declared the area a state disaster on Day 5 (City of Colorado Springs, 2013, p. 41). The other way to request help from local military bases is through the Stafford Act's provision of DSCA as defined in Department of Defense Directive 3025.18 called Immediate Response Authority (IRA). This provision allows local city/county officials to ask local bases for assistance. Provided the request meets the prescribed guidelines, the base commander can order military assets to help/support local responders (Department of

[43] The USFS' wildfire air tanker fleet has grown much smaller recently—from 44 in 2002 to only 9 in 2012. In 2012, just over 900 requests were made for air tankers, yet only about half were supported due to lack of assets.

Defense, 2010).[44]

Also not mentioned is the fact that private mining companies offered the USFS bulldozers during the early stages of the fire to create fire-lines — swaths of land that contain little to no fuel (i.e., trees and other cover) — that could help contain the fire. The idea is to use bulldozers to make these swaths in front of the fire in hope of keeping the fire at bay by making it difficult for the fire to jump across the swath and continue to spread. Large bulldozers are vital to this effort, as they can clear large lanes quickly across rough terrain. Yet the USFS denied the mining companies' offers for jurisdictional reasons —i.e., it was USFS' responsibility to decide what would and would not be done (El Paso County Colorado, 2011, p. 8). Later, when the fire was headed toward the privately owned 53-year-old Flying W Ranch, the ranch owners requested the mining companies' bulldozers to create a fire-line and save their land. Here again, the USFS denied the request. The ranch was later destroyed.[45]

From the above discussion, it is clear that the public city/local community took the brunt of fighting the Waldo Canyon fire. Other public help was provided from federal and state entities (in the form of a Federal Type 1 IMT, state emergency Fire Fund monies, state National Guard forces, and perhaps some air tankers that arrived later, but, outside of this, external support was minimal. Some private/charitable organizations helped, yet other private organizations volunteered and were turned down by those in charge (e.g., no mining bulldozers allowed to help

[44] The guidelines are as follows: "In response to a request for assistance from a civil authority, under imminently serious conditions and if time does not permit approval from higher authority, DoD *(Department of Defense)* officials may provide an immediate response by temporarily employing the resources under their control, subject to any supplemental direction provided by higher headquarters, to save lives, prevent human suffering, or mitigate great property damage within the United States. Immediate response authority does not permit actions that would subject civilians to the use of military power that is regulatory, prescriptive, proscriptive, or compulsory." (Page 4) "Support provided under immediate response authority should be provided on a cost- reimbursable basis, where appropriate or legally required, but will not be delayed or denied based on the inability or unwillingness of the requester to make a commitment to reimburse the Department of Defense." (Page 5).
[45] (Senator Kent Lambert, personal correspondence, October 2014).

combat the fire). In sum, it was the nexus of local firefighting forces and community actors working together — many times independently — and in the face of jurisdictional problems, that ultimately constituted the bulk of the response.

6.2.4 Preparation and Planning

Prior to the Waldo Canyon fire, several county plans existed: (1) The 2008 El Paso County All-hazards Pre-Disaster Mitigation Plan, (2) The El Paso County Emergency Operations Plan, (3) The El Paso County Community Wildfire Protection Plan, and (4) The 2011 El Paso County Annual Wildfire Operating Plan. Because these plans are addressed in Appendix D on El Paso County, they will not be covered here. Instead, this section will discuss how plans and exercises impacted the conduct of the response, as revealed in reports and news articles.

Interestingly, Waldo Canyon fire after-action reports contain no evidence that El Paso County had any of these plans. One plan that was mentioned was the City of Colorado Springs' WUI Appendix to its 2008 Emergency Operations Plan, revised in June 2012 (City of Colorado Springs, 2013, p. 59). Lessons documented in the city's after-action report reveal that while this plan existed, it was not fully developed or exercised with community partners. Later, the report goes on to say that when the fire occurred, the plan was underutilized. This likely resulted from the lack of participation and follow-on engagement from the plan's stakeholders. The report also stated that inadequate staffing and training were commonplace, with the result that some workers were overworked to the point of exhaustion, while others were not trained to execute their assigned duties (p. 60).

Notwithstanding the lack of planning, the city (and county) had implemented response programs to help residents prepare for a wildland fire. The residents in Cedar Heights and other WUI areas were asked by the city of Colorado Springs to participate in voluntary training evacuations in 2009 and 2011. The city also offered education, mitigation outreach, and Citizen Emergency Response Training (CERT) programs to help residents prepare. At the same time, El Paso County offered programs to help residents rid their properties of yard waste, slash, and other fuels. It also established the Firewise Program designed to educate residents on creating fire-defensible space on their property (El Paso County Sheriff's Office Emergency Services Division [ESD], 2011, pp. 39-41). The effectiveness of these efforts is difficult to appraise in the aftermath, yet reports generally suggest the programs were effective. A lesson gleaned from the fire was the need to find additional ways to motivate more members of the community to participate in these programs. One method offered was to solicit community volunteers and conduct an outreach focused on their neighbors. This approach, based on pre-existing relationships, would provide a personal touch and help motivate residents to prepare for catastrophes (City of Colorado Springs, 2013, p. 63).

6.2.5 Support (as provided by the EOC)

The EOC was activated on June 23d at 12:49 PM, and its responsibility was to support first responders by helping manage resources and plan/coordinate the overall response. Throughout the incident, the EOC struggled to maintain situational awareness, with the result that it had difficulty responding to changing dynamics. To some extent, this occurred because EOC workers lacked necessary organizational skills and training. For example, they didn't construct fire response charts that could have helped EOC personnel know who to support and their associated needs. Additionally, EOC workers were not familiar with checklists, so that many were not used. This often resulted in required actions getting overlooked. The upshot was that some EOC decisions were made in error, and others were not coordinated or aligned with the Incident Commander's priorities. This, when combined with outdated and slow equipment, and insufficient staffing, resulted in lackluster support. Even arranging to have first responders' meals delivered — a key EOC support function — went unanswered (City of Colorado Springs, 2013, pp. 67-70).

Because of the EOC's lackluster performance, responders were forced to bypass the EOC and fend for themselves. In short, instead of letting the EOC support system work as designed, responders had to short-circuit the process by going directly to the source. This ad hoc approach increased responder workload, as everyone was forced to coordinate autonomously. With communications already saturated and degraded, this additional burden served only to frustrate the overall response (City of Colorado Springs, 2013, pp. 67-68).

6.2.6 Communications

In addition to the communications issues already discussed, three more problems are worth discussing, as they led to communications difficulties between incident commanders, the EOC, and other participating/support agencies. These problems include: (1) failure of Communication Unit Leaders (COMLs) to complete an ICS 205 multi-agency communications plan, (2) failure to plan for sporadic or non-existent wireless connectivity in the fire area west of Colorado Springs, and (3) failure to plan for a Joint Information Center (JIC).

The first problem was the failure of COMLs to develop an ICS 205 communications plan. ICS 205 plans are very important, because they allocate radio frequencies and associated communications nets to responders (City of Colorado Springs, 2013, p. 55). COMLs are charged to develop ICS 205 plans along with managing computers, networks, and radio/phone systems. In the Waldo Canyon fire, the Incident Command System did not assign COMLs to all operational periods of the incident. Without COMLs assigned consistently to the response effort, no holistic plan was developed or executed. This also meant that no one was routinely assigned to fix broken communications equipment. The end result was more communications problems that created more confusion (City of Colorado Springs, 2013, pp. 54-44).

The second communications problem was sporadic or non-existent wireless connectivity on the west side of Colorado Springs. Unaware of the poor connectivity beforehand, several incident command posts had to relocate after having spent precious time and effort to set up shop. In one case, the Type 1 IMT's command post was forced to vacate Holmes Middle School (initially chosen because of its proximity, size, and accommodations) soon after bedding down, due to inadequate wireless service (City of Colorado Springs, 2013, p. 55). In another case, the Colorado Springs Police Department's command post moved six times due to space requirements, lack of connectivity, and needed proximity to other commands. In both of these cases, the failure to ensure (or establish) connectivity before bedding-down detracted from the main effort (City of Colorado Springs, 2013, p. 77).

To prevent relocations due to non-existent or degraded service, wireless carriers often add capacity by deploying a mobile cell tower to the area. These mobile units have internal power supplies designed to operate in remote areas with little or no outside support. In the Waldo Canyon fire, mobile cellular equipment was added (after the Type1 IMT vacated Holmes Middle School), yet it was later found that the additional capacity boosted signals only for its own network. This left many users still without service. In the end, communications are a vital necessity in emergency response and, had planners examined the area for sporadic connectivity before the fire, a solid plan could have been devised and implemented beforehand to avoid wasting time and effort (City of Colorado Springs, 2013, pp. 55-56).

The final problem was the failure of authorities to plan for a JIC. A JIC is the key node that provides a single source of information from decision makers/leadership to the general populace. This communication normally takes place in the form of press conferences, newspaper articles, and a variety of social media. Here, the JIC serves as the single entity responsible for collecting, consolidating, and distributing information so that a clear and consistent message is sent to the public. This capability is important to avoid the confusion of different agencies broadcasting different stories.

Yet the city and county had no pre-established plan to use a JIC. When the fire broke out and there was an overarching need to provide information to the public, officials were forced to either broadcast information *ad hoc* or activate a JIC. Rightly so, authorities decided to form a JIC, but because it was not planned or exercised, its activation created much confusion among public information officers (PIOs). PIOs were unsure what processes to use to integrate and disseminate information. Making matters worse, the designated facility had not been properly equipped to handle complex communication needs, nor was it located in close proximity to the EOC, thus making it difficult for PIOs to stay abreast the fast-changing events (City of Colorado Springs, 2013, pp. 85-87). All in all, the *ad hoc* JIC served its purpose, but not without having to overcome significant challenges.

In the end, poor communications led to increased confusion during the Waldo Canyon fire. The lack of dedicated COMLs led to a non-existent ICS 205 communications plan. Poor wireless connectivity degraded communications, forcing many commands to relocate several times. By the time additional cellular resources were added to the area, signals were boosted, but not enough to make a significant difference. Communication with the public via a JIC was mostly an afterthought. PIOs and staffers struggled with insufficient communication lines in the JIC, while their displacement from the EOC and front-line responders made getting current information problematic. The bottom line is that emergency response communications were not fully thought out beforehand, and once the response began, several key pieces remained missing. With adequate preparation, planning, and investment, many of these problems could have been avoided. When done properly, responders can devote more of their time and resources to fighting the incident, rather than trying to fight the communications system.

6.2.7 Waldo Canyon Fire Conclusion

In conclusion, the Waldo Canyon fire presented a challenging scenario that stressed the emergency response system to its limits. While much went right in the response, much also went wrong. Deficiencies were found in detection, command and control, resources, preparation and planning, the EOC, and communications —and these deficiencies, summarized in Table 6, below, all stymied the system's overall effectiveness. The discussion now turns to the Black Forest fire to see how the region responded to another catastrophe less than one year later.

6.3 Black Forest Fire

The Black Forest fire erupted on June 11, 2013 and burned for ten days. The event occurred less than one year after the Waldo Canyon fire, and, like the Waldo Canyon fire, was classified as a WUI fire because it threatened a large number of homes and infrastructure in the area. Because of this, emergency responders were faced with a complex situation as the fire threatened to take lives, destroy houses, and devastate infrastructure. This mandated evacuations, setting up shelters for people and their animals, and taking other measures to limit the fire's impact on the community. Similar to Waldo Canyon, this additional complexity stressed the entire response system to the brink of collapse. When the fire was finally extinguished, it had consumed 14,280 acres, destroyed 489 homes, and killed two people. Firefighting costs and associated damage were $9.829 million, or $688.31 per acre (El Paso

County Sheriff's Office, 2014, p. 46).[46]

Table 6. Summary of Waldo Canyon Response Deficiencies

Area	Observations
Detection	- 16 hours / Lack of resources to search - Garbled communications & information - Jurisdictional issues - Late to get air support
Command and Control	- Delays in establishing command - Coordination problems – 2 fatalities - Unified command did not work well - Poor use of resources due to lack of situational awareness - Policy Group out of touch / mix-up in communications / lack of consistent message
Resources	- Mostly local responders - Late disaster declarations - Late support from Feds - Jurisdictional limitations prevented full use of available resources - Some private organizations stymied
Preparation and Planning	- City plan existed, but not coordinated or exercised - Positive efforts were made to prepare residents for fire in Cedar Heights / other WUI areas
EOC	- Not ready for prime time; poor training and equipment
Communications	- No plan to assign COMLs to ICS - No ICS 205 comm plan - No plan to deal with limited wireless - No plan to use a JIC - Ad hoc reactionary approach came up short in most cases

Other than on Day 1, June 11, 2013, the Black Forest fire was generally more predictable than the Waldo Canyon fire. This lone exception occurred soon after the fire was discovered, at about 2:30 PM, when a windstorm blew the two-acre ground fire into the crown that traveled from tree-top to tree-top at a rapid pace. Winds carried embers up to a mile ahead of the main body of the fire, igniting not only tree-tops but also small ground fires, as burning debris fell down into the dry, hilly terrain. This, along with weather conditions particularly ripe for fire

[46] In 2013, the national average cost for over 47,000 documented fires was $255 per acre. Here, over 1,541 homes and buildings were destroyed (p. 46).

growth (95 degrees Fahrenheit and 4% humidity), caused firefighters to pull back as the fire blew past established fire lines (El Paso County Sheriff's Office, 2014, p. 3, 8, 9). Especially difficult conditions (i.e., defined as Red Flag conditions) also existed on Days 3 and 8.

6.3.1 Detection

Unlike the Waldo Canyon fire, which took 16 hours to locate, the Black Forest fire took only about two hours. Authorities started receiving reports of smoke and fire at 11:54 AM. Because another fire was burning in the Royal Gorge area outside Canon City, Colorado (some 40 miles away), and because smoke from this fire was blowing into the Black Forest area, initial reports contained conflicting information that made it difficult for Dispatch to determine if the smoke was coming from the local fire (yet to be located) or from Canon City. Thus, no responders were dispatched. Later at 1:42 PM, the Air Force Academy control tower reported smoke in the area around New Life Church. This report, when followed with additional calls of smoke in the vicinity of Shoup Road and Highway 83, provided enough confirmation to dispatch responders at 1:43 PM and find the fire only 6-7 minutes later (KKTV, 2014). Responders arriving on the scene reported a ground fire 2-3 acres in size with smoke and winds gusting up to 15 mph (El Paso County Sheriff's Office, 2014, pp. 7-8). At about this time, two heavy tankers and two helicopters with dip capability were ordered (KKTV, 2014, p. 3).[47] At 2:03 PM, Chief Bob Harvey (referred to as Chief 700 of the Black Forest Fire Protection District, and no relation to Rich Harvey, who led the Type 1 IMT for the Waldo Canyon fire) took command with at least 22 units in the immediate area (El Paso County Sheriff's Office, 2014, p. 8).

The ability to quickly find the Black Forest fire was due to several factors: (1) the ease of accessibility to the area, (2) the persistent reporting and updates to Dispatch, and (3) the amount

[47] Though ordered, no air resources were immediately available as they were already tasked to the Royal Gorge fire outside Canyon City, CO.

of resources in the immediate area. The ease of accessibility to the area not only allowed responders to get to the scene quickly but also allowed for more people traveling through the area to take note of the fire and report it. With more people reporting the fire, Dispatch was continually updated on the situation, forming a more accurate picture of the fire's exact location. This, in turn, allowed responders to zoom onto the scene in single-digit minutes without having to comb the countryside. When combined with the large number of local responders immediately assigned to protect the area on a daily basis, the odds of locating and extinguishing the fire were high from the start. In fact, had the windstorm not occurred just as responders started to combat the fire, or had requested air assets been immediately available, it is possible the fire could have been quickly controlled and contained (KKTV, 2014, p. 3). Unfortunately, this was not the case.

6.3.2 Command and Control

Because this fire occurred on 95% private and 5% state/government owned lands, the USFS was never considered for taking command of firefighting efforts (El Paso County Sheriff's Office, 2014, p. 42). Instead, local responders initially took charge and then yielded responsibility up the chain as better prepared authorities arrived on scene. In this manner, Chief Bob Harvey took command at 2:03 PM and then, at 4:49 PM, delegated command to Assistant Fire Marshall (FMO) Scott Campbell leading a newly formed Type 3 Incident Management Team. FMO Scott Campbell remained in command until 06:00 AM on June 14th when Rich Harvey, a key player in the Waldo Canyon fire, was given command to lead a Federal Type 1 Incident Management Team (p. 24). The command's objectives, as delegated by local authorities, included: (1) protect life and uphold safety of the public and responders, (2) protect critical infrastructure, (3) protect private property, and (4) suppress the fire (p. 13).

Achieving these objectives through streamlined command and control was easier than in the Waldo Canyon fire because State Fire Management Officer Wasielewski declared that the Unified Command paradigm would not be used, in favor of a single command. In this way, the incident commander would have command of all resources needed to combat the fire. This was much different from the Waldo Canyon fire, where the City of Colorado Springs retained resources for its own use (El Paso County Sheriff's Office, 2014, p. 10). Now, there was no need to coordinate across multiple commands to achieve consensus. Priorities were set to accomplish objectives, and all resources worked together to achieve a common set of goals. This was made possible due to increased trust among parties.

The region had just finished combating the Waldo Canyon fire, which included hosting Rich Harvey and his Type 1 IMT, working with private and military organizations and across local response teams. As a result, many relationships were already formed, and trust already existed. For that reason, agencies did not feel the need to retain control of their assets. It was known that their voices would be heard and that the best answer was for everyone to work together as a team. While this seems trivial, experience in military command and control produces a similar finding: relationships and trust are important for successful operations.

6.3.3 Resources

Response to the Black Forest fire was supported by over 100 agencies. In general, IMT 3 requested most resources early in the incident before Rich Harvey's Federal IMT 1 arrived on the scene (El Paso County Sheriff's Office, 2014, p. 18, 45). This decision to "go big early" quickly brought a plethora of capabilities to the response, and though the impact thereof was not analyzed in the after-action report, there is little doubt that these resources helped get the incident under control faster than would have been the case without them. Table 7, below, reflects the resources that were ordered on a day-to-day basis.

Table 7. Resources Ordered (non-cumulative)[48]

Category	Day 1 – June 11*	Day 2 – June 12	Day 3 – June 13	Day 4 – June 14	Remainder thru June 21
Engines	21	22	34		No additional aircraft, equip, or crews ordered
Tactical Tenders		5	8		
Hand Crews	7	8	3		
Dozers			5		
Ambulances				3	
Helicopters	2	3	2		
Air Tankers		3	5	2	
Hvy Air Tanker	4				
Very Large Air Tanker		1	1		
Totals	32	42	58	5	0
* Requests for resources amounted to much more (e.g., 36 engines, 16 tenders, 5 helos, and more were requested, but not granted or available).					

As in the Waldo Canyon fire, resources can be categorized in four public areas (city/district, county, state, and federal) and one private area (private and/or non-governmental organizations). The initial response consisted of a total of six entities (Black Forest Fire Rescue Protection District, Donald Wescott Fire Protection District, El Paso County Wildland Team, Tri-lakes Fire/Police Department, Colorado Springs Fire Department, and Falcon Fire/Police Department). Once teams were dispatched at 1:43 PM, the fire was found only seven minutes later at 1:50 PM. Soon thereafter more and more resources flooded to the scene. By 2:30 PM, 22 units, three marshalls, the El Paso County Wildland team, and an AmeriCorps hand crew were

[48] El Paso County Sheriff's Office, 2014, pp. 28-29.

all on-site or in the vicinity. And even with all these resources already on-hand, more responders continued to augment the fight throughout the day (El Paso County Sheriff's Office, 2014, p. 8).

A key event occurred at approximately 2:15 PM that day, when a windstorm blew what was deemed a controllable 2–3-acre ground fire into the crown. Up to this point, firefighters thought they could contain and extinguish the fire. Afterward, with winds carrying embers up to a mile ahead of the fire, igniting tree-top to tree-top, the fire was deemed unstoppable. As the day continued and the fire spread further, responders from the Douglas County Strike Team, Calhan Fire Department, and Highway 115 Fire Departments all assisted in the effort. Utility companies helped by turning off electric and gas lines as the fire threatened to destroy them. Of note, military fire fighters and fire tenders assigned to the US Air Force Academy also contributed. And local officials, working through the Pueblo Interagency Dispatch Center (PIDC), were able to get air tankers and helicopters on-scene by about 4:00 PM – two hours after the fire was located (El Paso County Sheriff's Office, 2014, pp. 9-11).[49]

As the fire continued to rage, even more resources were brought to bear. Over 120 state-owned National Guardsmen were activated to help control evacuations by manning road closures and checkpoints (El Paso County Sheriff's Office, 2014, p. 44). In addition, Colorado's Air National Guard delivered 176,160 gallons of water using nine helicopters. As evacuations occurred and home sites were destroyed, a host of private, volunteer entities (such as the American Red Cross, Salvation Army, Humane Society, Black Forest Together, Samaritan's Purse, and Southern Baptists) provided shelter, in-kind donations, and various amounts of assistance (El Paso County Sheriff's Office, 2014, pp. 49, 52-55, 72). Social media was used to solicit individual volunteers from across the community to help in specific areas. The net result

[49] Air assets were not quickly available for use in the Black Forest area as they were previously tasked to help combat the Royal Gorge fire outside Canon City, CO.

was not just emergency responders acting to quell the fire, but an entire local-state-private community working together to help bring care to those in need. This effort also extended to federal military assets assigned to the local area.

As explained earlier in the Waldo Canyon discussion, the Stafford Act authorizes Federal military forces (either active duty or reserve) for use only after a presidential emergency declaration. According to reports, this declaration came on July 27, 2013, 46 days after the fire began (Colorado Division of Homeland Security and Emergency Management [CDHSEM], 2014). The delay is somewhat explained by Colorado Governor Hickenlooper's failure to request a presidential declaration until July 8. It is unclear why the governor waited so long to make the request. But on a positive note, federal forces assigned to local bases (e.g., US Air Force Academy, Fort Carson, Cheyenne Mountain, and Peterson AFB) engaged very early with local authorities to provide additional resources.

The local federal military forces were brought to bear under a unique provision in the Stafford act and Department of Defense Directive 3025.18 called IRA. This provision allows federal military forces located in the immediate area to help local authorities respond to an emergency, provided (1) the requested resources are available, (2) their use is limited in time and geographical area, and (3) payment is made for services received (Department of Defense, 2010).[50] In a liberal application of this provision the 4th Infantry Division's helicopters at Fort Carson flew 167.7 hours and dropped 689,970 gallons of water, and their engineers contributed

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[50] As stated earlier in the document, the guidelines for using IRA are as follows: "In to a request for assistance from a civil authority, under imminently serious conditions and if time does not permit approval from higher authority, DoD officials may provide an immediate response by temporarily employing the resources under their control, subject to any supplemental direction provided by higher headquarters, to save lives, prevent human suffering, or mitigate great property damage within the United States. Immediate response authority does not permit actions that would subject civilians to the use of military power that is regulatory, prescriptive, proscriptive, or compulsory" (p. 4). "Support provided under immediate response authority should be provided on a cost- reimbursable basis, where appropriate or legally required, but will not be delayed or denied based on the inability or unwillingness of the requester to make a commitment to reimburse the Department of Defense" (p. 5).

900 man-hours to building 22 miles of firebreaks (El Paso County Sheriff's Office, 2014, p. 69). In a similar fashion, C-130 aircraft from Peterson AFB, equipped with the Modular Airborne Fire Fighting System (MAFFS), made 14 drops of retardant for a total 37,529 gallons (p. 70). Here again, Cheyenne Mountain's Fire & Emergency Services and the US Air Force Academy provided personnel, facilities, and equipment under the IRA provision. In the end, federal military leaders authorized assigned assets to engage with local responders to bring more resources to bear, though it is unclear if payment for these services has yet been made (Department of Defense, 2010).

A key question regarding the handling of this fire was how the fire got out of control if it was found so quickly and if adequate resources were committed to extinguishing it. This is the exact question El Paso County Sheriff Terry Maketa had for Bob Harvey after the catastrophe. To answer the question, an independent investigation was conducted with about 60 interviews and analysis of the initial attack. It was found that based on the unprecedented weather and fuel conditions, lack of immediate air support, and the high winds that occurred at about 2:15 PM, no amount of resources would have been able to quell the fire. The report went on to deem the event a "perfect storm" whereby it was in "God's hands" (KKTV, 2014, pp. 104).

With the report having assessed Bob Harvey's actions as appropriate based on the situation, thereby nullifying Sheriff Maketa's contention that enough resources were not committed (or used properly) in time, it went on to offer 13 recommendations and a host of conclusions. Of note, several of the recommendations involved incorporating the resources of and/or conducting joint training between nearby agencies to create a faster response. Thus, while the report found Chief Bob Harvey's actions without fault, it also found that the initial attack was less than desirable. And the report never fully investigated why air support was unable to respond at the outset, or if better decision-making and information flow could have provided the impetus to retain some air support in reserve for the initially deceptive Black Forest fire. Also, the report never explained why responders were dispatched at 1:43 PM when various callers reported smoke columns in the local area "in the morning and early afternoon hours" (KKTV, 2014, p. 3, 6). The upshot from these questions recently became manifest when a group of 60 residents filed a lawsuit against the State of Colorado, El Paso County, and the Black Forest Fire Protection District for negligence in letting a "containable fire" become out of control, eventually causing millions in damage (p. 6).

In sum, the resources committed to locating and fighting the Black Forest fire were considerable, yet not sufficient to quell the fire during the initial attack. Unlike the Waldo Canyon fire, where resources were limited, officials fighting the Black Forest fire pulled significant resources from across all public and private levels to include using air support once it became available later in the day. At one point, a total of 1,175 personnel (79% in operations) were helping combat the incident (El Paso County Sheriff's Office, 2014, p. 24). One noteworthy improvement was the application of federal military assets (enabled by a liberal interpretation of IRA) that brought over 700,000 gallons of water/retardant to the fight (p. 68-71). Though the outcome was still a significant disaster, the pace at which resources were brought to bear in the early and mid-stages of the engagement likely helped keep losses to a minimum.

6.3.4 Preparation and Plans

In most respects, El Paso County was much better prepared for the Black Forest fire, having just gone through the nightmare of Waldo Canyon. Local responders were well versed and local officials, private organizations, and charities were familiar with what needed to be done. This helped eliminate some fog and friction from the catastrophe. Some examples where this clearly occurred: (1) the use of a JIC, this time planned with a well-equipped facility (though no laptop computers were available) that was co-located with the EOC, (2) integration of local responders/officials with Rich Harvey's Type 1 Federal Team (the same team who had fought the Waldo Canyon fire less than one year prior), (3) the EOC's improved support of the mission (e.g., having arranged this time for meals for first responders) with increased awareness, manning, and organization, and (4) officials ordering resources earlier (El Paso County Sheriff's Office, 2014, p. 89). Yet, even with the steep learning curve from Waldo Canyon, there were some critical areas where lessons learned in Waldo Canyon had to be re-learned in the Black Forest fire. These lessons can be grouped into three categories: (1) Communications, (2) Resources, and (3) EOC support.

There are several communications problems that occurred in Waldo Canyon that should have been resolved in time for the Black Forest Fire. First, in both incidents Dispatch was overwhelmed with calls (El Paso County Sheriff's Office, 2014, p. 76). With so much chatter occurring with users exercising poor radio discipline (e.g., talking over each other), critical pieces of information went unchecked and unnoticed. This resulted in poor coordination and slowed down the response. Second, cellphones were saturated to the extent that they were practically unusable. Cellphone coverage in the area was also sporadic. AT&T brought in a Cellular on Light Truck (COLT) at a cost of $5,000 per day to help alleviate the problem. Third, a useful and meaningful COP was never developed. Without a common picture to help decision makers piece together a holistic response scheme, they were left with incomplete information that often resulted in an *ad hoc* verses integrated approach. Fourth, there was difficulty at the EOC maintaining situational awareness of fire operations due to poor communications. Here, no direct feed from the incident command post was provided back to the EOC (El Paso County Sheriff's Office, 2014, pp. 44, 77-78, 87, 96). Thus, it was difficult to impossible for EOC personnel to get ahead and anticipate for future needs in a timely manner.

From a resource perspective, a huge planning deficiency appears to exist in the lack of reconnaissance to detect and locate fires quickly with an adequate response. The Waldo Canyon fire took 16 hours to locate, resulting in a fire of 4,000 acres, and though the Black Forest fire took only 2 hours with a slow-moving ground fire of 2-3 acres, the initial attack response still was not fast enough to contain it before winds bellowed the fire out of control. In both fires, reports arrived at Dispatch well before crews were sent to the area. This is problematic, especially since the county's All-Hazards Pre-Disaster Mitigation Plan specifically mentioned that "luck" has historically been a key component along with mutual aid agreements in finding and extinguishing fires before they could grow out of control. The report then goes on to say that increased amounts of fuel in the area will likely result in fires growing faster and more difficult to contain in the future (El Paso County, 2008, p. 31).[51]

Armed with this knowledge, it is unclear why El Paso County had not yet pursued an air reconnaissance system or other ground-based system capable of quickly detecting fires and relaying that information to first responders, rather than the general populace making conflicting calls to an under-equipped dispatch service. This question is even more important if multiple fires or unrelated events were to occur concurrently (or within a short time of each other). Consider an active-shooter event followed by a wildland fire. With thousands of calls coming

[51] Exact verbiage from the plan reads as follows: "Current ability to hit a fire, "keep it small", and extinguish it is severely limited due to the lack of brush trucks in the County. In 2006 El Paso County set a record for most wildland fires in a 90-day period. Fortunately, a significant amount of luck and automatic mutual aid from throughout the County, helped keep these fires small. With the current fuel load and weather trends, it is expected that a wildland fire not immediately suppressed will quickly grow at an incredibly fast rate" (p. 31).

into Dispatch regarding the active shooter, the fire would go relatively un-noticed from a responder's perspective. This would occur because dispatchers would be so focused on gathering and relaying the active-shooter information to responders, that the fire would get sidelined until phone lines and personnel became available to handle another crisis. By the time this occurred, it might be too late to respond to the fire and bring it under control.

Some of the recommendations listed in the independent investigation of the Black Forest fire (mentioned earlier to determine if Chief Bob Harvey's actions during the initial attack were appropriate) also contained some revealing findings that may help explain the situation. Of the thirteen recommendations, seven focused on increasing teamwork across agencies and neighboring responders. This included everything from developing more refined plans and communications to training together to combining resources to building more trust through better relationships and daily interaction (KKTV, 2014, pp. 1-2). The bottom line is to collaborate more to increase teamwork in hope of responding faster with more resources and capability. The other six recommendations mostly involved better planning and equipment. Some of these recommendations highlighted the need for (1) incident commanders to have brush trucks (or something similar) that can provide access to difficult to reach fires, (2) pre-located command posts, and annotation of water cisterns on maps (p. 6). All of these recommendations are necessary to building a better response. But they are not sufficient by themselves to bring meaningful change to the overall system. There are simply too many other components, parts, and pieces that need integrating (e.g., better methods of detection) to significantly shorten the critical path to an effective response.

6.3.5 Support (as provided by the EOC)

Generally speaking, the EOC performed immeasurably better during the Black Forest fire than in Waldo Canyon. Nevertheless, some problems remained unresolved: old and outdated equipment, poor awareness and under-utilized information technology support, and poor resource tracking.

The EOC's equipment included laptops purchased several years before. These outdated laptops were slow and difficult to use. Plus, there were not enough power cords, drives, keyboards, and other ancillary equipment, nor were there any backup servers or backup power supplies.

This situation was made more difficult because some EOC workers did not know that information technology (IT) support was available to help resolve the problems, and because of this, they continued to struggle throughout the incident. In one case, workers kept trying to use a malfunctioning wireless system, yet none of the users knew that they could call on IT to get the problem solved (El Paso County Sheriff's Office, 2014, p. 89).

Resource tracking was also a problem. Here, the EOC's COP did not include a master resource list. This meant that EOC personnel did not have situational awareness on requests and the status of assets. This was more problematic in the Black Forest fire than in Waldo Canyon, because resources were requested from multiple locations and from multiple users. In the end, some resource data were maintained by the Resources Section in the EOC and could have been shared, but even if the data were shared, there was still no comprehensive resource-tracking log for the entire incident (El Paso County Sheriff's Office, 2014, p. 88). If the goal of the EOC is to support the fight, then having a complete picture of what resources are needed, desired, and available, along with the ordering status of each, is mandatory information. Otherwise, the EOC support team becomes akin to a gathering of cheerleaders trying to spur their team on to victory, while not possessing the knowledge or skills needed to provide any meaningful help to win the day.

6.3.6 Communications

This section starts by highlighting things that went particularly well in the Black Forest fire, then focusing on areas that went poorly, and concluding with a brief summary of findings.

There were three communication areas that went very well in the Black Forest fire: (1) designating a communications unit to provide dedicated 24-hour service/support and to execute a communications plan, (2) establishing a JIC, and (3) designating a Home Assessment Team to provide residents with the status of their properties.

Authorities fighting the Black Forest fire activated the El Paso County Special Communications Unit. This team assigned members to both the EOC and Incident Command and provided 24/7 support to responders. This communications team not only executed a communications plan — unlike Waldo Canyon where a communications plan was never fully devised/executed — county communications experts had completed an ICS 205 multi-command communications plan for the Black Forest fire, and they also reprogramed radios so that responders could talk with each other. The team made important contributions by adding repeaters to extend communication range and coverage, and they worked with Verizon and AT&T to deploy additional equipment to expand service (El Paso County Sheriff's Office, 2014, pp. 11, 44-45, 67). These efforts were vital, because the mobile command post and responders in the area had limited internet and communications capabilities without these additions.

A second area that went particularly well was the JIC. Because the plan was thought out beforehand, the JIC was activated within three hours of the fire; located adjacent to the EOC; and contained adequate phone lines, a separate media room, and the necessary means to communicate with local and national stations as well as social media (e.g., Twitter and

Facebook) (El Paso County Sheriff's Office, 2014, pp. 64, 91-92). The primary spokesman for providing updates to the public was Sheriff Maketa, who worked closely with Rich Harvey and his Type 1 team to provide the latest information (p. 92). This avoided problems that occurred in the Waldo Canyon fire, where the Policy Group had difficulty staying abreast the situation, as quickly changing dynamics put them behind the information curve.

With a dedicated communications team and a properly functioning JIC, additional JIC resources were used to create the Home Assessment Team. This effort was a proactive response to provide residents updated information about their properties without having to ask. JIC personnel routinely checked the status/conditions of properties in the affected area and posted the data on a webpage (El Paso County Sheriff's Office, 2014, pp. 64-65). This measure averted many calls to the JIC's Call Center as residents no longer had to phone in to get updates, the information being readily accessible on the web. Other information showing status of the fire was available on ColoradoFireMaps.com. That website used color-coding on a map to show what areas were unaffected, suffered partial loss, or were totally destroyed (p. 65). In the end, using these types of venues to communicate was a big improvement from the Waldo Canyon fire, where victims had much less information or had to go to great lengths (i.e., attend a public meeting) to get meaningful updates.

Despite the improvements in these three areas, others came up short. Shortfalls emerged in three general categories: (1) Microwave and cell phone connectivity, (2) communications operability/integration and backup capabilities, and (3) shared situational awareness.

Microwave and cell phone connectivity did not meet the needs of the area during the fire. On day 1 at 5:55 PM and again at 8:08 PM, the fire consumed communications towers; this, together with high call volume, quickly saturated cell phone lines so that they were practically useless. To make it worse, there was no backup plan in place to make up for the loss. This was especially difficult, because the Mobile Command Post relied on wireless connectivity, and without broadband, phone, and data flows, it was hindered. To add capacity, AT&T provided a cellular truck at a cost of $5,000 per day, and Verizon deployed a communications trailer with phone and broadband/computer access (El Paso County Sheriff's Office, 2014, pp. 10-11, 44, 76-77, 96). These helped the situation, but, like the Waldo Canyon fire, did not fully compensate for the losses.

When losses and/or failures occur, a key system requirement is resiliency so that communications continue despite it. One way to add resiliency is to provide a mix of interoperable devices that can plug and play into the system, so that when primary devices fall offline (e.g., cell phones, broadband, etc.), responders can still communicate with their backups. In the Black Forest fire, this did not fully occur because people operating on VHF (mostly handheld devices) could not communicate with those operating on the 800 MHz system. This created two different comm systems, necessitating that someone relay information from one system to the other. One lesson noted in the report was the need to purchase a cross-path radio system that would allow VHF and 800 MHz users to talk with each other (El Paso County Sheriff's Office, 2014, pp. 94-95).

The third category of communication problems stemmed from lack of shared situational awareness. The Incident Command System theoretically fulfills this need via a Common Operating Picture (COP), yet, as demonstrated in both the Waldo Canyon and Black Forest fires, the COP has been woefully inadequate. The problem resides in its lack of robustness and ability to integrate all needed data in one place, and then make it available to decision makers regardless of their location. Currently, the county's system is essentially a website page (called SharePoint) that does not contain necessary data. It does not include locations and status of infrastructure, manning/equipment, evacuation areas, access points, water systems and reservoirs, and resources. This makes achieving Unified Command problematic, since, by definition, this command structure mandates that multiple agencies work together across jurisdictions to accomplish a shared set of objectives as defined in a single incident action plan (Department of Homeland Security, 2006, p. 13). Thus, without a shared understanding of the solutions and priorities available to appropriate responders, working together is hindered right from the start (FEMA, 2011, p. 15).

This requirement is acknowledged in NIMS and spelled out as follows: "a common operating picture is an overview of an incident by all relevant parties that provides incident information enabling the Incident Commander/Unified Command and any supporting agencies/organizations to make effective, consistent, and timely decisions (FEMA, 2008, p. 137). This capability extends past the local level as well. An excerpt from lessons taken from Hurricane Katrina suggests that Federal response elements need COPs to synchronize their efforts too (Department of Homeland Security, 2006, p. 42). This begs the question that if COPs are so important, then why are COPs not already fully orchestrated and integrated into the response framework? The answer is difficult to ascertain, because some agencies have invested significant time and energy developing shared awareness tools for certain areas, yet no single, comprehensive system exists for all responders. U.S. Northern Command (NORTHCOM) made a commitment several years ago "to actively promote the development, availability and employment of a timely, comprehensive and relevant common operating picture for continental security," yet, according to a Government Accounting Office report, the DOD still does not have a formal, unclassified system to track requests for help (Department of Homeland Security, 2006,

p. i; North American Aerospace Defense Command and United States Northern Command, 2007, p. 5). Instead, the Defense Security Cooperation Agency's Automated Support System that is available for use by the DOD, specifically within United States Northern Command, does not link to the appropriate lead civilian agencies; nor does it incorporate requests (though it does include FEMA and the Interagency Fire Center) (United States Government Accountability Office, 2010, p. 44). The lack of linkages to civilian agencies might have resulted from the DOD's DSCA strategy document, which asserted that a shared situational awareness tool would be developed with primary focus on linking only between military units (Department of Defense, 2013, p. 19).

Apart from this effort, United States Northern Command developed the Situational Awareness Geospatial Enterprise (SAGE) that responders could access on the Homeland Security Information Network (HSIN).[52] Accordingly, SAGE "provides information about the physical environment that we all live in … it's information about buildings, infrastructure – where the police stations are, where the hospitals are, and where certain businesses are" (Brayman, 2007). Thus, while this system provides a look at overarching infrastructure and effects of catastrophe, it still does not provide all the functions and capabilities needed in a COP.

At this juncture, the only hope of developing an all-encompassing COP resides in the future. The system currently in conceptual design is called "FirstNet" and is expected to provide responders with a 700 MHz Broadband network focused on public safety (National Telecommunications and Information Administration, 2014). The new network is expected to use FirstNet mobile devices (designed to be rugged enough for field use) that will augment the more than 10,000 separate, incompatible land mobile radio networks used today. With enough

[52] The HSIN is unclassified, but access is limited to those with accounts. Getting an account is centrally controlled and users must get sponsored to gain access.

responders on the system, and if built with open standards that ease connectivity and use, the system could be a start to a COP that meets the users' needs (FirstNet Authority, 2014).

One problem with FirstNet is that many states and communities are opting out of this new network in favor of developing their own communications networks. One driver spurring this behavior is lack of confidence that the system will ever materialize. Here, federal funding necessary to design and construct the system has become questionable, and many believe the initial cost estimate of $7 billion needed to implement the system is woefully optimistic (Jackson, 2013). Thus, waiting and hoping for FirstNet is not a valid option, especially when users' needs demand a more timely approach.

6.3.7 Black Forest Fire Conclusion

In conclusion, the Black Forest fire was a difficult scenario that pushed the emergency response system to the breaking point. Lessons learned from the Waldo Canyon fire helped responders mount an effective response, and the inclusion of federal military forces acting under IRA authority, along with increased trust among participants, served to bring more resources to bear while reducing fog and friction in the system. Yet, even with this, the system still faltered in several areas. Table 8 below highlights these areas.

Major areas of concern include muddled detection, conflicted calls to Dispatch, a lack of reconnaissance, and little-to-no air support during the initial attack phase. This allowed the fire to break from a 2-3 acre ground fire into an uncontrollable disaster that would burn thousands of acres. Another major area of concern is the EOC's support to the incident. Though it was much improved (over Waldo Canyon), EOC personnel still struggled with limited awareness and outdated equipment. Communications between officials and the public were better with the use of a JIC, yet the lack of shared situational awareness, poor wireless connectivity, and less than optimum operability/integration between communications devices led to a frustrated response.

Table 8. Summary of Black Forest Response Deficiencies

Area	Observations
Detection	- 2 hours / Dispatch late to send resources to locate fire - Garbled communications & information; faulty assumption that smoke was the Royal Gorge fire - Lots of responders on initial attack due to close proximity, but still not fast enough - Air support already used in Royal Gorge fire—no reserves available - Fire easier to find due to increased access and denser population of people observing the area
Command and Control	- Single command worked well – but lacked shared awareness - Good coordination between local, state, and federal teams - Sheriff was the primary public spokesman. Worked well - High levels of trust remained between responders from Waldo Canyon fire – served to reduced fog/friction and help with integration
Resources	- Went big early – most resources ordered within first 2-3 days - Resource tracking not good; more resources strained the effort - Presidential disaster declarations came late - Federal military forces on the scene early using DSCA IRA authority - Good support from private/charitable organizations
Preparation and Planning	- Dispatch not adequately resourced to receive/analyze/take proper action - No backup plan for saturated comm lines - EOC not resourced fully to support the response - No means to detect/locate fire quickly via reconnaissance
EOC	- Not ready for prime time - Lacked shared situational awareness - Better, but still no comprehensive resource tracking for all participants
Communi-cations	- Muddled cell phones / destroyed towers / no backup plan - Poor cellular and microwave tower coverage - Poor operability to plug and play comm devices - Lacked connectivity at mobile command post - COP not comprehensive / needs better integration

6.4 Summary of Analysis

Key takeaways from both fires are as follows:

1) Detection and Initial Attack

- Finding and fixing the fires muddled each operation.
- Conflicting calls

- Overwhelmed dispatchers
- Late or delayed decisions to put responders in the field
- Little or no reconnaissance to find/confirm fires (from the air)
- Responders arriving too late, with fire either already out of control, or containable but becoming out of control in the face of changing conditions
- Not enough assets committed to fighting the fires initially. Air usually requested early, yet other factors led to delays in receiving support.

2) Command and Control
    - Single Command executed during Black Forest Fire allowed for better use and integration of resources.
    - Higher levels of trust and shared cooperation existed in Black Forest than in Waldo Canyon. Relationships bred cooperation.
    - Command and control mechanisms that were recently exercised in Waldo Canyon led to familiarity and better execution in Black Forest.
    - Unified Command in Waldo Canyon was difficult to execute without a shared understanding of the situation and the dynamics of change. There was not an effective and efficient COP to help get support and responders fully integrated. A lack of awareness detracted from support actors' ability to anticipate and push resources; instead, responders had to pull resources-based requests.
3) Resources
    - The "Go Big Early" approach generally worked better, as evidenced in the Black Forest fire, than the piecemeal, *ad hoc* approach that was used in Waldo Canyon.
    - Military forces executing under federal IRA authority were helpful in the Black Forest

fire, but it was unclear to what extent El Paso County and the local military overstepped boundaries as dictated by DOD Directive 3025.18. The answer to this question is not overly important to this study, but it should be answered in future research to determine if IRA provides enough latitude and flexibility for engagement on the local scene.

- Jurisdictional issues were problematic and created a less than optimum response; private resources were turned away (e.g., bulldozers in Waldo Canyon).
- Private resources own 85% of the infrastructure but were not fully incorporated into the response.

4) Preparation and Planning

- The response system used to fight the Waldo Canyon fire was largely unprepared even though five regional plans existed. The system was not exercised and ready to meet the challenge.
- The response system used to fight the Black Forest fire had the benefit of a recent real-life event (i.e., Waldo Canyon fire) that served to better prepare the system. It was evident that the system used to fight the Black Forest fire had much higher levels of integration and collaboration due to increased familiarity and trust among actors, and higher proficiencies due to training.
- Communications planning and analysis on the region conducted before the events might have averted many of the communications problems.

5) EOC

- The EOC was not fully ready to meet either fire event. In both fires, it was not fully effective in supporting the response due to lack of investment, manning, and integration.
- With poor situational awareness, poor communications and connectivity, along with the

larger amounts and diversity of resources used in the Black Forest fire, the EOC could not keep up and at many times was ineffective and/or incapable.

- Without a shared understanding of the situation and system needs, the EOC was largely hamstrung. This suggests that regardless of other shortfalls existing in the EOC, if this critical need is not met, fixing all other shortfalls may not do much to significantly improve overall EOC performance.

6) Communications

- The response to both fires were muddled with connectivity problems. This led to *ad hoc* responses as different response elements worked independently, cross-circuiting system components verses integrating as a team using established system interfaces.
- The JIC was critical in both events. In the Waldo Canyon fire, the JIC was an *ad hoc* entity that functioned poorly. In the Black Forest fire, the JIC was well-thought out beforehand, with dedicated personnel, facilities, and equipment; the result was a JIC that functioned very well and met the needs of the event.

CHAPTER 7: EERS VALIDATION

7.1 Overview

One of the primary ways that systems engineering ensures successful systems are built – that is, to ensure developed systems are built right and also meet stakeholder goals and objective – is by conducting system verification and validation via test and evaluation. Verification, also known as developmental test, focuses on helping to discover and guide the system's developmental pathway (using tools such as experimentation, analysis, modeling, simulation, and prototyping) to verify that the system is "built right" as it progresses through the systems engineering lifecycle. In this light, verification is akin to confirmation: ensuring that system parts, subcomponents, components, subsystems, and interfaces/interactions are working properly before moving on to the next development phase and/or stage. When considering that complex systems use advanced technologies and techniques, and/or seek the state of the art, it is easily seen how verification is a crucial aspect of systems engineering in helping to illuminate problem areas, find solutions, decide on tradeoffs, and thereby guide the developmental pathway by mitigating and/or lowering risk.

Validation, also known as operational test, is much different. It occurs at the end of system development but usually before a system is handed over to the end-user. Here, validation's sole intent is to gain confidence (i.e., to validate) that the "right system was built" and that it meets stakeholder operational goals and objectives. Unlike verification, where the burden of proof lies on the test object to confirm itself successful, validation usually starts from the assumption that the developed system already meets goals, objectives, and associated requirements. Thus, validation does not have to test and/or confirm everything; it seeks only to confirm the most vital system aspects usually identified as critical operational interests. Here, validation asks the following questions: (1) does the system effectively perform (i.e., do what the stakeholders intended it to do) in its operational environment(s), and (2) is the system suitable for use? If the system does not pass in either of these two areas, it is deemed faulty. Because of the need to test the system in regard to these two aspects, validation usually requires (1) the use of a production representative system (normally produced during low-rate initial production), (2) an independent test process to avoid developer bias, and (3) testing by representative end-users without influence by the developers, and in a realistic test scenario that takes place in a representative system environment. When looked at holistically, validation requires significant resources: a realistic environment, scenarios, operators, and other integrated systems that all are needed to ensure the correct system was built to meet stakeholder needs. If validation is successful, the system is approved for full-rate production; if not, the system is either rejected and re-enters developmental test to rectify the deficiencies, or it is accepted with contractual agreements to rectify the problems in the future.[53] With the foregoing serving as foundation, the following section explains the validation process for the EERS.

7.2 EERS Validation Approach

As discussed above, validation is normally conducted with an actual production-representative system in a realistic scenario operated by independent, normalized operators. Unfortunately, the EERS discussed and built in this paper, along with its functionality and operating modes, cannot be realistically (i.e., physically) built and operated in this research environment, nor can an actual complex emergency (consisting of thousands of people and usually over a hundred organizations) be fabricated in order to test the system's effectiveness and

[53] This process is indicative of major Department of Defense system acquisitions that require Congressional oversight.

suitability. Thus, this research must validate the EERS indirectly through the use of models and empirical data. To accomplish this, EERS effectiveness is validated using the Functional Dependency Network Analysis (FDNA) model along with empirical data from the two fires. System suitability and compliance requirements are assessed subjectively and qualitatively. After both effectiveness and suitability requirements are addressed, a Delphi study composed of subject matter experts further validates the system to gain needed confidence in areas of feasibility and the value of using a systems approach to build the EERS.

Using this type of approach to validate is not atypical. Figure 14 below lists the continuum of ways to gain knowledge through test and evaluation.

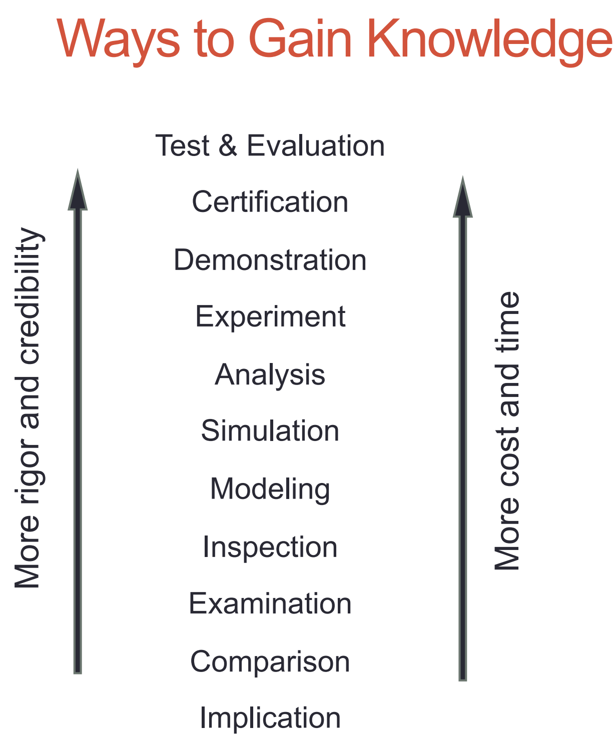

Figure 14. Ways to Gain Knowledge[54]

As shown in the figure, the continuum of test and eval methodologies is quite broad and ranges greatly with cost and time. At the lower end of the spectrum are methodologies such as

[54] Reynolds, 2013.

implication, comparison, inspection/examination, and modeling. These are methods that take less time and costs, while at the higher end are methodologies such as demonstration, certification, and test/evaluation that are much more involved and costly. There is no one right answer in determining which methodology to use. The correct methodology largely depends on a number of factors, including what data are needed to inform what decisions, how many unknowns exist, how much confidence is needed, and how much time and money is available to conduct the test/study. For this validation, there is no way to create a parallel system to conduct the validation. Thus, this validation must these other methodologies, along with subject matter opinion, to gain necessary confidence.

When using these methodologies, priority is placed on using empirical data from the two fires, along with associated trends and best practices, and on expert subject matter opinion. This approach is used because (1) even though the empirical data are derived from only two events, those events are representative of other types of complex response activities (as premised earlier in this paper), and (2) the events took place within one-year of each other and in the same locality/region, so that many of the responders—fortuitously, even including federal Type 1 IMT responders—fought in both events. This allows insight into how the responders interacted with each other from one event to the next. It also allows insight into how their interactions, along with their training and experience, influenced overall response integration. Enough data exists from both events so that these and other system-to-system event comparisons can be made in and across the two events. For all of these reasons, and because the scope of the two events and responses were local in nature with regional involvement – similar to the involvement of other communities across America when responding to complex emergencies – the use of empirical data, though limiting, helps keeps the analysis focused on real-world problems and solutions in regard to this system.

The data are limiting for two primary reasons: the number of events is only two, and the data are heavily confounded. As is well established in statistical analysis, the requirements needed to prove cause and effect are largely related to the number of experimental variables, the number of samples (i.e., usually designated as N), and the amount of confidence the researcher is hoping to achieve. Random selection, signal to noise ratios, and other experimental design factors also play a part in determining the needed number of samples. Design of Experiments is a proven methodology that uses Analysis of Variance (ANOVA) in experimental design to gain needed confidence while greatly reducing the number of samples. A key benefit to this method is that the analysis also identifies how and to what extent the experimental variables interact with each other.[55] However, using a Design of Experiments statistical approach that could prove cause and effect in this complex system (e.g., there were six independent variables as listed in the I-P-O model in Chapter 5) would require at least eight events (i.e., N), and the data would need to be robust, with sufficiently strong signal-to-noise ratios for the researcher to identify necessary correlations. Of course, this is not what we have here.

The other limiting factor is heavily confounded data from the two fire events. Confounding occurs when so many independent variables (i.e., inputs) are changed from one experiment to another that, when the outcomes from the experiments are assessed, there is no reasonable way of determining which changed input factors were responsible for the changed outcome. In essence, the experiments generate a changed outcome, but determining exactly what caused the change remains impossible. In the case of the two fires, changes were made in and

[55] See Montgomery (1991) for a full discussion on DOE.

across the system, most notably in the subsystems that resulted in better system performance. Yet there is no way to determine exactly what factor (or set of factors) was responsible. In order to combat this, this validation uses the empirical data holistically and categorically to identify trends and best practices. By keeping the data grouped together and in context with associated outcomes, correlations can be found that provide insight into what could have made the change in outcome. These correlations, where critical, are strengthened via reference to existing research/literature and subject matter experience in the Delphi survey. Again, the validation's intent with this data is to discover correlation – not deterministic outcomes based on probabilistic calculations.

The last validation method is a Delphi survey. This method is used (1) to validate the systems engineering application to build the system, and (2) to garner additional confidence in the system engineering application along with the system's feasibility. Here, a survey is formulated and sent to a panel of subject matter experts to gain their thoughts on these areas (see Appendix B). Their responses are compiled, analyzed, and used to either support or refute the validation.

7.3 Burden of Proof

As stated earlier, the goal of this validation is not to prove and/or verify every system function —that is the job of developmental test and is outside the scope of this research. The goal of this validation is to make a reasonable determination based on the preponderance of evidence as to whether or not the emergency response system as presented in this treatise can successfully achieve its stated objectives. Preponderance of evidence is achieved when the evidence suggests it is "more likely than not" that the object or process under investigation would succeed. As a reminder, system goals and objectives from Chapter 1 are restated next.

7.4 Background – System Goals and Objectives

As stated in Chapter 1, the purpose of this research is to apply systems engineering to build a more effective, engineered emergency response system called the EERS. The EERS is necessary to handle the high levels of complexity involved in responding to larger, complex incidents. According to the United States Coast Guard, an effective emergency response system "minimizes adverse impacts and consequences of the incident and maximizes public confidence and stakeholder satisfactions" (United States Coast Guard, 2014, p. 4-15). This research considers "effective," as applied to the EERS, in the same way, because public confidence and shareholder satisfaction are highly correlated to the impacts of an emergency (Bimel, 2002; The White House, 2003).[56]

The transition to a systems framework used to build the EERS is shown in Figure 15 starting from the existing system used to respond to the Waldo Canyon fire and Black Forest fires, which are respectively indicated as Events A and B toward the bottom of the figure, and working upward to Design C – the EERS – at the top. The EERS is depicted "Design C – Future System Capability," and it possesses more "green" (i.e., it is more effective in responding across the entire continuum of events, including those events containing increased levels of severity and complexity). In conducting the needs analysis and requirements definition, most EERS effectiveness requirements were derived from the system having to perform four necessary functions: (1) an ability to observe/sense (i.e., detect a need to respond), (2) an ability to understand and characterize the observation in order to decide how to respond, (3) an ability to act (i.e., direct resources to physically conduct the response), and (4) an ability to garner

[56] Homeland Security Presidential Directive-8, a key document guiding the National Preparedness System, states the primary goal of the system is "to minimize the impact on lives, property, and the economy" (The White House, 2003, n.p.).

feedback with which to refine the response as conditions change (i.e., to cycle back through steps 1-3).

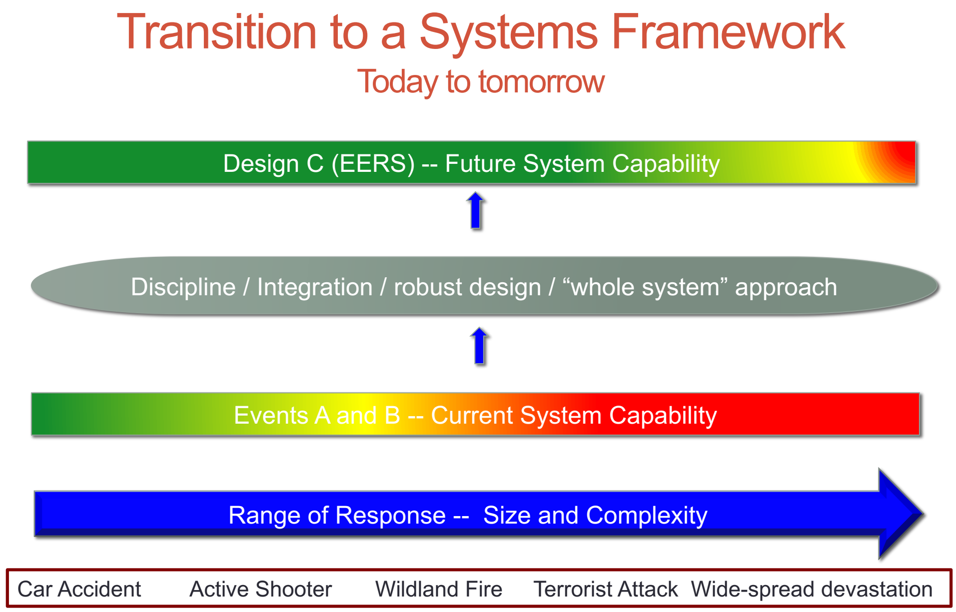

Figure 15. Transition to a Systems Framework for Emergency Response

Effectiveness requirements are below:

- The EERS shall operate on the expectation of chaotic and imperfect information associated with chaotic, complex events. As such, the system shall seek out needed information, learn, and adapt.
- The EERS shall be capable of handling complex/dynamic/multi-jurisdictional events, yet still have the means to handle the mundane, non-complex, emergency events that happen daily.

Along with having to meet these requirements, the system must also fit into a larger system – or system of systems. This means the EERS must be built so that it is suitable (i.e., it must properly interface and interact with its external environment). This was largely addressed normatively from established guidance along with using logic and rationale to address other existing needs. Suitability requirements are below:

- The EERS shall follow guidelines as established in the National Response Framework and the National Incident Management System Framework. A few of the applicable framework features include: (a) the system shall be tailorable, scalable, and layered, (b) the system shall handle all types of incidents, and (c) the system shall use the Incident Command System's unified command concept.
- The EERS shall not degrade or inhibit the community fragility concept as presented in Chapter 4. Instead, the new system should support and/or enhance this concept. This concept is grounded in three areas: community connectedness, stability, and sustainability. These areas are essential in helping to generate effective emergency responses via community wellness.
- The EERS should strive to morph itself into existence from the existing response system using non-monetary solutions. Monetary investment is limited.

The next chapter begins the validation using FDNA to model the EERS in an operational environment.

CHAPTER 8: VALIDATION TEST SCENARIO

The goal of this chapter is to validate the EERS built in Chapters 4 and 5 by evaluating how it responds to complex incidents when compared to what occurred in the Waldo Canyon and Black Forest fires. This is necessary to show that the EERS is actually an improvement over the response systems that existed and were used in El Paso County to fight the two fires. This examination will also help gain confidence and provide evidence that the EERS encompasses appropriate amounts of robustness and resiliency to meet response challenges in ways not achievable by the El Paso County's response system that was used to combat the two fires. To accomplish this, this chapter contains four sections. The first section highlights the Waldo Canyon and Black Forest fires' problem areas as identified in Chapter 6, and then prioritizes those areas using criteria derived in Chapter 5. These prioritized problems are addressed in the validation to show how the EERS learns and adapts—changing its architectures when necessary—to allow the system to overcome challenges such as were encountered in two fires. Prioritizing problem areas in which to focus the validation is common practice and well established. (Defense Acquisition University, 2021). The third section assesses EERS effectiveness. The assessment offers insight into EERS successes showing how the system overcame problem areas. The chapter ends with the fourth section – a brief summary.

8.1 Prioritized Problem Areas from Two Fires

This section starts by listing broad problem areas from the two fires as discussed in Chapter 6 and prioritizing them based on criteria developed in Chapter 5. To do this, the problems are numbered below and then placed in Table 9.

8.1.1 Detection and Initial Attack

1. Finding and fixing the fires muddled each operation.
2. Conflicting calls
3. Overwhelmed dispatchers
4. Late or delayed decisions to put responders in the field
5. Little or no reconnaissance to find / confirm fires (from the air)
6. Responders arriving too late –fire either already out of control, or fire containable but changing conditions spurred the fire out of control
7. Not enough assets committed to fighting the fires initially. Air usually requested early, yet other factors led to delays in receiving support.

8.1.2 Command and Control

8. Single Command executed during Black Forest Fire allowed for better use and integration of resources.
9. Higher levels of trust and shared cooperation existed in Black Forest than in Waldo Canyon. Relationships bred cooperation.
10. Command and control mechanisms that were recently exercised in Waldo Canyon led to familiarity and better execution in Black Forest.
11. Unified Command in Waldo Canyon was difficult to execute without a shared understanding of the situation and the dynamics of change. There was not an effective and efficient common operating picture to help get support and responders fully integrated. A lack of awareness detracted from support actors' ability to anticipate and push resources; instead, responders had to pull resource-based requests.

8.1.3 Resources

12. The "Go Big Early" approach generally worked better in the Black Forest fire than

the piecemeal, *ad hoc* approach that was used in Waldo Canyon.

13. Military forces executing under federal IRA authority were helpful in the Black Forest fire, but it was unclear to what extent El Paso County and the local military overstepped boundaries as dictated by DOD Directive 3025.18. The answer to this question is not overly important to this study, but it should be answered in future research to determine if IRA provides enough latitude and flexibility for engagement on the local scene.
14. Jurisdictional issues were problematic and created a less than optimum response; private resources were turned away (e.g., bulldozers in Waldo Canyon).
15. Private resources own 85% of the infrastructure but were not fully incorporated into the Waldo Canyon response. The Black Forest response did much better incorporating both military and private resources.

8.1.4 Preparation and Planning

16. The response system used to fight the Waldo Canyon fire was largely unprepared even though five regional plans existed. The system was not exercised and ready to meet the challenge.
17. The response system used to fight the Black Forest fire had the benefit of a recent real-life event (i.e., Waldo Canyon fire) that served to better prepare the system. It was evident that the system used to fight the Black Forest fire had much higher levels of integration and collaboration due to increased familiarity and trust among actors, and higher proficiencies due to training.
18. Communications planning and analysis of the region, if conducted before the events, might have averted many of the communications problems in both fires.

8.1.5 EOC

1. The EOC was not fully ready to meet either fire event. In both fires, it was not fully effective in supporting the response due to lack of investment, manning, and integration.
2. With poor situational awareness, poor communications and connectivity, along with the larger amounts and diversity of resources used in the Black Forest fire, the EOC could not keep up and, at many times, was ineffective and/or incapable.
3. Without a shared understanding of the situation and system needs, the EOC was largely hamstrung. This suggests that, regardless of other shortfalls existing in the EOC, if this critical need is not met, fixing all other shortfalls may not do much to significantly improve overall EOC performance.

8.1.6 Communications

1. The responses to both fires were muddled with connectivity problems. This led to *ad hoc* responses as different response elements worked independently, thereby cross-circuiting system components, verses integrating as a team using established system interfaces.
2. The JIC was critical in both events. In the Waldo Canyon fire, the JIC was an *ad hoc* entity that functioned poorly. In the Black Forest fire, the JIC was well thought out beforehand with dedicated personnel, facilities, and equipment; the result was a JIC that functioned very well and met the needs of the event.

The above numbered problems are placed into Table 9.

Table 9. Prioritized Problem Areas from Two Fires

Response Area	Independent Variables	Associated Components and Processes	Priority (VH/H/M)	Problem Area
Speed of Response	Detection	Sense and Detect (A)	VH	1, 5
		PSAP (C, C1)	VH	3
	Communications (IRS)	Communications (B1, B2)	VH	2
		Dispatch (D)	VH	
Initial Attack Response Effectiveness	Initial Attack	Confidence (C2)	VH	4
	Resources (Adequate)	Initial Capabilities	VH	6
	Resources (Scaling)	Scaling Loop 1	H	7
		Scaling Loop 2	H	12
Response Management Effectiveness	Command and Control	Response Management Loop	H	8, 17
	Communications		H	11,18, 21,22, 23
	Spirit of Cooperation		H	9, 10, 14
	Resources Applied Holistically		M	13, 15
	Training/Preparation		M	16
	EOC Support		M	19, 20

(VH-Very High, H-High, M-Moderate)

The table lists in priority order the problems encountered in the two fires. The very high (VH) priorities correspond to problems 1 through 6. These problems are all related to components of two response areas: speed of response (problems 1, 2, 3, and 5) and initial attack response effectiveness (problems 4 and 6). Two-thirds of the problems prioritized as high (H) are in two components of the third response area, response management effectiveness. Those components are communications and spirit of cooperation. The communications component is correlated with five problems, and spirit of cooperation with three. The many problems in these two components suggests that they are also worth investigating. The following section investigates these 14 VH and H problems using a systems approach, to show how a properly designed and functioning emergency response system would work to overcome these limitations.

8.2 Smart Learning and Adaptation

As shown above, empirical analysis presented in Chapter 6 of two epic wildfires that occurred in Colorado—the Waldo Canyon fire (2012) and the Black Forest fire (2013)—found that many system-level shortfalls and failures existed that served to hamstring the response system. The specific problems, prioritized above, suggest that many of the shortfalls existed in the Initial Response Subsystem (diagrammed in Chapter 3, Figure 7) and are related to timeliness of detection, response, and needed capabilities. This equates to three areas in need of significant improvement: (1) a more effective mechanism to detect and locate the fires; (2) a more robust dispatch center with associated communications to overcome saturation, gain increased cognition, and enable proactive measures to help ensure adequate responders/capabilities arrive on the scene; and (3) enhanced integration and communications to increase situational awareness to allow for increased support —all in the interest of generating a more effective response.

Looking at these areas more closely, the deficiencies in the existing system are mostly symptomatic of the response system's inability to handle uncertainty. In short, the system had difficulty handling events that are hard to observe, locate, or report; or complex events where incoming information is disjointed or erroneous. The system has proven itself to work well when complete information is available, or when time is available to seek out answers in order to formulate the optimum plan. As shown in both fires, however, the system faltered when these conditions were not met, and the system's ability to learn and adapt in these uncertain, complex situations needs improvement. To show how the EERS overcomes these deficiencies, it demands addressing EERS operation from a holistic perspective. Performing analysis on the three areas *vis-à-vis* overall system operation, and knowing that systems are largely constrained (or enabled) by their architectures, this validation investigates how the above difficulties are overcome by the EERS using systems engineering thinking and associated toolsets.

Consider the following hypothesis as a segue to validation: If the EERS' architecture smartly adapts to allow more learning to occur while simultaneously decreasing dependencies among system entities, then system response performance significantly improves —especially during events with increased amounts of complexity and uncertainty. In order to find answers to validate the hypothesis, a systems approach is used to consider the EERS from a holistic functional perspective. To do this, Functional Dependency Network Analysis (FDNA) is introduced and applied across the system. Next, subsystem and component operations and dependencies are analyzed, leading to system-level solutions. These solutions are then integrated to show how they impact overall EERS performance. Discussion of the findings follows, and the chapter concludes with a brief summary.

8.2.1 Nodes and Dependencies

To understand system response, Guariniello and DeLaurentis suggest that using nodes to represent each system (or capability) adds clarity (Guariniello & DeLaurentis, 2013; Guariniello & DeLaurentis, 2014). By linking nodes together based on their interfaces and interactions, one can determine how a change in one node affects the others, whence an overall system performance determination can be made based on aggregation. This typology is useful, because systems are often designed in isolation from the greater whole, making it difficult to determine how changes in one part of one system impact the greater whole. Guariniello and DeLaurentis assert that FDNA can quantitatively calculate the impact of these changes on overall performance.

FDNA is a modeling tool used to aggregate performance, where nodes represent a system or a capability. Each node operates at a given system effectiveness (SE) level based on how well that particular node (or system) functions without regard to its dependencies. When one node is dependent on another, the downstream node's operability level (O) is calculated as a function of its own SE level, the upstream node's operability level, and the node's strength of dependency (SOD), criticality of dependency (COD), and availability of data (AOD). See Figure 16 below.

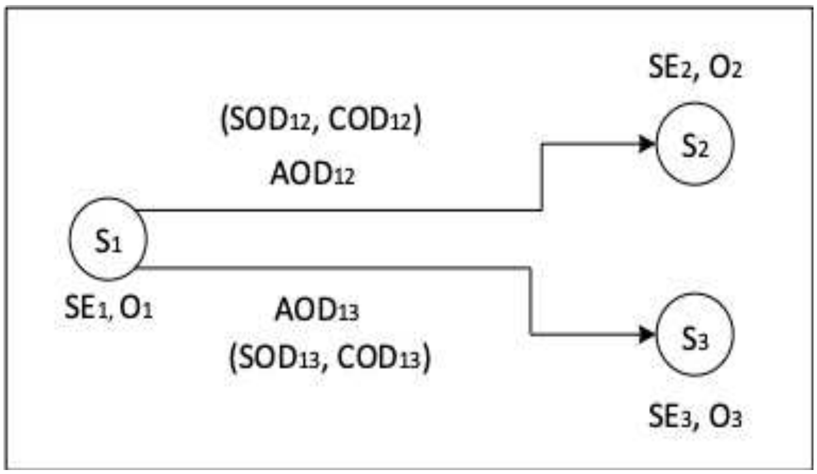

Figure 16. FDNA Diagram

When using FDNA to aggregate system performance, it is first necessary to calculate each node's operability—starting at the front and working through the system. The equations for calculating operability for node S_i having n predecessors are below (Guariniello & DeLaurentis, 2013):

$$O_j = \min(SOD\_O_j, COD\_O_j) \quad (1)$$

$$SOD\_O_j = \text{Average}(SOD\_O_{jl}, SOD\_O_{j2}, \ldots, SOD\_O_{jn}) \quad (2)$$

$$SOD\_O_{ji} = SOD_{ij}O_i + (1\text{-}SOD_{ij})SE_j \quad (3)$$

$$COD\_O_j = \text{Min}(COD\_O_{jl}, COD\_O_{j2}, \ldots, COD\_O_{jn}) \quad (4)$$

$$COD\_O_{ji} = O_i + COD_{ij} \quad (5)$$

For a root node with no upstream dependencies, its operability level is equal to its SE-level. For other nodes, operability depends on SOD, COD, and AOD values. SOD reflects how much of a node's behavior is determined by the behavior of its parent, and COD reflects how much of a node's functional performance degrades when its parent completely fails. These values are determined empirically or through analysis. For example, if 40 percent of node S_2's behavior were dependent on node S_1, then SOD_{12} would be 0.4. SOD values range from 0 to 1, and higher values equate to more dependency. Thus, if a node behaved freely without impact from its parent, SOD would be 0. Unlike SOD, which addresses behavior, COD reflects functional degradation when a parent node completely fails. For example, if node S_3 functionally operated at 20 percent when its parent node S_1 failed, then COD_{13} would be 20. COD values range from 0 to 100, and lower COD values equate to stronger dependencies. If a node experienced no degradation when its parent node failed, its COD would be 100 (Guariniello & DeLaurentis, 2014, p. 720).

AOD accounts for availability of data between nodes and is used to capture degradation effects that limit data transfer from one node to another. This factor is important to account for degraded communications and/or system saturation when crisis occurs. As evidenced in many large-scale catastrophes, data availability often becomes scarce as communication systems struggle to overcome saturation. For these situations, AOD is a critical part of the equation. As an example, if the linkage from S_1 to S_2 were operating at 70 percent, AOD_{12} would be 0.7. A full description of how to conduct the operability calculations is found in Guariniello and DeLaurentis (2013; 2014).

In the end, FDNA provides a means to conduct quantitative analysis of individual nodes based on dependencies, and, when taken across a system, shows how changes in each can enable or constrict overall performance. We now apply FDNA to the EERS in order to show how architectural changes made to the system create increased operability across the system. The analysis shows how changing the EERS' architecture can make the overall system respond faster and with more effectiveness. The discussion begins by more fully defining the problem and then proceeds to offer different architectures with analysis. It concludes by presenting findings.

8.2.2 Analysis of Key Problem Areas

The existing response system, by design, is very dependent on people acting as sensors to collect information and report irregular behavior/events to a 9-1-1 PSAP. When warranted, the PSAP responds by dispatching first responders while continuing to monitor the situation. The underlying assumption for such a system to operate is that the sensors (i.e., people) can observe, locate, and report to the 9-1-1 PSAP. If a decision is made to respond, the PSAP must then determine who to send and where they should go. If this first step is not completed with a high degree of timeliness and accuracy, the response is delayed and less effective. Hence, meeting the underlying assumption is important if the system is to work (Meissner et al., 2002; Manoj & Baker, 2007, pp. 51-53).

Unfortunately, some behavior is not easily observed, located, or reported, especially during complex events where communications systems become saturated and people are reporting disjointed or erroneous information. A recent report, "Crisis Leadership in a Hyper-VUCA Environment," suggests that even more uncertainty is likely to occur in the future due to a host of factors, and, because of this, the report suggests that an increasing need exists to find clarity along with agility to act amidst the chaos (Alkhaldi et al., 2017, pp. 117-132). In two of these types of incidents, the Waldo Canyon and Black Forest fires, conflicting information reported to the PSAP created confusion as to where the fires were located. In Waldo Canyon, the PSAP dispatched first responders to the wrong area. In the Black Forest, the PSAP waited too long trying to glean more information before sending responders to help (El Paso County Sheriff's office, n.d., pp. 2, 16). In both cases, help came too late, which allowed the fires to grow much larger, thereby necessitating much more extensive follow-on efforts to bring the fires under control. The impact to the community was severe. This is not to imply that if the system had worked perfectly the fires would have been snuffed out without losses, but it does cast considerable doubt on why the system did not have imbedded mechanisms—or at least more effective ways—to adapt when faced with these types of challenges.

The problem was magnified because El Paso County's response system architecture was structured in series with extremely strong dependencies among actors, so that any upstream degradation/failure was relayed directly to the next node. This resulted in cascading failures that crippled the response. See Figure 17 below.

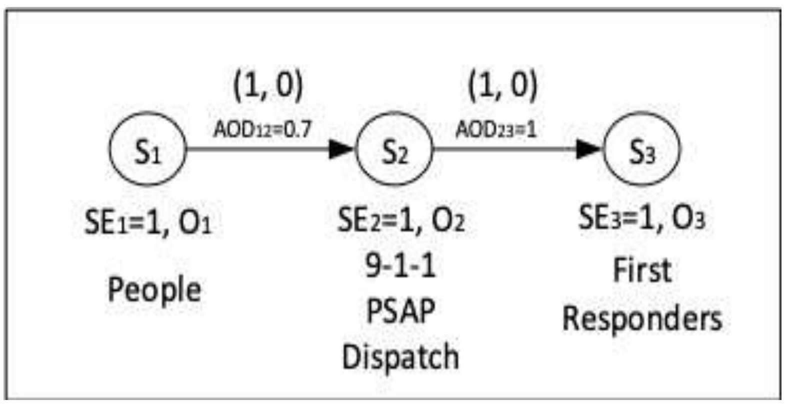

Figure 17. Response System (Baseline)

From the figure, Dispatch (S_2) is wholly dependent on People (S_1), and First Responders (S_3) are wholly dependent on Dispatch (S_2). Thus, overall system performance decreases (1) when there are degradations in the people's ability to accurately observe, locate, and report, or (2) in Dispatch's ability to receive, process, and pass the information to first responders, or (3) when the first responders' ability to function is decreased. The degree of failure depends on the aggregation of failures across the nodes. For example, if, as shown in Fig. 17, the availability of data between S_1 and S_2 were degraded 30 percent (AOD_{12}=0.7), the best operability-level that both Dispatch (S_2) *and* the First Responders (S_3) could achieve would be 70 percent, if all three nodes and all other paths were working at full capacity. If taken further such that the People's (S_1) SE-level were also degraded 30 percent ($SE_{1=}$ 0.7, O_1= 70%), the best achievable operability for both S_2 and S_3 would fall to 49 percent, i.e., O_1 =70%, O_2 =70%, which is the *baseline system* for purposes of this discussion. This degraded operability helps explain why architectures built in series can fail so quickly, and it helps to explain why the initial response subsystem failed to meet the demands during the two fires. The system, by its design, propagated delays and/or problems based on strong dependencies among actors.

8.2.3 EERS Operation

To help rectify the problem, the EERS actively changes its architecture to decrease dependencies, increase learning, and adapt. Several options are presented in this section to explain how this works. To start, consider adding an additional sensor (S_2) that directly supports Dispatch (S_3). See Figure 18.

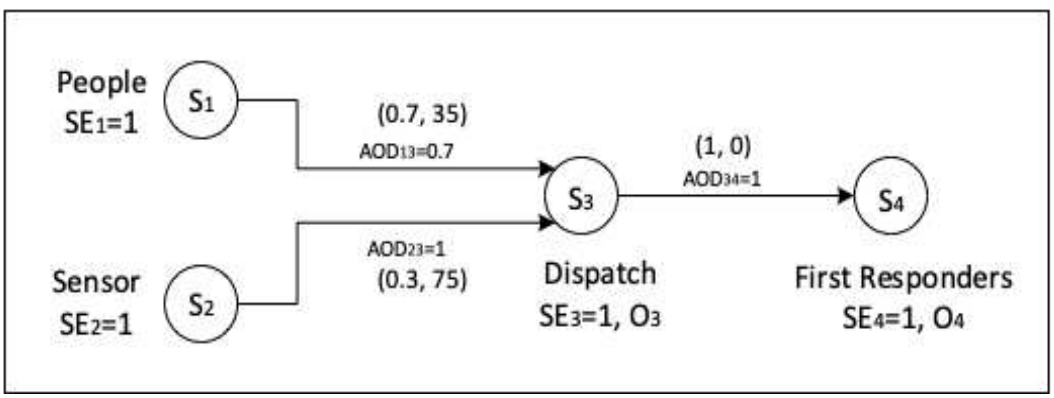

Figure 18. Response System (B)

This sensor could take many forms—social media, overhead satellite imagery, unmanned aerial vehicles, real-time data analysis, etc.—to provide additional awareness and cross-cueing to help eliminate ambiguities when uncertainty exists. (FEMA 2013). One key observation found during analysis is that adding an additional capability enhances overall system performance only to the extent that it reduces a node's *most restrictive* dependency. This is to say that a node's operability is constrained by what it *needs*, not by an overabundance of other data. For example, if Dispatch (S_3) needed a critical piece of information that could only come from the People (S_1), then it matters not how well the additional sensor (S_2) is providing other data —S_3 and, thus, S_4 remain constrained. The take-away is that to increase overall system performance, it is better to think of ways to reduce dependencies than to simply add capacity. In this case, the additional sensor (S_2) should primarily strive to help relieve S_3's dependency on $S_{1;}$ the additional sensor capacity that extends beyond this is deemed of secondary importance. This methodology used by the EERS adds resiliency and improves overall performance. The benefit of using this approach is shown quantitatively below.

For Example: Consider adding sensor (S_2) with the values shown in Figure 18. The resulting operability levels for S_3 and S_4 are 90 percent, a 20 percent increase from the baseline system. Should SE_1 fall to 0.7 (reflecting a 30% decrease in the People's (S_1) ability to observe and locate), S_3's and S_4's operability levels decrease to 82 percent, up 33 percentage points from the 49% baseline system. This suggests that when more degradation exists in a given path, even more gains occur from having additional redundancy. The SODs and CODs used in this example are estimations based on a notional response, but, if optimized, could likely result in even higher increases. In the end, sensor S_2 is making a notable impact by meeting S_3's needs. Considering that, in this example, Dispatch's (S_3) operability directly impacts First Responders (S_4), these increases are significant to increasing overall EERS performance.

The main takeaway is that communities wanting to implement the EERS to improve their response systems must consider more than just adding new capability; they must know how that capability fits into the larger system; they must know how it affects other components; and they must know how it reduces system dependencies so that it removes chokepoints when failures occur. Otherwise, the addition of a new capability may result in little to no difference when the system becomes stressed and existing dependencies continue to constrict performance.

Another EERS architecture to increase performance is to use capabilities already present in the existing system, albeit in different ways. Consider Figure 19 below.

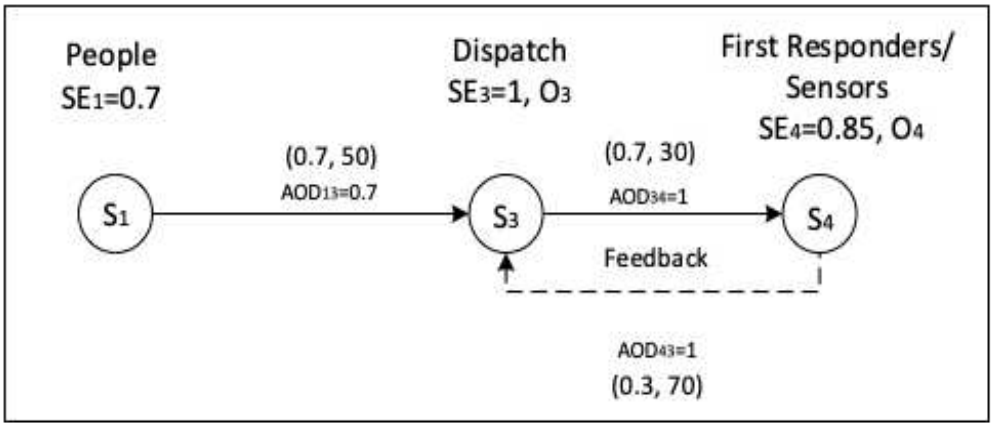

Figure 19. Response System (C)

This EERS architecture uses first responders (S_4) as sensors and then backchannels data to Dispatch (S_3). Although this modification may not cue responders to the exact location of an incident, it does offer several benefits worth mentioning. First, by adding additional sensors in the field—sensors that are trained and networked together—they can work together to home in on the incident. They also remove Dispatch's (S_3) reliance on a single source. This is an important feature, as explained earlier, because, when degradation occurs along path S_1 to S_3, redundancy now exists from path S_4 to S_3 to help alleviate the deficiency. How much alleviation? Using the values in the diagram, S_3's operability-level rises from 49 percent to 78 percent, an increase of 29 percentage points from baseline, and S_4's operability is 70 percent, up 21 percentage points from baseline. The reason S_4's operability is not higher is due to its decreased (from baseline) SE-level of 85 percent. This value was used to account for lack of efficiency from using first responders in a manner inconsistent with their normal operation.

It is also important to note that once the First Responders are in the general vicinity looking to find the incident, their reliance on Dispatch (S_3) decreases, as they are now able to observe and act without direct guidance. This decreases response time once the incident is found, and the system is no longer paralyzed waiting on S_1 to provide information. Taking a proactive approach as shown here in the EERS – using capabilities already present in the system (albeit downstream) – promises faster and more effective response.[57]

As mentioned above, one drawback to this architecture is getting the responders close enough to the incident so they can find it. During the Waldo Canyon fire, responders went out to find the fire, but a combination of changing wind direction, multiple reported areas, and nightfall prevented them from doing so. They did not receive adequate cuing. Starting again the next morning, the responders eventually found the fire, but not until almost 16 hours had elapsed from initial reports. One might conclude from this that sending resources early is wasteful and could lead to delays should another event occur that demanded the same resources. Examining the Black Forest fire response suggests otherwise.

During the Black Forest fire, Dispatch received calls of smoke in and around the area but did not immediately dispatch responders. This was due somewhat to having wrongfully associated incoming reports with another fire burning in Canyon City, some 40 miles away. Amidst this and other existing confusion, first responders were not dispatched for almost 2 hours (Gabbert, 2014, January 24, p. 3). This late response contributed to allowing the 2-3 acre ground fire to be blown into the crown as responders arrived. After this point, the fire was deemed

[57] See Gabbert, January 24, 2014, and Harrald, 2006, for additional insight.

unstoppable (El Paso County Colorado, 2014, pp. 7-8). A faster response might have prevented the ensuing catastrophe, and this is a good example of where taking additional risk early could have significantly paid off later.

Another EERS architecture is shown in Figure 20 below. This architecture adds even more capabilities —capabilities associated with downstream entities. These capabilities may consist of many different items, some of which might include air vehicles (e.g., helicopters, fixed-wing airplanes, and unmanned aerial vehicles), ground structures (e.g., lookout towers, traffic cameras), special capabilities (e.g., night vision goggles, infrared devices, robots) or data (e.g., intelligence). A good example is Code Blue, a medical sensor system used by medical first responders that relays information back to the hospital (Lorincz et al., 2004). When added to the EERS in ways that reduce existing dependencies, significant gains are achieved.

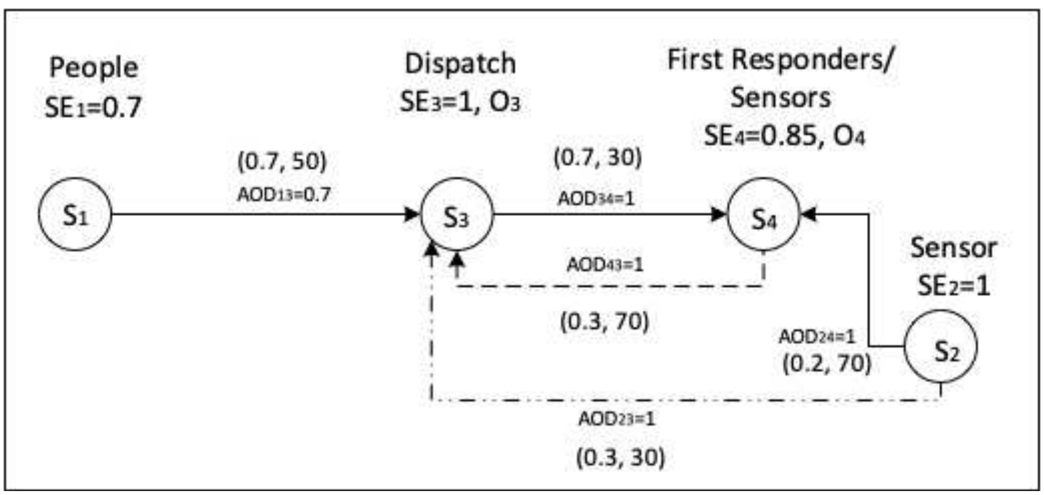

Figure 20. Response System (D)

FDNA suggests that the best way to add and operate such capabilities from a system perspective is for the owners to operate their associated capabilities. This optimizes SE levels, keeping them high due to increased familiarity and training. After this, the capabilities should share data outward to other nodes in the system. Here, sensor S_2 in Figure 20 would not only share data with S_4, but also with S_3. Based on earlier discussions highlighting the importance of reducing dependencies through redundancy, it would be best if S_2 not only shared data, but also met a portion of S_3's needs. If employed with a hub-and-spoke communications network to help eliminate chokepoints when stressed, even more gains would be achieved (Meissner et al., 2002). After adding sensor S_2, operability levels increased—S_3 jumped to 86 percent, and S_4 to 80 percent. These figures are based on estimated SOD and COD values (as shown in the diagram) with no attempt to optimize them. Some values were changed (SE_4, SOD_{34}, and COD_{34}) when sensor (S_2) was added to reflect dependency changes associated with the new EERS architecture.

As mentioned above, a hub-and-spoke communications network is beneficial because it adds redundancy throughout the system. Proposed systems such as First Net, a \$7B nation-wide broadband network designed to link responders, is a good example. But it does not abrogate the need for a well thought out underlying network, if for no other reason than becoming overly dependent on it creates an Achilles' heel, and such dependency on any entity that can paralyze the system when it fails or degrades is poor system design. Using multiple pathways that result in graceful degradation is the best approach.

8.2.4 Sensitivity Analysis

A sensitivity analysis was conducted to check for the sensitivity and changes to overall system operability levels with regard to changes in system input. To conduct the analysis, the parent node (S_1) and its corresponding data pathway (i.e., Availability of Data (AOD_{ij})) in each architecture was varied 30 percent. The S_1 node and its AOD_{ij} pathway was selected because they are upstream, and also because analytical analysis conducted via a Jacobian matrix and determinant showed that these variables had the strongest scaling effect on the model. Once the sensitivity analysis was conducted for the system architectures, the baseline's *best case* operability was compared to *worst case* operability levels for Systems B, C, and D. In addition, the *worst case* baseline was also compared to the *best case* operability of Systems B, C, and D. The results of the sensitivity analysis are shown in Table 10.

Table 10. Sensitivity Analysis Results

Node	Baseline O_i	System B O_i	System C O_i	System D O_i
S_3	49 +/- 15%	82 +/- 5%	78 +/- 6%	86 +/ 3%
	Best: 64%	Worst: 77%	Worst: 72%	Worst: 83%
(Difference)	--	+13	+8	+19
	Worst: 34%	Best Oi: 87%	Best Oi: 84%	Best Oi: 89%
(Difference)	--	+53	+50	+55
S_4	As above	As above	70 +/- 6%	80 +/- 3%
			Worst: 64%	Worst: 77%
(Difference)			0%	+13%
			Best: 76%	Best: 83%
(Difference)			+42%	+48%

Looking at the differences for node S_3, the *worst case* improvement in Systems B, C, and D operability levels range from +8 to +19 percent, and for node S_4 from 0 to +13 percent. This suggests that even with a 30 percent change in parental input, Systems B, C, and D still offer improvement in operability when compared to the baseline system. When looking at the *best case* for improvement, operability levels range from +50 to +55 percent for node S_3, and +42 to +48 percent for node S_4. These results help confirm that smartly adapting the system's architecture to allow more learning to occur while simultaneously decreasing dependencies results in improved performance.

8.2.5 Discussion of Findings

The findings are presented in two areas: system structures and community considerations. This section compares the different EERS structures and architectures presented in the study. It then offers communities suggestions on how to apply the EERS framework to their local response systems, and how to identify and map system dependencies that they can strive to overcome in order to transform their *ad hoc* systems into the engineered, more capable, EERS.

Analysis of the EERS using FDNA and system's thinking suggested that by changing system architecture by adding redundancies and communication pathways, improvement in the accuracy and speed of incoming information occurs. This is especially important, because accuracy and speed are vitally needed during times of crisis when system elements often degrade and/or fail. To explore how architectural changes affected overall system performance, four systems were investigated—System A (baseline), System B (upstream capacity), System C (downstream capacity), and System D (downstream capacity with increased capability). The focus of each system was to note the performance (i.e., operability levels) of S_3 (PSAP/Dispatch) and S_4 (First Responders) because of the impact those nodes have in mounting an effective response. The results are shown in Table 11.

Table 11. Comparison of Architectures

Operability	Baseline	System B	System C	System D
S_3	49%	82%	78%	86%
S_4	49%	82%	70%	80%

Each system was evaluated based on a 30 percent degradation in the People's ability to accurately observe and locate (SE_1=0.7), and a 30 percent degradation in their ability to report (AOD=0.7). These values were selected based on qualitative judgement in consideration of the empirical evidence from the Waldo Canyon and Black Forest fires (Marzolf & Sega, 2017, pp. 19-21). For other large-scale, complex incidents such as the fires that occurred during the summer of 2017 in Napa Valley, California, degradation could exceed these values based on information available on the website 911DispatcherEDU.org (2017).

Several observations are noteworthy: First, there is only a 4-percentage point difference in S_3's operability between System's B and C. This is explained largely by the fact that S_4 in System C is acting similarly to S_2 in System B. Here, S_4 is providing needed data through feedback, while S_2 is sending data forward. The main differences not accounted for in the calculations are associated time delays that might exist between the two systems. Assuming that S_2 in System B is continually operating and providing steady-stream data, and recognizing that (by design) S_4 in System C must be ordered by S_3 to deploy first, it is concluded that System B could offer temporal advantage not evidenced in the calculations. Some of System B's advantage could be negated through very proactive use of S_4, but as explained earlier, this could result in additional risk if the cueing sends first responders on a wild goose chase, not only leading to an ineffective response, but also increasing costs. Of course, the cost of waiting to deploy S_4 in hope that the right information will get reported to Dispatch results in much larger costs, as evidenced in the Black Forest fire.

A second observation is comparing S_4's operability levels in Systems B and C. The 10-percentage point difference exists largely because S_4 is less efficient in System C, since it is required to perform additional roles (i.e., search and locate) and responsibilities (i.e., provide necessary feedback to S_3/Dispatch). Fulfilling these additional tasks reduces S_4's focus on purely combating the incident. To account for this degradation, S_4 was assigned an SE-level of 85%. With training, it is possible that S_4's SE-level could increase and produce operability levels that come closer to System B's.

A third observation is System D's high level of performance. This system adds more downstream capabilities that increase S_4's operability and, because they are networked and designed to meet the needs of others, too, the overall system significantly improves. With 36 percent degradation from path S_1-S_3, S_4 still achieved 80 percent operability. This increase occurs, because decreased dependencies allow freedom of action across the system. As explained earlier, these numbers do not account for the time needed to activate the system, which could be significant depending on responders' availability and how well they work together.

As noted by the system architectures presented, the results suggests that decreasing dependencies increases system performance. When reducing dependencies, the results also suggest that adding redundancies that have the ability to establish a network across the system is beneficial. These features allow the EERS a better chance to continue operating when individual entities become degraded and/or communications become less effective. This is a daunting task, especially in large, complex incidents that place severe stress on the system (Meissiner et al., 2002; Manoj & Baker, 2007, p. 51-53).

Proposed systems such as FirstNet, a $7B nation-wide broadband long-term evolution (LTE) network designed to link responders together, promise to help in this area but should not be regarded as a panacea. FirstNet will increase information sharing, but it will not abrogate the need for a well thought out underlying network, for no other reason than to avoid becoming overly reliant on it (i.e., creating an Achilles' heel), as was mentioned earlier.

The response system, as evidenced in the two fires, already contains high amounts of dependency, and it would be prudent to consider ways to reduce it before disaster strikes. Adding other capabilities, such as deployable wireless systems or solar-based systems that continue to work when the electric grid fails, are options that can help achieve balance while adding resiliency (Midkiff & Bostian, 2002; Houghton et al., 2006, pp. 12-13).

A study accomplished by Shen and Shaw (2004) on how to manage emergency response coordination with information technologies reveals some interesting conclusions. Here, the authors mapped out a sample emergency response system and presented three different types of dependencies among actors: flow, sharing, and fit. Flow dependencies occur when one actor is wholly dependent on another actor such that information flows from one to the next. Shared dependencies occur when information is shared between actors. Fit dependencies occur when the outputs of multiple activities need to fit into a single product. The analysis found that to optimize system operation that included avoiding information overload, flow and shared dependencies are best accommodated by synchronous, low bandwidth types of communications, which include text messages. Fit dependencies that usually require database and knowledge management capabilities (as might be encountered in an EOC or ICP) require more diverse media choices such as tele/video conferencing and should cover larger geographic areas. These findings suggest that the system could, in fact, operate on existing technologies provided necessary redundancies (such as deployable communication repeaters) exist to ensure operational continuity.

An interesting suitability question (and necessary to address because it is a desired EERS requirement) for communities is for them to determine how they could transform their existing systems into the EERS without monetary investment. Systems C and D were created with the premise of using existing capabilities, and they provide improved performance especially in light of Shen and Shaw's findings where the EERS could likely use existing communication structures. Thus, exploring new ways to use existing resources pays off. Simply taking a more proactive approach also makes a positive impact. A poor choice, on the other hand, is waiting to take action because the system remains stagnant and non-adaptive. The upshot is that because the EERS proactively changes its architecture, these deficiencies are overcome. The EERS allows for increased learning, and increased learning improves response.

The impact of using the EERS' approach to communities is worth noting. Here, communities wanting to improve their response systems should consider more than just adding new capabilities. They must know how a new capability fits into the larger system, how it affects other components, and how it reduces system dependencies so that it removes chokepoints and degrades gracefully when failures occur. In order to do this, community leaders and response workers must team up and begin to identify system dependencies and perform risk-based analysis to determine how to achieve the best gains in the EERS. This requires a holistic approach focused on the entire response system. (White 1995; Abrahamsson, Hassel, and Tehler 2010). The goal is to operate the EERS based on an overall response strategy—one that increases overall system performance—not just the performance of individual components (Comfort 2007 provides more insight on how to achieve this). Formulating the strategy requires strong relationship building and increased trust among actors. (Moynihan 2009; Drabek 1985; Anderson 2014). It also requires an understanding of how mission-type orders and decentralized command and control enable emergent networks to form and self-organize. (Krackhardt and Stern 1988; Turoff, Chumer, Van De Walle, and Yao 2004). Fortunately, most of these functions and processes are already advocated for and built into the EERS as shown in this chapter and in Chapters 4 and 5, where the EERS was initially built.

8.3 Assessment

The goal of this chapter is to validate prioritized system areas using a realistic scenario in light of the *effectiveness* requirements listed below.

- The system shall operate on the expectation of chaotic and imperfect information associated with chaotic, complex events. As such, the system shall seek out needed information, learn, and adapt.
- The system shall be capable of handling complex/dynamic/multi-jurisdictional events, yet still have the means to handle the mundane, non-complex emergency events that happen daily.

With these requirements in mind, the validation must determine, from an overall perspective, whether or not the EERS is effective in minimizing an emergency's adverse impacts and consequences. This was accomplished using a difficult, complex scenario derived from problem areas identified in the two fires —problem areas common to many other complex events. These areas largely consisted of the initial response subsystem's ability to meet speed requirements (problems 1-3, 5), testing the initial attack to obtain both speed and adequate resources (problems 4, 6), and testing the response management effectiveness subsystem to integrate with regard to communications and spirit of cooperation.

The burden of proof to make a determination is based on the preponderance of evidence, by asking this question: "Is it more likely than not that the process, object, and/or system can successfully achieve its stated objectives?" With that in mind, and based on this chapter's analysis using both qualitative and quantitative (FDNA calculations) considerations, the following determinations are made.

Per the stated requirements above, was the EERS presented:

- With chaotic and imperfect information? Yes
- In a chaotic and complex event/environment? Yes
- In a multi-jurisdictional event? Yes
- Did the system seek out needed information, learn, and adapt? Yes
- Does the system still handle mundane, everyday events? Likely yes, because mundane, everyday events are not complex – and thus not in need of a rapidly changing system. Here, the system functions as designed but has no need to transform its architecture because there is little to no need to gain additional confidence. Only when deemed necessary do system operators use EERS transformative architectural capabilities –

capabilities largely absent in today's response system as was observed in the two fires. This then leads to making an *effectiveness* assessment:

- Is the system more effective in minimizing adverse impacts and consequences of an incident? Yes. This analysis provides evidence to support the hypothesis that this system is more effective in minimizing adverse consequences of an incident.

When assessing the EERS via analysis as presented earlier in the SysML Activity Diagram (see Chapters 4 and 5) and considering the response premises offered in Chapter 5 that underscores a faster response with adequate resources leads to a more effective response, the EERS is more likely than not to produce a more desired outcome than the current response system. Architectural transformation leads to an active and faster observation and detection process, which leads to more situational awareness and a better chance of dispatching adequate resources to the scene, which leads to a more effective initial attack. As an event continues to dynamically evolve, the EERS continues to learn and adapt producing a more effective response and a higher chance of a desired outcome. Shen and Shaw address communications and suggest low-bandwidth solutions may already exist. Spirit of cooperation among actors is addressed in this validation, and it is addressed again later. More research is needed to determine the exact amount of increased EERS effectiveness. This involves finding optimum SODs, CODs, and the best mix of sensors, capabilities, and architectures for which to combat a variety of diverse complex scenarios.

8.4 Validation Summary

This chapter provides evidence to validate system effectiveness through modeling by showing how operating the EERS dynamically with respect to its architecture can make dramatic improvements in the system's overall performance. Yet in order to implement these changes to transform existing *non-integrated* systems into the EERS—which might only require some ingenuity with no additional investment—emergency responders must first understand their system's dependencies and how the various subsystems and components work together to bring a favorable outcome. They must also understand that there are methods to increase their system's performance when underlying design assumptions are no longer valid, and that waiting for the system to transform by itself is not a good answer. Instead, taking proactive actions, decreasing dependencies, pulling on additional sensors, and integrating them smartly as shown in the EERS can all lead to better outcomes. By doing this, the EERS learns and adapts, and effectiveness improves. The next chapter validates the EERS using empirical data to correlate trends into best practices, validates suitability and compliance requirements. The chapter also conducts a Delphi survey to validate the value of using a systems engineering approach along with assessing system feasibility. After this, an overall EERS validation determination is made.

CHAPTER 9: ADDITIONAL VALIDATION AND OVERALL ASSESSMENT

This chapter is divided into four sections: (1) validation by correlation of best practices – identifying trends that occurred from one fire to the next, and then analyzing them to show how the correlations are either reinforced in the EERS, in the case of favorable correlations (i.e., best practices), or avoided, when unfavorable, (2) suitability and compliance validation, (3) a Delphi study to address feasibility and value, and (4) an overall assessment of validation.

9.1 Trends and Best Practices

The goal of this section is to show how the EERS reinforces positive performance correlations and suppresses or overcomes negative performance correlations. Table 12, below, correlates emergency response system components and processes with how they performed as evidenced in the Waldo Canyon and Black Forest fires. The data are generated from Chapter 6, along with earlier analysis that explained how the response system use to fight the two fires changed from the Waldo Canyon to the Black Forest fire. Here, the table identifies how the response system's performance changed from the first event, the Waldo Canyon fire, to the second event, the Black Forest fire, which occurred approximately one-year later.

Areas that did not perform well are annotated with a minus (-), areas that were average in performance are annotated with an "o," and areas that performed well are annotated with a plus (+). The "Trend" column shows how that area of the system performed in Black Forest in comparison to Waldo Canyon. These performance trends are identified as improvements (up arrow), degradations (down arrow), or those with little to no change (horizontal arrow). For instance, the Sense and Detect (A) Component and Process did not perform well in either fire, and, as such, the trend in that area is depicted with a horizontal arrow showing that no real improvement occurred from one event to the other. The initial attack phase improved from the first to the second event, and the improvement is shown with an up arrow. As mentioned earlier, confounded data limits the ability to identify exact correlations between changes in independent variables and outcomes. Thus, this validation requires a more generalized, qualitative analysis so that changes in these variables are addressed together and within context, in order to avoid overstating deterministic outcomes.

Table 12. Empirical Analysis—El Paso County—Two Fires

Response Area	Independent Variables	Associated Components and Processes	System Priority	Waldo Canyon	Black Forest	Trend
Speed of Response	Detection	Sense and Detect (A)	VH	-	-	⇔
	Communications (IRS)	PSAP (C)	VH	-	-	⇔
		PSAP (C1)	VH	-	-	⇔
		Communications (B1)	VH	-	-	⇔
		Communications (B2)	VH	+	+	⇔
		Dispatch (D)	VH	+	+	⇔
Initial Attack Response Effectiveness	Initial Attack	Confidence (C2)	VH	-	o	⇧
	Resources (Adequate)	Enough Resources	VH	-	o	⇧
		Scaling Loop 1	H	-	+	⇧
		Scaling Loop 2	H	-	+	⇧
Response Management Effectiveness (F)	Command & Control	Response Loop F	H	-	+	⇧
	Communications		H	-	o	⇧
	Spirit of Cooperation		H	-	+	⇧
	Resources Applied	Response Loop F	M	-	o	⇧
	Training/Preparation	Response Loop F	M	-	+	⇧
	EOC Support:	Response Loop F				
	• Overall		M	-	o	⇧
	• Awareness		M	-	-	⇔
	• Resources		M	-	o	⇧
	• Comms		M	-	o	⇧
	• Care/Feeding		M	-	o	⇧
	• JIC		M	-	+	⇧

The data in the table offer some general observations. First, every trend in the Speed of Response category shows little to no improvement between events. This is logical considering that major problems of observation/detection, communications, confidence, and timeliness of dispatch occurred in both fires. Showing how the EERS overcomes these problems was largely addressed in Chapter 8. Since neither event's response went well in the Speed of Response area, and because it is clear that a speedy response with adequate resources is needed to generate an effective outcome, a correlation likely exists between the two. Bottom line: Speed and adequate resources were required for an effective initial attack; neither was present, and the initial attacks were deficient.

This correlation is reinforced by looking at the events in more detail. For example, the Waldo Canyon fire took 16 hours to locate, and, once found, the fire was approximately 4,000 acres strong. The Black Forest fire only took two hours to find and was only 2-3 acres strong at that time. Once found, a plethora of responders and resources were immediately dispatched to the scene. As the responders arrived, an unfortunate windstorm blew the fire up into the crown (i.e., the treetops), and, once that occurred, the fire was deemed unstoppable. The fire might have been extinguished right away (a) if the PSAP had acted sooner —dispatch waited to send responders, because their confidence was low due to confusion with incoming calls from the Royal Gorge fire burning some 40 miles away, or (2) if air tankers and/or helicopters had been immediately available —they were requested much earlier than in the Waldo Canyon response, but the assets were not immediately available. In the end, and as shown in the table's initial attack section with the "up arrows," the system improved from a 16-hour to a 2-hour response. With a little more luck (i.e., without the windstorm), the more responsive system could have saved the day. In short, it was not that the system components and processes did not function;

they simply did not work fast enough to meet event demands. Here, every minute makes a difference. This evidence suggests that the validation conducted in Chapter 8 — largely addressing speed, uncertainty, integration, and resources – addresses the correct deficiencies because these aspects are deemed critical (as shown above) in mounting an effective response. This also adds credence to the validity of the premises regarding speed, resources, and integration presented in Chapter 5.

Second, four of the six areas in the Response Management Subsystem show improvement: command and control, communications, spirit of cooperation, and training . This, too, is likely correlated to an effective response, based on the trust and confidence that improved among system participants from the first to the second event. A large portion of the responders that fought the Waldo Canyon event also fought the Black Forest event. This included Rich Harvey's Type 1 Federal IMT. The events were separated by about one year so that the relationships, trust, and confidence that were formed in the former event remained intact in the latter. This became evident when the City of Colorado Springs delegated full authority to Rich Harvey to fight on its behalf during the Black Forest event, while, before, in Waldo Canyon, the city retained its authority. Evidence suggests the mayor retained authority due to lack of trust. Stronger trust in the second event, along with increased training and experiences obtained by system participants during the Waldo Canyon event, helped to produce a more integrated system. These increases in system integration and performance correlate to the importance of establishing and maintaining relationships and trust among actors – forming a team, if you will – so that a spirit of cooperation exists before a complex event occurs. This essential element is advocated for and reinforced in the EERS.

Third, the Response Management subsystem's Resources Applied area indicates improvement in the Black Forest event, which used a "Go Big Early" approach. This approach was a significant improvement over the Waldo Canyon response, which used a piece-meal, *ad hoc* approach where resources were late to need and often poorly coordinated. As discussed earlier, in Chapters 4 and 5, the system activity analysis results suggested the necessity for adequate responders and resources to arrive sooner rather than later in order to quell the situation and, hopefully, avoid an out-of-control situation. The need for this to occur, when taken in light of the empirical data in this category, suggests a correlation likely exists. This is observed in several ways.

Officials fighting the Black Forest fire pulled significant resources from across all public and private levels to include using air support, once it became available. As discussed in Chapter 6, at one point 1,175 personnel (79% in operations) were helping combat the Black Forest fire incident (City of Colorado Springs, 2014, p. 24). Volunteers from the American Red Cross, Salvation Army, Humane Society, Black Forest Together, Samaritan's Purse, and Southern Baptists provided shelter, in-kind donations, and various amounts of assistance (pp. 49, 52-55, 72). This plethora of resources were activated early in the Black Forest event, and evidence suggests this timely activation helped minimize the event's impact. Military assets were also integrated into the response.

The integration of military equipment and personnel (i.e., helicopters, bulldozers, and personnel) in the Black Forest event far surpassed that of Waldo Canyon. This application of federal military assets (enabled by a liberal interpretation of IRA) in the Black Forest response brought 700,000 gallons of water/retardant to the fight (City of Colorado Springs, 2014, pp. 68-71). Though the Black Forest outcome was still a significant disaster, the pace at which military resources were brought to bear in the early and mid-stages of the response minimized losses and saved infrastructures.[58]

The early application of all of these resources, taken in their entirety, helped minimize the impact of the Black Forest fire to an extent well beyond that seen in the Waldo Canyon event. Thus, evidence suggests that the “Go Big Early” approach is correlated to generating a more desired outcome. The EERS strongly advocates for taking this approach in several areas, to include quickly dispatching responders, preparing/staging additional responders and resources even before they are needed, and scaling the response by “going big early” verses waiting until the need arises and/or it is too late.

The fourth and last area of interest is EOC Support. The EOC functioned better in Black Forest than in Waldo Canyon. Analysis provided in Chapter 6 suggests this was mostly the result of personnel experience and operating familiarity (gained during the Waldo Canyon event), along with updated equipment. Resource tracking, communications, care and feeding, and the JIC all were improved. All of these areas proved helpful and are embedded and reinforced into the new system. Of note, one area that did not improve was awareness.

Having awareness is a necessary element of support. As explained in Chapter 6, during the Waldo Canyon event the EOC support system did not have much awareness, and the result was an *ad hoc* support system that led to increased responder workload. This happened because many of the responders had to coordinate their needs autonomously versus the EOC planning and coordinating on their behalf. This ad hoc approach impacts the response system even more unfavorably when using the unified command concept. This concept mandates that command entities and their subordinates work together to accomplish a shared set of objectives as defined

[58] Air tankers and helicopters dropping water and retardant generally target areas around critical infrastructures and facilities. This is done in hopes of saving them from burning and minimizing losses.

in a single incident action plan (Department of Homeland Security, 2006, p. 13). If the EOC does not have an awareness of what is needed to support responders at these different levels, it is practically impossible to fulfill this responsibility.

NIMS recognizes the need for awareness and advocates obtaining it from a COP. A COP is defined by NIMS as “an overview of an incident by all relevant parties that provide incident information enabling the Incident Commander/Unified Command and any supporting agencies and organizations to make effective, consistent, and timely decisions” (Department of Homeland Security, 2008, p. 33). Even with this recognition, however, a fully functioning COP did not exist in either event. Because of the correlation between awareness and providing support, and the correlation between support and response effectiveness, this is an area that needs improvement so that responders can focus on their tasks, receive needed support, and thus improve overall system effectiveness.

The EERS scenario validation that was offered in Chapter 8 does not address solutions to this area, because it was ranked as moderate priority, and because Shen and Shaw suggest a different framework that could likely meet these demands. For other possible solutions, see Balfour (2014), Turoff and White (2008), and Turoff et al (2004). This area requires additional research and is under investigation by DisasterTech (Lee DePalo, interview, July 23, 2021).[59]

In sum, empirical data suggest several best practices exist. First, speed of response and adequate resources are likely correlated to achieving a better outcome. This reinforces the premise offered earlier in Chapter 5. Second, solid relationships built on trust and confidence are correlated to achieving a spirit of cooperation, and spirit of cooperation is likely correlated to forming an effective response team. Third, “going big early” is correlated to requesting and

[59] (Lee DePalo, personal interview, July 23, 2021).

dispatching adequate resources to the scene, which, in turn, is correlated to mounting an effective response. Lastly, effective EOC support is correlated to operator experience, familiarity, and having needed equipment. A COP is also needed to provide higher levels of awareness that likely correlates to achieving higher system performance. This area is not fully investigated in this research, because it is assessed as a moderate priority, as shown in Chapter 8. The EERS – as built in Chapters 4 and 5, and as exercised and validated in Chapter 8 – incorporates these best practices.

9.2 Suitability and Compliance Requirements

This section validates EERS suitability and compliance requirements. As stated earlier, in Chapters 1 and 7, there are three areas to consider: compliance with the NRF/NIMS framework, alignment with the Fragility concept, and a stakeholder desire to avoid monetary investment to transform the existing system into the new design. Each area is discussed below.

9.2.1 Compliance with the NRF/NIMS Framework

First, the EERS conforms to both the NRF and NIMS frameworks. The system is tailorable, scalable, and layered. The system is highly adaptable: it can transform itself based on the different needs, requirements, and architectures presented in Chapter 8.

The EERS also conforms to the ICS' unity of command concept that NIMS mandates when the system is responding to multi-jurisdictional events. This concept mandates shared responsibility and teamwork in such events so that no one person is solely in charge. Instead, jurisdictions work together through collaboration to form shared goals, objectives, and pooled resources to respond to the event. The new system, through the OODA Loop construct, along with increased emphasis to form relationships and trust among appropriate entities well before disaster strikes, all serve to support this command concept.

9.2.2 Compliance with the Concept of Community Fragility

The concept of Fragility as offered by Lori Hodges is important to overall community emergency response and management functions. For this reason, it is a desired requirement that the EERS to support these functions. Table 13, below, qualitatively assesses how the new system and its operating methods impact community fragility areas.

<u>Table 13. Assessment of System Operation on Community Fragility</u>

If	Then	Enhance (E) Neutral (N)
-Community has no loss of leadership or a community lead during or after the emergency, and… -Communities are not isolated, have multiple routes in and out, and work with neighboring communities, and… -Communities have high social capital in the forms of trust in formal systems, a high degree of community engagement, and strong social cohesion, and… -Communities use a hybrid approach to incident management through the use of 1) a formal incident management system to work with governmental entities, and 2) a collaborative approach using horizontal authority structures to ensure inclusion of non-governmental partners.	Community Connectedness is Strong	N E E E
-Communities have strong relationships with nonprofit, non-governmental, private sector and volunteer organizations, and… -The emergency management structure involves key support hubs, or compartmentalization to ensure each priority can be met, and… -Communities have strong leadership from both the informal community as well as the formal government structure, and… -Communities have flexible and adaptable plans and procedures that are able to change as needed to meet the circumstances of the disaster.	Community Stability is Strong	E N E E
-Communities have strong resources management plans, mutual aid agreements, and supply chain management procedures, and… -Communities have redundancies and/or the ability to quickly recover the lost lifelines to continue efforts toward recovery, and… -Communities are resilient through mitigation efforts, system redundancies, and strong community ties… Communities have systems in place to recognize small system disruptions or disturbances, reducing the chance of cascading or full systemic failures.	Community Sustainability is Strong	N E E

The “enhancements” focus largely on relationship building, increased trust, considering the emergency response entire system as a whole, and filling gaps by reducing dependencies among system entities. This mandates that communities collaborate and work with each other to build multi-jurisdictional capabilities and systems that integrate and function together. The other aspect that is favorable to decreasing community fragility is through adaptable system architectures that increase resiliency by providing fewer dependencies. The entire system becomes a smart, learning organism that adapts and integrates more effectively to meet response needs. The EERS supports all of this; therefore the EERS helps decrease fragility to enable a stronger and more resilient response through more capable communities.

9.2.3 Transformation and Monetary Investment

Calculating exact costs to transform the current system into the EERS would differ for each community’s emergency response system and is beyond the scope of this research. However, it is shown in Chapter 8 that transforming to the EERS with little cost is not only possible, but also plausible. EERS architectures C and D were created with the premise of using existing capabilities in new ways. Both architectures provided improved performance over the baseline system. Communications dependencies as addressed by Shen and Shaw suggest that advanced, highly technical communication upgrades may not be necessary to make the EERS work. Low bandwidth systems such as simple text messaging could suffice. Moreover, it was found that simply taking a more proactive approach could make a positive impact. A poor choice is to do nothing, leaving the system stagnant, non-adaptive, and passive. Using the EERS with existing capabilities to learn and adapt, even if not in an optimal manner, is a more effective approach.

In sum, the three suitability and compliance areas are deemed validated. The system meets suitability and compliance requirements.

9.3 Value and Feasibility – Delphi Study

A Delphi study is a research method that asks subject matter experts to answer questions on a topic. The experts are engaged individually in order to avoid group think and/or prevent other peer biases from forming. In most cases, an iterative approach is used so that the questions start broad, and then based on the answers, additional questions are formed and presented to the experts so that additional insight is obtained. After some number of iterations, when the researcher is satisfied with the quality and content of the study's data, results are tabulated to help inform the research. Please refer to Appendix B for the survey instrument.

In the case of this research, the survey posed seven questions to a group of five experts. The experts were selected based on their expertise and time serving in the field of emergency response. Experience of participants ranged from those that had led emergency response functions for a large city to those that had managed a FEMA region consisting of several states. All participants had at least five years of experience – with most having more than fifteen years.

A five-point Likert scale was used to probe the participants ranging from Strongly Disagree, Disagree, Neutral, Agree, to Strongly Agree. The results were evaluated treating the data as discrete and ordinal in nature. This was done because the survey's scale is not continuous. The participants could perceive and assign different values to the rating scale based on their individual biases. That is, the difference between Strongly Disagree and Disagree could be different than the difference between Disagree and Neutral, and thus result in a non-Gaussian distribution. To account for this, the strength of agreement for *each question* is simply determined by the amount of responses in each category (i.e., 1 though 5) and then calculated into a percentage based on a total number of responses to each question. When calculating agreement in *overall areas* of value or feasibility, the number of responses in each category is divided by the total number of responses in that *entire area* of questioning.

Because of the limited number of participants, and because many of them were contacted directly to take the survey, upon which they agreed, reverse-worded questions used to obtain confidence, integrity, and consistency in each participant's survey was deemed as unnecessary.

Assessment of Responses

The survey results are shown below in Table 13.

Table 14. Delphi Survey Results

		Number of Responses in Category				
Question #	Topic	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
1 (Value)	Focus on Overall Performance				2 (40%)	3 (60%)
2 (Value)	Multi-Disciplined Approach					5 (100%)
3 (Value)	Disciplined and Proactive Approach				1 (20%)	4 (80%)
4 (Feasibility)	Build Spirit of Cooperation			1 (20%)	1 (20%)	3 (60%)
5 (Feasibility)	Free to Obtain Capabilities		3 (60%)	1 (20%)		1 (20%)
6 (Feasibility)	"Go Big Early" Approach				1 (20%)	4 (80%)
7 (Feasibility)	Complex Exercises and Non-attribution			1 (20%)	3 (60%)	1 (20%)

Based on the number of responses to each question, the percentage of responses in each category is calculated and shown in the table in parenthesis. That is, for Question 1, 60 percent of respondents "Strongly Agreed" with the question. The responses from questions 1 through 3 show that the subject matter experts "strongly agreed" casting 12 out of 15 responses in that category. This resulted in 80 percent of experts expressing strong agreement. The remaining 3 responses (i.e., 20 percent) were “agree.” The participant’s comments, listed in Appendix B, further emphasize their desire and appreciation for using a systems approach in this application/research area.

The results from questions 4-7 suggest subject matter experts also have adequate flexibility and freedom to transform their existing, non-integrated, systems into the EERS. This suggests that the EERS is largely feasible because these four questions probed areas that are of prime importance in making the EERS work. 70% (i.e., 14 of 20 responses) expressed strong agreement in the form of either “strongly agree” or “agree.” 15% (i.e., 3 of 20 responses) of the participant’s answers were of “neutral” agreement, and the remaining 15% were “slightly disagree.” The three “slightly disagree” responses were all linked to Question 5.

Question 5 probed whether or not emergency managers have adequate authority to obtain needed capabilities. Here, 60 percent (i.e., 3 out of 5) of participant’s responded to that particular question as “slightly disagree.” Comments associated with the question are as follows:

> “Many times in complex situations, due to governance, State, Tribal and Federal agencies also need to be involved to cover the shortfalls….(Stafford Act.” (Expert 1).
>
> “Historically, most local level emergency managers are underfunded and often wear multiple hats so they aren’t full time in that role. This is particularly true for smaller communities that have a more difficult time competing for grant money.” (Expert 2).
>
> “See notes above in Question 4 which are relevant; also add here that local resources are generally very limited. They can handle the most routine of disaster/emergency management – minor flooding, windstorms, blizzards, traffic and hazmat incidents but quickly overwhelm during extended/protracted/growing responses.” (Expert 3).
>
> “There are many EM agencies who have very little authority which causes unnecessary delays in action needed to mitigate harm. Additionally, many programs are inflexible and not robust enough

> to handle complex events. Finally, laws can sometimes be a limiting factor to success." (Expert 4).
>
> (No comments were provided by Expert 5).

The expert's comments related to this question suggest that smaller communities have small budgets, little authority, and thus do not have much leeway to obtain needed capabilities. This reinforces the requirement, as offered by Expert 1, for state, tribal, and/or federal agencies to respond quickly to bring these needed resources when disaster strikes. Of course for this to happen, it reemphasizes the mandate to "Go Big Early" and integrate. These areas were probed in Questions 4, 6, and 7 – and were "Agreed" and "Strongly Agreed" to by the experts. The end result is that even though Question 5 showed low agreement – because the experts agreed that Questions 4, 6, and 7 were feasible, it is likely that the inability to obtain needed capabilities addressed in Question 5 could likely be obtained through other system entities. If this were to occur, and it appears from the experts that it could, then low agreement to Question 2 does not inhibit EERS function.

In summary, the survey confirms that applying systems engineering methodologies onto the response system is of value, and the EERS is likely feasible.

9.4 Overall Assessment and Determination

The validation followed a logical sequence of test, experimentation, and analysis that began with (1) EERS operation in a complex scenario, (2) existing system trends that correlated into best practices and deficiencies, (3) EERS suitability and compliance, and (4) expert opinion to determine systems engineering application value and EERS feasibility. Analysis focused on available data using methods of implication, comparison, inspection and examination, and modeling to show how the new system improved outcomes. Greater confidence was achieved using quantitative calculations (FDNA) and qualitative and subjective assessments. Burden of proof was based on preponderance of evidence, with the overall goal of determining whether or not the system was more effective (i.e., minimizing adverse impacts and consequences of the incident), particularly in chaotic, complex, multi-jurisdictional events. Suitability and compliance constraints were also addressed, as was feasibility. The following list offers a holistic perspective of these areas.

Effectiveness requirements: Was the EERS tested and validated?

- With chaotic and imperfect information? Yes
- In a chaotic and complex event/environment? Yes
- In a multi-jurisdictional event? Yes
- Did the system seek out needed information, learn, and adapt? Yes
- Does the system still handle mundane, everyday events? Likely yes, but more research is needed to ensure there are no unintended consequences and/or emergent behaviors.
- Are best practices based on trends/correlated data embedded in the system?
    - Speed of response and adequate resources? Yes
    - Spirit of Cooperation to include command and control, communications, and training? Yes
    - Resources applied in the Response Management Subsystem advocated for and integrated –public, private, and military – to "Go Big Early?" Yes
    - EOC improvements supported? Yes. Adding awareness via a COP is addressed but not fully investigated. This is an area needing more research.

Overall effectiveness assessment: Based on the preponderance of evidence, is the response system *more effective* in minimizing adverse impacts and consequences of an incident? Yes.

Suitability and compliance requirements: Was the system tested and validated?

- To conform to the National Response and the National Incident Management System Frameworks. Yes
- To enhance and support the community fragility concept? Yes.
- To morph itself into existence from the existing response system using non-monetary solutions? Likely yes, but only to a degree. Determining exact investments to create a robust system for a particular community/region requires additional research.

Overall suitability assessment: Based on the preponderance of evidence, is the response system suitable based on given constraints and requirements? Yes.

<u>Delphi Study</u> – is the application of a systems engineering approach to create an engineered system of value and feasible based on expert professional opinion?

Overall Delphi assessment: Yes, and yes.

<u>Overall system assessment:</u> The validated areas presented above – effectiveness, suitability and compliance, and feasibility – all suggest that the EERS built (Chapters 4 and 5) and operated (Chapter 8) using systems engineering processes and methods is feasible and will meet stakeholder requirements. The next chapter concludes this research and offers areas needing further inquiry.

CHAPTER 10: CONCLUSION AND FUTURE WORK

10.1 Summary of Work

This research applied systems engineering principles and frameworks to build a more effective emergency response system (i.e., the EERS) to minimize adverse impacts and consequences of incidents. This research considered "effective," as applied to emergency response, as minimizing the adverse impacts and consequences of an incident, because, when this is achieved, public confidence and stakeholder satisfaction follow. The research used Wildland Urban Interface (WUI) fires as exemplars to inform and validate the system, because they, like other types of complex emergency response scenarios, involve thousands of people, hundreds of organizations, with large amounts of equipment. The EERS must respond fast, effectively integrate the large and diverse amounts of stakeholders/responders, and do this while learning and adapting to event dynamics.

A literature review was conducted to investigate what has, and what has not, been done to contribute to this area of work. The review was organized starting with systems engineering applications to emergency response systems and continuing with command and control, decision-making and knowledge, and system integration, planning, and training. The review showed that this research's contribution to the existing body of knowledge is twofold: first, a contribution is made to the emergency response community by extending systems engineering into this relatively obscure but highly important and complex area, and second, a contribution is made to the systems engineering discipline by expanding it into a less-technical, yet highly complex area in a new and novel approach.

The systems engineering "V" model and lifecycle processes were used to build the EERS. Stakeholder & Needs Analysis, Requirements Definition, Architectural Definition, and Integration were used to build the EERS. Here, these systems engineering formal methodologies helped guide the developmental pathway to ensure a logical, efficient, and economical approach was selected. A key aspect of the pathway was that it focused on the system as a whole. This meant that finding balance was important so that risks and uncertainty were kept in check with associated tradeoffs and other desired system attributes and functions.

Emphasis was placed on building a more capable *engineered* system that could handle not only routine emergencies, but also events containing increased complexity, uncertainty, and severity. Thus, finding the correct balance between the reactionary (i.e., acting/reacting to stimuli) versus the predictive (acting on the expected) is difficult, and practically impossible if conducted via an undisciplined approach. EERS effectiveness was largely centered on achieving two operational requirements. First, the EERS had to operate on the expectation of jumbled, imperfect information associated with chaotic, complex events. As such, the system had to seek out needed information, learn, and adapt. And second, the EERS had to handle complex, dynamic, multi-jurisdictional events, yet still have the means to handle non-complex emergency events that happen daily. The system was also built on suitability constraints.

EERS suitability constraints included conformance to the National Response Framework (NRF), the National Incident Management System (NIMS) Framework, and the community fragility concept, as well as ease of transformation from the existing system using non-monetary means.

Empirical data from two complex events in Colorado's El Paso County, the Waldo Canyon WUI fire in 2012 and the Black Forest WUI fire in 2013, were used to inform EERS design and operation. System deficiencies were mostly symptomatic of the existing response system's inability to handle uncertainty. The existing system had difficulty handling events that were hard to observe, locate, or report; and complex events where incoming information was disjointed or erroneous. The existing system's ability to learn and adapt in these uncertain, complex situations was poor and needed improvement.

To inform and verify EERS design and operation, system activity analysis showed that waiting to obtain more confidence resulted in increased response delay that then resulted in a worsening situation. And if waiting to gain increased confidence resulted in the need to execute scaling loops to further tailor the response, even more time was needed before adequate forces could arrive to mount an effective response. The design feature used in the EERS to overcome this limitation was that rushing to the fire with limited responders and then scaling was a better option than waiting to act in hope of receiving more information to build more confidence. This suggested getting "eyes on" the situation quickly (even with a small numbers of responders) and then adapting was better than waiting to generate the perfect plan.

The activity analysis, when combined with complex event dynamics, verified that time-based components and processes were a very high priority because of their criticality in enabling the system to respond quickly and with enough resources to control the event. Failure to achieve this kind of response resulted in much higher damages and costs. Scaling loops were deemed high priority, as their timely use allowed for quick adaptation if other time-based components and processes proved inadequate. Response management effectiveness areas of (1) command, control, communications and (2) spirit of cooperation were rated and verified as high priority, because they provided the mechanisms for smart, adaptive learning and teamwork, and effective execution of the response. Other response management areas, though also very important, were rated and verified as moderate, because they did not prohibit a response.

To ensure the EERS design and operational concept contained system-level solutions to address these deficiencies, verification was conducted. It was found that the existing system was constructed mostly in series, often requiring that outputs from components be accomplished sequentially before response actions could be taken. This type of architecture propagated delays and/or failures downstream, such that a delay and/or failure occurring in one part of the system cascaded to other processes and components, thereby degrading overall system operation. It was also found when first responders arrived on the scene and the Response Management Subsystem began, the time required to make any adjustments to resources and/or needed capabilities that were missed or not addressed earlier in the IRS also hindered the response. Analysis was performed *vis-à-vis* overall system operation and verified that the EERS could largely overcome these deficiencies by actively changing its system architectures to smartly learn, adapt, and mount a more effective, integrated response.

Validation of the EERS in regard to the system's effectiveness was successful. EERS architectural effectiveness was modeled using Functional Dependency Network Analysis (FDNA). By linking nodes together based on their interfaces and interactions, it was determined how a change in one node affects the others, whence an overall system performance determination was made based on aggregation. Using this methodology, analysis of the EERS based on using non-optimized qualitative Strength of Dependencies (SOD), Criticality of Dependencies (COD), and Availabilities of Data (AOD) suggested that changing EERS architecture by adding redundancies and communication pathways, improved the accuracy and speed of incoming information. It also afforded the ability to establish a network across the system, allowing it a better chance to continue operating when individual entities became degraded and/or communications became less effective. A sensitivity analysis was conducted to confirm the results. Synchronous, low bandwidth types of communications were investigated to show the possibility of using focused, streamlined communications to enable system operation. This helped to avoid information overload and allowed the EERS to work more effectively. This capability produced a more effective response and a higher chance of a desired outcome than the existing baseline system. The validation provided evidence that the EERS was more likely than not to produce a more desired outcome than the current response system. Architectural transformation led to an active and faster observation and detection process, which led to more situational awareness and a better chance of dispatching adequate resources to the scene, which, in turn, led to a more effective initial attack. This provided evidence that the EERS could dynamically change in order to learn and adapt. Suitability was also validated to conform to the NRF, NIMS, the community fragility concept, and likely without monetary investment.

The resulting impact to communities wanting to improve their response systems was identified. Communities should not consider adding new system capabilities until they fully understand how the new capabilities fit into the larger response system, affect other components, and reduce system dependencies. Before adding new capabilities, communities should fully understand how the new capabilities will help remove system chokepoints and allow the EERS to degrade gracefully when failures occur. Some changes might only require some ingenuity with no additional investment —using existing capabilities in new, innovative ways. EERS architectures C and D were created with the premise of using existing capabilities in new ways. Both systems provided improved performance over the baseline system. Community leaders and response workers must team up to identify system dependencies and perform risk-based analysis to determine how to achieve the best gains. This requires a holistic approach focused on the entire system. The goal was to operate the EERS based on an overall response strategy—one that increases overall system performance—not just the performance of individual components.

A Delphi study was used to gain additional insight into the feasibility of transforming the existing response system into the EERS. The study used a 5-point Likert scale to probe a group of subject matter experts. The experts agreed in feasibility-related areas suggesting that the system could, in fact, be built and operated per this study. The experts also agreed that systems engineering as applied in this research was of value and helpful in creating a more effective emergency response system.

10.2 Future Work

Additional work would be beneficial in several areas. First, this research suggested in Chapter 1 that many of the study's findings would most likely apply to similar communities' emergency response systems. This suggestion was offered because Colorado Springs, Colorado is likely similar to many to many other communities – a large city, many jurisdictions, military presence, consisting of a variety of hazards – in this case fires in the WUI. Yet, there are exceptions. Some communities might require heavier amounts of medical response capabilities or other special requirements (i.e., nuclear and/or chemical). These requirements could drive a more tailored approach. Here, the EERS would need tailoring too. The tailoring could start with analysis of SODs, CODs, and AODs derived from that particular community's empirical data. To do this, more research focused in these areas would help these communities better equip and discover optimum EERS architectures for their specific locality.

The second area is to more fully determine what unknown, unintended consequences, and/or emergent behaviors might exist in the new system. Implementing the EERS—even if only making subtle changes from the existing system—could result in unexpected and unfavorable system behaviors. These types of unknown behaviors are usually found and addressed in developmental testing and during system integration testing. In this research, however, due to lack of a physical system and representative environment, these tests were not accomplished. This creates uncertainty as to what undesired and, as yet, undiscovered behaviors might be lurking in the dark.

The third area is to apply this framework to higher levels of government to determine if further gains can be achieved. Evidence from the Waldo Canyon and Black Forest fires suggests that many problems existed at the levels where the state and federal entities operate. Since these entities are often critical to help support response efforts, as also suggested by expert opinion in the Delphi study, additional research in this area could significantly benefit the entire operation.

The fourth area to investigate is command and control. Because self-learning, adaptive systems have different needs than rigid systems that rarely change, additional work is needed to determine exactly what types of command and control schemes will best support EERS operation. The OODA Loop construct is advocated for and used in the EERS – yet there is some debate in the research community as to how to make some of the OODA Loop functions work. Research as identified in the literature review asserts that NIMS is far too rigid and inflexible to meet users' needs. If true, then offering the OODA Loop as an adaptable, learning command and control system is likely appropriate to support an adaptable, learning EERS. More fully exploring the decision-making apparatus itself would be useful, however, because operating the EERS as an adaptable, learning system also requires different demands from decision makers. Much has already been written on how leaders make decisions during times of crisis, and the bulk of material suggests that leaders often make poor choices based on biases, confusing probability with recency, and neglecting information that conflicts with what they want to hear. This is one reason the OODA Loop was selected as it provides ways to overcome such bias. This is why one recent study suggested adding a crisis leader advisor position to the system in order to help guide the process (Alkhaldi et al., 2010). Yet, even with this suggestion, more insight would be helpful. Perhaps decision support systems could help filter and present data in unique ways to help decision makers generate a better outcome. Machine learning, human-machine interfaces, knowledge management, and other types of methods to increase the "system's cognition" would help. Combining improved cognition along with additional operator training is a promising approach.

The fifth and last area identified for further research is to determine how the EERS should function when responding to events occurring in different domains, e.g., domains such as cyber and medical. Evidence provided by the two fires, and as evidenced in other complex events, suggest that having the ability to observe and detect a stimuli was the first step in generating a response. Thus, the system must be looking. Cueing systems to identify warnings and indications in these other domains would be needed – along with integration into the rest of the EERS. This demands metrics, tracking, and analytics in order to identify perturbations that could trigger the EERS to start its transformation – proactively learning, adapting, and integrating – to mount an effective response. The Department of Defense is taking a similar approach in the application of all-domain warfighting to address the increasingly complex battlespace now in existence (Garamone, 2020). Perhaps this is an area in which EERS could benefit in the future. More layers of sensors integrated with faster, more capable response capabilities with data analytics informing cognitive function. In the meantime, evidence suggests that the Engineered Emergency Response System – EERS -- as built and validated in this research, is more effective in handling more complex, larger-scale incidents. With more severe events looming on the horizon with ever more frequency, the EERS could likely prove beneficial in saving lives, money, and turmoil.

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APPENDIX A: LIST OF ACRONYMS AND ABBREVIATIONS

AOD	Availability of Data
ANOVA	Analysis of Variables
CDHSEM	Colorado Dept of Homeland Security and Emergency Management
CERT	Community Emergency Response Team
CIKR	Critical Infrastructure and Key Resources
COD	Criticality of Dependency
COLT	Cellular on Light Truck
COML	Comm Unit Leader
COP	Common Operating Picture
DOD	Department of Defense
DSCA	Defense Support to Civil Authorities
EERS	Engineered Emergency Response System
EMS	Emergency Medical Service
EMAC	Emergency Management Assistance Compact
EOC	Emergency Operations Center
ERS	Emergency Response System
ESF	Emergency Steering Function
ETOPS	Extended Twin Operations
FDNA	Functional Dependency Network Analysis
FEMA	Federal Emergency Management Agency
FMO	Field Marshall Officer
HSIN	Homeland Security Information Network

IC	Incident Commander
ICP	Incident Command Post
ICS	Incident Command System
IMT	Incident Management Team
INCOSE	International Counsel of Systems Engineering
IPO	Input, Process, Output
IRS	Initial Response Subsystem
IRA	Immediate Response Authority
IT	Information Technology
JIC	Joint Information Center
LTE	Long-Term Evolution
MAFFS	Modular Airborne Fire Fighting System
NICC	National Incident Command Center
NIMS	National Incident Management System
NORTHCOM	United States Northern Command
NRF	National Response Framework
OODA	Observe, Orient, Decide, and Act
PIDC	Pueblo Interagency Dispatch Center
PIO	Public Information Officer
PSAP	Public Service Answering Point
SAGE	Situational Awareness Geospatial Enterprise
SE	System Effectiveness
SOD	Strength of Dependency

SysML	Systems Machine Language
UML	Universal Modeling Language
USFS	United States Fire Service
VOAD	Voluntary Organizations Active in Disaters
VoIP	Voice Over Internet Protocol
WUI	Wildland Urban Interface
VHF	Very High Frequency

APPENDIX B: DELPHI SURVEY INSTRUMENT AND PARTICIPANT COMMENTS

Name: Date:

Position:

Due back:

Privacy: All responses are kept anonymous in this research. I only ask for your name/position, so I have some understanding of who took the survey and their experience level/position. Your information will never be released / your response will be erased on/before August 31, 2021.

Instructions: The below survey contains 7 questions – and a place for you to add comments if desired. Please highlight / circle / underline your answer to each question. Add comments if you wish. *Please do not discuss your answers with peers or other participants.* Then save and return to greg.marzolf@colostate.edu. For questions, call me at 801-927-7005.

Background: I have suggested in my research that the existing Emergency Response System could use some improvements when responding to more complex, larger-scale incidents. In discovering problem areas and finding solutions, I applied systems engineering that looks at finding innovative ways to accomplish needed response functions to better meet response requirements. The research also focused on finding ways to better integrate the existing system to generate shorter (i.e., faster) response times along with dispatching more adequate resources when needed. This approach promises to obtain more system agility. I am interested in your thoughts as to the value of this work (the first 3 questions) – and if a few of the solutions are feasible (the last 4 questions). Thank you for your time. I am very grateful. Prof. Greg Marzolf.

Questions: Please use the following 5-Point Likert Scale to answer.

1 – Strongly Disagree / 2 – Disagree / 3 – Neutral / 4 – Agree / 5 – Strongly Agree

1/ Applying systems engineering tools and methodologies onto the Emergency Response System to help find system solutions leading to higher levels of overall system performance is of value.

1 2 3 4 5

Additional thoughts/comments:

2/ Applying systems engineering tools and methodologies that advocates for a multi-disciplinary approach (e.g., breaking down stovepipes to obtain the right mix of experts) to respond to more complex, multijurisdictional, larger-scale incidents is of value.

1 2 3 4 5

Additional thoughts/comments:

3/ Applying systems engineering tools and methodologies that advocates for using a disciplined, proactive approach to emergency response is of value.

1 2 3 4 5

Additional thoughts/comments:

4/ Community/county-level emergency management officials can build a multijurisdictional spirit of cooperation among the different actors so that trust, confidence, and teamwork is established before disaster strikes.

1 2 3 4 5

Additional thoughts/comments:

5/ Community/county-level emergency management authorities have enough flexibility to obtain needed capabilities to improve their emergency response systems – filling in gaps and shortfalls where needed.

1 2 3 4 5

Additional thoughts/comments:

6/ It is generally a good idea, when responding to large-scale incidents that contain high levels of complexity and uncertainty, to take a "go big early" approach. This means, as an example, to aggressively dispatch an adequate (if not an abundance) of responders, quickly activate the EOC, and request specialized capabilities such as air support and/or military assets (via the Stafford's Act Immediate Response Authority).

1 2 3 4 5

Additional thoughts/comments:

7/ The emergency response system is exercised (at least annually) in very difficult, complex scenarios so that participants can learn, adapt, and operate without fear of attribution if they make a mistake.

1 2 3 4 5

Additional thoughts/comments:

Thank you for your help and support. Prof. Greg Marzolf

//////////// Participant Comments ////////////

Q1.

Surveyor 1. Every tool is important at some time for finding solutions.

Surveyor 3. there is a lot of room for systems engineering in emergency response work, and yet it must be appreciated that few scenarios are exactly the same and so there is art, as well as, science in this craft. The benefits of applied system engineering are to address the system design and replicable delivery where possible, and that will help decipher where art must be employed in unique scenarios/application.

Surveyor 4. A systems approach is critical to effective emergency response and emergency management.

Q2.

Surveyor 1. It is important to view items with a 360 approach. We don't know what we don't know until someone else brings that data to the table. The more complex an incident the more "expertise" is required.

Surveyor 2. Collaboration across local, state and federal lines is challenged by the lack of a common collaboration platform and operating picture.

Surveyor 3. It is absolutely critical we get out of stovepipe communities to shared awareness and purpose-built solutions. The Community Lifelines found in the National Response Framework are particularly helpful in doing this work.

Surveyor 4. Emergency Management must use a multi-disciplinary approach but we continually run into the siloing of agencies and partners. Building systems that keep this from happening would be best.

Q3.

Surveyor 1. Proactive is always better than reactive and one must always be disciplined in emergency activities….safety..

Q4.

Surveyor 1. Collaboration is critical when building teams prior to a disaster. That includes planning, training, exercises and response/recovery/mitigation.

Surveyor 2. Yes but it helps if they have a common threat to focus on to help build a culture of preparedness. A great example is Pueblo Colorado. They come together every year to practice as a community with the US Army and the chemical depot that is in Pueblo. Even the elementary schools participate and it is a whole of community exercise.

Surveyor 3. Additional thoughts/comments: turnover, multiple job functions beyond emergency management, jurisdictional politics and lack of training funding are all impediments to this noble goal. As the profession of emergency management continues to evolve and sophisticate in congruence with the frequency and intensity of disaster, this becomes more achievable into the future.

Surveyor 4. This should be done in every jurisdiction and in every EM agency.

Q5.

Surveyor 1. Many times in complex situations, due to governance, State, Tribal and Federal agencies also need to be involved to cover the shortfalls….(Stafford Act)

Surveyor 2. Historically, most local level emergency managers are underfunded and often where multiple hats so they aren't full time in that role. This is particularly true for smaller communities that have a more difficult time competing for grant money.

Surveyor 3. See notes above in Q.4. which are relevant; also add here that local resources are generally very limited. They can handle the most routine of disaster/emergency management – minor flooding, windstorms, blizzards, traffic and hazmat incidents but quickly overwhelm during extended/protracted/growing responses.

Surveyor 4. There are many EM agencies who have very little authority which causes unnecessary delays in action needed to mitigate harm. Additionally, many programs are inflexible and not robust enough to handle complex events. Finally, laws can sometimes be a limiting factor to success.

Q6.

Surveyor 1. Phoenix FD Chief Alan Brunnicini used to say "ask early and ask for a lot. It is better to have it and not need it than wish it were here and it is still on its way. Totally agree. Thus the importance of mutual aid and auto aid agreements along with pre-contracts with the private sector.

Surveyor 2. Resource phasing during a disaster response because everyone tries to rush to the scene. Certainly local responders will go big but state and federal assets don't have to get there right after it happens with the exception of unique capabilities like Urban Search and Rescue teams.

Surveyor 3. As the adage goes – it is easier to send you home if not needed, than it is to get you here, so a go big early mantra is worthy. Historically, the first 72 hours of a response dictates how the rest will go.

Surveyor 4. It is best to be proactive in response and to bring in resources early. But I am hesitant to say this should happen every time. Proactively looking at the problem and having everything on stand-by is critical, but there should be triggers established for the movement of resources into the area.

Q7.

Surveyor 1. I believe that agencies and individuals must indeed train and exercise annually. One functions in an emergency as they have "practiced and played"

Surveyor 2. There is an annual National Level Exercise and other exercises that support the NLE. That said, the NLE rarely exercises SLTT and the Federal government.

Surveyor 3. There are many exercises at all levels exercising multiple plans. The National Priority Exercise (odd years; FEMA directed) and National Level Exercise (even years; Whitehouse directed) are the nation's largest FTXs.

Our system exercises quarterly with a full activation. We have not had an exercise this year however since we have been activated so much for real events.

APPENDIX C: EL PASO COUNTY AREA PLANS

Prior to the Waldo Canyon fire, several county plans existed:

- The 2008 El Paso County All-hazards Pre-Disaster Mitigation Plan
- The El Paso County Emergency Operations Plan
- The El Paso County Community Wildfire Protection Plan
- The 2011 El Paso County Annual Wildfire Operating Plan

The three plans most applicable to wildfires were the 2008 El Paso County All-Hazards Pre-Disaster Mitigation Plan, the El Paso County Community Wildfire Protection Plan, and the 2011 Annual Wildfire Operating Plan. Each of these plans was focused slightly differently to provide the county with a broad blanket of planning and preparation.

The first plan was the *All-Hazards Pre-Disaster Mitigation Plan*, and it was established in accordance with the Disaster Mitigation Act of 2000 to help mitigate the impact of disasters before they occurred (El Paso County Colorado, 2008). This act made monies available to states via the Federal National Pre-Disaster Mitigation Fund to help offset costs of formulating the plan. The act also stated that if a state had an approved plan in effect at the time a major disaster was declared, the state would enjoy a 5% increase of available funds (i.e., from 15% to 20%) from the Hazard Mitigation Grant Program (p. 9). Thus, incentives made formulating an approved Pre-Disaster Mitigation plan lucrative.

The overall goal of a Pre-Disaster Mitigation Plan was not to provide a “one-stop shop” for all community planning needs, but to provide a cornerstone upon which other plans and programs could build. In this way, the plan’s goal was to raise awareness of key stakeholders, maintain and improve existing programs, create new programs, and strengthen response frameworks to decrease losses. The plan addressed this concern (along with large hazardous material spills and severe weather events) by providing the goals listed below (El Paso County Colorado, 2008, pp. 7-10):

- Protect life, safety and property by preventing future damages and economic losses that result from natural and human-caused hazards
- If prevention methods fail, reduce the impact on residents of both natural and man-made disasters
- Support future grant requests for pre- and post-disaster initiatives
- Speed recovery, including economic recovery, and redevelopment following future disaster events
- Demonstrate El Paso County's commitment to hazard mitigation principles
- Comply with federal and state legislation and guidance for local hazard mitigation planning
- Provide outreach and educational programs that will increase the awareness, knowledge and preparedness of residents in the County, which may reduce the loss of life and property caused by a disaster

To address the direct threat of wildfires, the plan specifically provided the following guidance (El Paso County Colorado, 2008, p. 5):

- Goal: Reduce the probability and effect of a catastrophic Wild Land Fire (WLF)
- Objective: Identify those areas of the County that require WLF fuels mitigation efforts and establish programs to reduce fuel loading in those areas
- Objective: Improve the ability of First Responders to reach WLF and improve their ability to fight the fire

- Objective: Improve the ability of residents to prevent fires

To achieve these goals and objectives, the plan analyzed county resources and assessed that the county was not well equipped to achieve them. Here, the plan stated that the county's ability to keep fires small and extinguish them quickly was limited because of inadequate amounts of brush trucks. Here, only 13 of 25 Volunteer Fire Departments had the trucks, and because of this fact, past firefighting success was credited to luck and fast response times due to well-executed mutual fire response partnerships throughout the county. This is important as most Volunteer Fire Departments in the county have 20-30 minute response times. Yet even with fast response times, high fuel loads and dry/windy conditions create the conditions that any wildfire not immediately suppressed will grow quickly. Considering the high amount of residents living in WUI areas, this becomes even more problematic as the need to immediately extinguish increases as more life and property is at stake (El Paso County Colorado, 2008, pp. 31-32).

Because of this high risk, the plan specifically outlined two actions aimed at helping people prevent fires and defend their property. The first action is to educating property owners to build defensible space around their structures. This amounts to removing fuels from the property (especially close to structure) that could provide enough heat to ignite. The second action is providing a community/public wood chipping program that allows residents to not only clear fuels away from structures, but to remove it entirely from their property (p. 95).

The second plan, the *El Paso County Community Wildfire Protection Plan,* was created as directed by Colorado Senate Bill 09-001 that requires each county to address fire hazards in its unincorporated areas (El Paso County Sheriff's Office ESD, 2011, p. 1). The plan's intent was to not infringe on smaller local communities responsibility to develop their own plans, and thus the county plan did not provide too much detail to remove this burden from local community responsibilities. Though not directed at Federal lands and/or entities, the county's five military installations participated in the plan as requested by the county (El Paso County Sheriff's Office ESD, 2011, pp. 1-2).

The plan addresses some key areas important to this discussion; they include jurisdictions, command and control, and educational programs. With twenty-one fire protection districts, five military installations, two metropolitan districts, a state park and Pikes Peak National Forest, defining jurisdictions and a response framework that provides "adequate give and take" is critical (El Paso County Sheriff's Office ESD, 2011, pp. 3, 63).[60] Here, the plan places responsibility on the jurisdiction where the fire starts (p. 46). For all unincorporated areas throughout the county, the county sheriff is ultimately responsible and has a dedicated team called the Wildland Fire Crew (consisting of all-volunteers) to meet this mandate. The Crew also helps the county in other ways such as helping residents create and maintain defensible boundaries, execute chipping programs, and conduct prescribed burns (pp. 39, 45-46).

As mentioned earlier, a key to El Paso County's success is different fire departments working together to arrive rapidly on scene with enough resources to extinguish fires before they grow out of control. To do this, several mutual aid agreements exist between fire departments so they are executed automatically. In this way, groups of departments are sent to any fire in any of their areas. On National Forest lands the jurisdiction remains with the USFS, yet they have response agreements with county jurisdictions to maintain an adequate response. The first fire department on scene is in charge of sizing up the fire and taking appropriate action until the fire

[60]A fire protection district is formed to provide firefighting, emergency medical services, ambulance services, rescue, or diving and grappling.

crew from the fire's area of jurisdiction arrives and takes over (El Paso County Colorado, 2011, p. 14). Air assets are requested and dispatched through the Pueblo Interagency Dispatch Center.

Another area addressed is command and control. Here, the plan states that the Incident Command System (ICS) will be used as defined in the National Response Framework and National Incident Management System. Since the ICS is the system of record for use across all emergency response levels (local, state, and federal), it provides a useful system known by all with common themes—such as how to handle overlapping jurisdictions (p. 46).

The last area is an education program to help residents prepare for wildland fires. Specifically mentioned in the plan is the Firewise program that, like mentioned in the Pre-Disaster Mitigation Plan, helps teach homeowners how to construct and landscape their properties to increase defensible space and increase their chances of survival. The program includes offering risk assessments and providing resident's chipping services and disposal (El Paso County Sheriff's Office ESD, 2011, p. 41).

The last plan in place when the Waldo Canyon fire erupted was the county's *2011 Annual Wildfire Operating Plan.* This plan, unlike the others, provided specific details on jurisdictional responsibilities, mutual aid agreements, and procedures for using out-of-county assets, communications, and the process for ordering air support (El Paso County Colorado, 2011).

According to the plan, and as mentioned above, wildland fire protection is the responsibility of each jurisdiction, and for unincorporated areas, the sheriff is responsible. In areas inside fire protection districts, the sheriff and the district share the responsibility (p. 7). For wilderness and/or areas without roads, fire suppression cannot be conducted unless an official representing the jurisdiction grants approval. Specific approval is also required before any type of mechanized equipment (i.e., bulldozers, etc.) can be used on Federal lands (p. 8). If or when a wildfire spreads or threatens other jurisdictions, a shared command structure may be established using the unified command paradigm as defined in the National Response Framework. If unified command is established, then the members of command work together to coordinate release of information to public. Here, a JIC should be established incorporating each member's public information officers. If the event unified command is bypassed in favor of single command, then authorities from the responsible jurisdiction are required to provide input into the priorities, objectives, and strategies/tactics (pp. 13-14).

To request additional county fire forces, the process is to make the request through the County Sheriff or via the individual fire department. Requests for federal resources are required to go through dispatch to the Pueblo Interagency Dispatch Center. When requested, the Colorado State Forest Service Fire Duty Officer must also be notified (p. 17).

If needed resources exceed El Paso County's, the county may request help from the state per Colorado's Emergency Fire Fund. When this occurs, El Paso County agrees to delegate responsibility to the Colorado State Fire Service for suppression and maintain active forces and participation in the Unified Command (p. 20).

In cases needing air attack assets, requests are made to Pueblo Interagency Coordination Center. Here, multiple air assets are available through a host of programs. One program available is the Single Engine Air Tanker that is sponsored by the Colorado State Forest Service. Another channel is the Colorado Air National Guard that has helicopters stationed in Aurora and Eagle Colorado. These assets can be airborne in as little as 20 minutes on most days, and within about 2 ½ hours on weekends and holidays (p. 24). Another source of air assets are nationally contracted aircraft. These aircraft may or may not be stationed in the local area, and if not, may require some time to arrive on the scene. The last source of air assets is federal military assets.

As discussed earlier, they are not normally deployed until a presidential disaster is declared and are specifically requested. Otherwise, the forces can be requested under the Stafford Act's Independent Response Authority provision.

To assist the States and Nation in recovering from disasters, the U.S. Congress passed the Robert T. Stafford Disaster Relief, and to encourage States to conduct mitigation efforts to reduce the impact of disasters they enacted the Emergency Assistance Act also known as the Disaster Mitigation Act of 2000 (DMA 2000). With this legislation the Federal government has placed renewed emphasis on pre-disaster mitigation of potential hazards. Most relevant to state and local governments under the DMA 2000 are its amendments to Sections 203 (Pre- Disaster Hazard Mitigation) and 322 (Mitigation Planning).

Section 203 of the DMA 2000 establishes a "National Pre-Disaster Mitigation Fund" to support a program that will "provide technical and financial assistance to state and local governments to assist in the implementation of pre-disaster hazard mitigation measures that are cost-effective and designed to reduce injuries, loss of life, and damage and destruction of property, including damage to critical services and facilities under the jurisdiction of the state or local governments." Section 322 of the DMA 2000 provides a new and revitalized approach to mitigation planning by:

- Establishing a requirement and delivering new guidance for state, local and tribal mitigation plans;
- Providing for states to receive an increased percentage of Hazard Mitigation Grant Program funds (from 15 percent to 20 percent) if, at the time of the declaration of a major disaster, they have in effect an approved State Mitigation Plan that meets criteria defined in the law; and

- Authorizing up to seven percent (7.0%) of grant funds available to a state to be used for development of state, local and tribal mitigation plans.
- Provide outreach and educational programs that will increase the awareness, knowledge and preparedness of residents in the County, which may reduce the loss of life and property caused by a disaster (pp. 9-10).

The Pueblo Interagency Dispatch Center (PIDC) must be notified promptly of all fires on or threatening National Forest, or Bureau of Land Management (BLM) lands. Use of mechanized equipment such as bulldozers, graders, etc., will not be permitted on federal lands without the approval of the appropriate federal official. If a wildfire crosses or threatens jurisdictional boundaries and becomes a multi- agency fire, the responsible jurisdiction may request a unified (shared) command structure for any fire situation. Where such unified command is not implemented, the responsible jurisdiction should obtain an agency liaison capable of providing input to objectives, operational strategies and tactics or other items from the relevant agency prospective. They should also provide information on local resource availability. A unified command will be made up of representatives from all agencies involved including the Colorado State Forest Service. The purpose of a unified command will be to meet as a group and identify policies, objectives and strategy, resulting in one common set of objectives given to a single Incident Commander, via a formal delegation of authority, for tactical implementation. This group shall coordinate the release of all information to agencies and the media. When possible a joint information center will be established utilizing all involved agency public information officers.

Notification upon receiving a fire report, the agency first receiving the report shall immediately notify other agency whose lands may be involved. First agency on scene will provide a situation size up to the appropriate dispatch center, i.e., PIDC for Federal lands, El Paso Fire Dispatch for private lands. It shall be agreed that all agencies shall send forces promptly to start suppression action unless it is clearly and mutually understood that one agency will promptly attack and/or follow through on all necessary action.

A fire burning on or adjacent to a known or questionable protection boundary will be the initial attack responsibility of the protecting Agencies on either side of the boundary. Fires occurring in areas where structures are located near and in areas of multiple jurisdictions can cause significant safety as well as financial concerns. The Agencies agree that public and firefighter safety are the first priority. The Agencies agree to coordinate suppression management through the use of a *Unified Command* or with *Delegations of Authority* from all jurisdictions to an agreed Incident Commander.

As a participant to this agreement, the State agrees to come to the aid of El Paso County should suppression resource needs exceed county capability. When EFF is implemented, CSFS assumes responsibility and authority for all suppression activity until the fire is returned to county responsibility; however, the county must maintain a minimum level of participation after EFF is implemented as outlined in section 9.

- All fires will utilize a Unified Command consisting of, at a minimum, El Paso County Sheriff and CSFS. If land administered by another agency is threatened or involved, that agency will provide a member of the Unified Command as outlined in section IX.
- The PIDC will be the point of contact for all El Paso County dispatch points for notification of fires threatening or involving federal (USDA Forest Service or Bureau of Land Management) lands.

- The Colorado State Forest Service sponsors a Single Engine Air Tanker (SEAT) program for use on wildland fires within the State of Colorado.

APPENDIX D: TYPES OF CATASTROPHIC SCENARIOS

This appendix extends the discussion of emergency response into a multitude of other catastrophic scenarios. The fact is that a future emergency response system must not only handle forest fires, but also operate in a complex and dynamic world where many different catastrophes can happen at any given time for any number of reasons. One such (and most notable) example occurred on September 11, 2001 when Islamist extremists hijacked four airliners. They flew two into the World Trade Towers in New York City, one into the Pentagon in Washington, DC, and the last crashed in Pennsylvania as passengers tried to apprehend the hijackers. The attack mandated not only response at the local and state level, but also a national-level response that few could have imagined.[61] Many other examples exist—from power grid failures to civil unrest where protesters purposely damaged infrastructure to create attention. In the end, the emergency response system must effectively meet all of these challenges. To shed additional light on the matter, deliberate attacks and secondary effects are addressed.

For the purpose of this discussion, a deliberate attack is defined as an intentional act to create injury, property damage, business disruption or environmental impact. A terrorist attack is a good example of this, and it includes an intelligent attacker using a structured and/or coordinated method to achieve their ends. According to a defense study, this type of attack "would cause cascading failures across various types of infrastructure that could challenge or degrade our national security" (Energy Sector Public Private Partnership National Capital Region Case Study Scoping Document, n.d., n.p.). Other ramifications could include degraded

[61] Major additions and revisions from across government occurred—USNORTHCOM was created to protect and defend the homeland (Homeland Defense); the Department of Homeland Security was created to focus on internal threats and provide mechanisms for increased security (Homeland Security).

physical environments where roads and bridges are not useable, residential areas are flooded, and ports are inoperable (Defense Science Board, 2012, p. 16). In the end, any of these events would be classified as an Incident of National Significance and require "extensive and well-coordinated response from federal, state, local, tribal, and nongovernmental authorities to save lives, minimize damage, and provide the basis for long-term community and economic recovery" (Business Executives for National Security, 2007, p. 17).

Another type of deliberate attack could occur from disgruntled citizens trying to express their dissatisfaction with a situation. A good example of this was the recent outbreak of civil unrest in Ferguson, MO. In this case, citizens were acting out their anger over a young black man who was allegedly shot by a white police officer without due cause. The ensuing outbreak went on for days and resulted in shootings, looting, and attacks on infrastructure (Business Executives for National Security, 2007). This type of behavior is not new as residents during Hurricane Katrina also conducted similar behavior that served to frustrate the recovery response (p. 17).[62]

Secondary effects of catastrophes are sometimes overlooked because they are not viewed as the responsibility of responders – until after they propagate from a nearby area. For example, an attack on a neighboring country (e.g., Canada or Mexico) may not be seen as an attack on the United States' homeland, but it could indirectly have huge consequences, nevertheless. Consider an attack in Mexico that created a large-scale humanitarian crisis so that thousands of Mexicans flooded to the US border. If this attack were to include a pandemic (such as Ebola) where thousands aliens were not just trying to obtain food, water, and shelter, but also seeking refuge and, if needed, comprehensive medical care, the effect would be devastating as immigrants

[62] Lawless behavior in Katrina "delayed restoration of essential private sector services such as power, water, and telecommunications" (Department of Homeland Security, 2006, p. 40).

poured across the border -- some infected without a means to contain them. Although this is scenario is portrayed at the national level, the responders dealing with the situation along the Texas, Arizona, and New Mexico border are local. And thus, the saying goes, “all emergencies are local.” And to a great extent, that saying is on target.

In the above scenario, there is no question that trying to contain the influx would be difficult, yet another out-of-country attack focused on the global supply chain could also present challenges. Over the past decade, supply chains have become more and more globalized as the use of super-sized transport ships, containerized shipping, and lower costs of goods from foreign markets have provided the means to execute just in time logistics. This has created a situation where the transportation / supply chain has become so saturated that little to no slack remains in the system to absorb disturbances. The upshot increases risk so that if a significant disturbance were to occur, America’s ability to get needed supplies on time would falter. If severe enough, a national security crisis would occur.

A recent example of this occurred when a massive 9.0 magnitude earthquake created a tsunami that devastated Japan on March 11, 2011. The tsunami’s 30 foot waves hit the island killing 15,884 citizens and destroying or damaging 202,000 homes. Along with this, about 6 million more homes (or 10% of Japan’s households) lost electricity and 1 million were without water (CNN Library, 2011). These electrical losses occurred because of the highly damaged infrastructure that included meltdowns of nuclear reactors at the Fukushima site. American military and charitable organizations worked to help stabilize the situation, yet effects of the disaster were felt around the globe to include many American companies that were dependent on Japanese parts for production. It also cost Hawaii tens of millions of dollars, California up to $40 million in, and Oregon millions of dollars of damage to its boats and harbors. Other repercussions included bans on Japanese food exports (due to high levels of radioactivity), thousands of ton of debris floating in the Pacific ocean, and shipping bottlenecks (Congressional Research Service, 2012, pp. 3, 5, 12-14).

In summary, deliberate attacks are intentional acts to create injury, property damage, business disruption or environmental impact. Good examples are terrorist attacks and damage done by disgruntled citizens seeking revenge. Secondary effects are the after-shocks that impact adjacent regions and are not often planned for until after the disaster occurs. In both cases, the emergency response system must provide an effective response.

APPENDIX E: WALDO CANYON RESPONSE ORGANIZATIONS[63]

Community Organizations	
American Red Cross	Goodwill
Care and Share	Humane Society of the Pikes Peak Region
Catholic Charities	Pikes Peak United Way
Colorado Volunteer Organizations Active in Disaster (COVOAD)	Salvation Army
Community Advancing Public Safety	Samaritan's Purse
Community Animal Response Team	The Navigators
Governmental Organizations	
Air Force Academy	El Paso Teller E-911 Authority
Civil Air Patrol	Fort Carson
Colorado Army and Air National Guard	Mountain Metropolitan Transit Bus Service
Colorado Department of Transportation	National Weather Service
Colorado National Guard	Natural Resource Conservation Service
Colorado Springs Utilities	Pikes Peak Community College
Colorado Water Conservation Board	Pueblo Chemical Depot
District 11 Transportation	Pikes Peak Regional Building Department
El Paso County Assessor's Office	Small Business Association
El Paso County GIS	United States Forest Service
El Paso County Public Health	United States Geological Society
Facilities	
Cheyenne Mountain High School	Lewis Palmer High School
Chipeta Elementary School	Penrose Equestrian Center
Coronado High School	Southeast YMCA
Eagleview Middle School	The Springs Church
Freedom Financial Services Expo Center	University of Colorado at Colorado Springs (UCCS)
Holmes Middle School	Verizon Wireless, Garden of the Gods
Emergency Management	
Colorado Department of Local Affairs	
Colorado Division of Emergency Management	
Colorado Division of Homeland Security and Emergency Management	
Colorado Office of Emergency Management	
Colorado Springs Office of Emergency Management	
El Paso County Emergency Services Division	
Federal Emergency Management Agency	
Great Basin Type 1 Incident Management Team	

[63] El Paso County Sheriff's Office, n.d., pp. 94-95

Fire	
Air Force Academy Fire Dept.	Golden Fire Dept.
Arvada West Fire Protection District	Green Mountain Falls Chipita Park Fire Dept.
Aurora Fire Dept.	Hanover Fire Protection District
Beulah Valley Volunteer Fire Dept.	Littleton Fire Department
Black Forest Fire/Rescue	Manitou Springs Fire Dept.
Boone County Fire Dept.	National Fire Protection Association
Broadmoor Fire Protection District	Northeast Teller County Fire Protection District
Calhan Fire Protection District	Palmer Lake Volunteer Fire Dept.
Cascade Volunteer Fire Dept.	Peterson Air Force Base Fire Department
Cheyenne Mountain Air Force Station Fire Dept.	United States Army Pueblo Chemical Depot
Cimarron Hills Fire Dept.	Pueblo County Sheriff's Office
Colorado Center Metro District	Pueblo West Fire Dept.
Colorado Springs Fire Department Explorers	Rye Fire Protection District
Crystal Park Volunteer Fire Dept.	Security Fire Dept.
Colorado Springs Utilities Wildland Fire Team	South Metro Fire Rescue Authority
Denver Fire Dept.	Southwest Highway 115 Volunteer Fire Dept.
Donald Westcott Fire Protection District	Stratmoor Hills Fire Dept.
El Paso County Wildfire Suppression Team	Tri-Lakes Monument Fire Protection District
Falcon Fire Protection District	West Metro Fire Protection District
Fort Carson Fire and Emergency Services	West Park Fire Dept.
Fountain Fire Dept.	Wheat Ridge Fire Protection District
Law Enforcement	
Alcohol Tobacco and Firearms (ATF)	El Paso County Sheriff's Office
Aurora Police Department	Federal Bureau of Investigation (FBI)
Colorado Department of Corrections	Fountain Police Department
Colorado State Patrol	Pueblo County Sheriff's Office
Department of Homeland Security Federal Police	Pueblo Police Department
Drug Enforcement Administration (DEA)	University of Colorado at Colorado Springs (UCCS) Police Dept.
El Paso County District Attorney's Office	
Medical/Behavioral	
Air Life Denver Ambulance	Memorial Hospital Transport Team
American Medical Response-Canon City	Mount St. Francis Nursing Center
American Medical Response-El Paso County	Rocky Mountain Mobile Medical
American Medical Response-Denver	Rural Metro Ambulance
American Medical Response-Pueblo	Silver Key Transportation
Aspen Pointe	Spanish Peaks
Calhan Ambulance Service	Mount St. Francis Transportation
Fountain Fire Department Ambulance	Stratmoor Hills Fire Department Ambulance
Hanover Fire Department Ambulance	Ute Pass Regional Ambulance District (UPRAD)
Medical Reserve Corps of El Paso County	Memorial Hospital Transport Team